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# Parametric Study of Twin Tunnel Interaction in Soft Ground

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**Abstract**
The demand of multiple tunnel construction has been growing extensively for cities like Kathmandu built on limited space but densely populated. Construction of such underground structures however on an already built up spaces poses imminent risk to the adjacent structures.In the present study finite element method is employed to carry out the parametric study on the interaction between tunnels and ground surface. The interaction is assessed based on the ground displacement and internal lining forces on tunnel due to the construction of second tunnel. For the three cases variation in tunnel spacing and volume loss is carried out. Results showed that for cohesionless soil the settlement observed at the ground surface is maximum. The movement of soil in such type of soil is restricted to narrow region while wider settlement is observed as the plastic nature of soil goes on increasing. The same trend is observed for the lining forces. The interaction between twin tunnel hence in terms of ground displacement and tunnel lining force is dominant in cohesionless soil. Similarly apart from the geotechnical properties of soil the distance has major influence in the twin tunnel interaction. The study gives in sight on as the tunnel spacing increases to three times the tunnel diameter the interaction becomes insignificant. It is maximum when there is close positioning of tunnel. The effect of volume loss on twin tunnel is found to increase the interaction between tunnels. Both the displacement and lining forces increases on the under its influence irrespective of the nature of soil.

**Keywords**
Twin Tunnel, FEM, Ground Displacement, Internal lining forces

## 1. Introduction

Kathmandu is one of the densely populated cities around the world. With the growth of population the demand for systematic and efficient infrastructure should be proportionate. But in the congested urban spaces further extension of infrastructure is restrained. Kathmandu is notably characterized by congestion, limited open spaces and as an unplanned city. The growth rate as per CBS(2021) in Kathmandu is 1.4%, Lalitpur 1.52% and Bhaktapur 3.32%. Hence even the minimal necessities needed by man will not be fulfilled if the projection of population growth in this city keeps on growing at this rate. One of the major affected part of infrastructure is transportation. Increasing population demands capacity enhancement by widening of the existing infrastructure exploiting the available land resources. But in already built up spaces the possibility of carrying out such activities is not viable and alternatives such as construction of underground infrastructure is favored. Considering the preservation of built of spaces and the cost of land resources to acquire, the demand of underground structure is increasing.

However the construction of such underground spaces on already existing environment subsequently leads to ground movement which inevitably pose serious problems to the safety and integrity of the already existing structures. But the cost of construction is comparatively lesser than construction activities on ground due to omission of land acquisition. Therefore,the study of tunnel interactions should be carried out to evaluate the interaction effect on ground and tunnel itself restricting the settlement of ground within minimum value.

## 2. Literature Review

Stress relief due to excavation for tunnel leads to ground movement[1]. These movements needs to be assessed and should be restricted before it causes havoc to the surrounding. To limit the ground movement TBM are mainly prefered to ensure face stability and minimizing ground movements. EPB are widely used to minimize soil disturbance in urban areas[2]. Previous researches approached the interaction between tunnel and surrounding by:empirical approaches,analytical approaches,physical model testing and finite element modelling. Peck(1969) from 20 case histories expressed transverse settlement trough in greenfield condition by a Gaussian curve which is commonly used for representing the ground settlement caused by tunnelling[3]. But it does not takes into account the geotechnical parameters of soil. As tunnels are being bored or passed through soil completely has major influence on deformability or induced srtress in soil and tunnel it self it has not been considered. Superposition method are proposed for evaluation of twin or multiple tunnelling-induced ground settlements[4].[5] proposed a closed form solution for isotropic and homogenous incompressible soil. Hence it cannot accurately predict deformation for soft soil and are more applicable for hard rocks. Prediction of surface settlement can be done by these methods but are not applicable to analyse interaction between tunnel based on lining forces. The numerical method based on Finite Elements are the most reliable method which tend to give more accurate prediction of ground settlement and change in lining forces as they could model the mechanisms of the soil-structures interaction and realistic soil behaviour with the inputs of soil heterogenity, tunnels construction method and tunnel confiuguration. As tunnelling is a three dimensional problem it is often modelled as 2D problem.3D problem requires large storage and time and lack of suitable soil model which represent the real soil behaviour.[6]compared settlement profiles obtained by 2D and 3D finite element analyses of a tunnel for clayey-marly terrain of Belgrade provided that if the choices of parameters done for 2D analysis is accurate enough the result produced by 2D analysis would provide similar results. As Nepal has just entered the realm of tunnelling by the construction of Nagdhunga tunnel which is constructed in rock formation so only different proposition is made regarding soft ground tunnelling.[7] has carried out geotechnical analysis of metro rail in ground condition of Kathmandu-Patan line by empirical and analytical approach. Such approach does not takes into consideration the full interaction between underground structures and ground surfaces. Hence, in this paper interaction between tunnels and ground surface in Kathmandu soil is carried out under the variation of different parameters.

### 2.1 Method for Estimating Tunnelling Induced Settlement

Many researches have been carried out to determine the settlement induced while constructing underground structures. Such approaches are listed below as:

#### 2.1.1 Empirical Method

Ralph Peck from 20 case histories deduce the short term transverse settlement trough in freefield condition by a Gaussian curve.

The equation oft he gaussian curve is approximated as:

$$S = S_{\max} \exp^{\frac{-x^2}{2i^2}} \tag{1}$$

where S=surface settlement
$S_{max}$=maximum surface settlement
x=transverse distance from tunnel centreline
i =trough width parameter

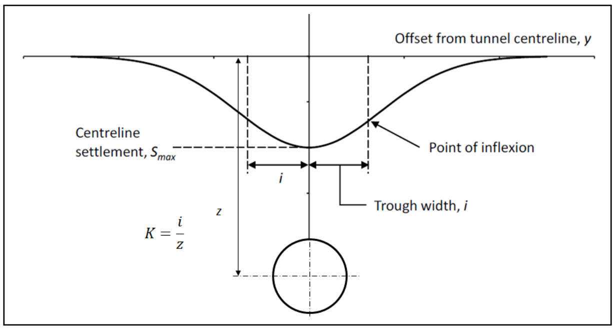


**Figure 1:** Gaussian curve for transverse settlement

#### 2.1.2 Analytical Method

In 1987,Sagaseta expressed displacements eliminating stresses when boundary conditions are only in terms of displacement and when the solutions required is only in term of displacement.

Chow in 1994 modified it to derive vertical displacement as:

$$S = \frac{-\gamma D^2 z^2}{4G(x^2 + z^2)} \tag{2}$$

where S=surface settlement
D=tunnel diameter
G-soil shear modulus
x=horizontal distance from tunnel centreline
z=depth from surface to tunnel centreline

## 3. Methodology

A case study of Cairo Metro line 2 is considered for the validation of work. The predicted surface settlement curve from the two dimensional Plaxis model is compared with the ground settlement measured in field. The comparision between the instrumented data and predicted from numerical model is used to assess the accuracy of the numerical model. The model was simulated in commercially available PLaxis 2D based on finite element method. The soil is modelled with Mohr-Coulomb criteria[8]. Then paramteric study is carried out varying different parameters as in table 4 for 3 different soil cases as mentioned in table 3. Geotechnical report of different area of Kathmandu Valley are considered. The construction is carried out by TBM so based on the methods of construction Volume loss in tunnel is taken as 0.5% -2%[9]. The research is carried out considering the diameter of tunnel to be 6.0m and located at a depth of 25m[7].

**Table 1:** Geotechnical properties in Central Cairo City(Mazek S.A et al)

| Layer | Fill | Silty clay | Sand |
|---|---|---|---|
| Bulk density (KN/m3 | 18 | 19 | 18.5 |
| Cohesion(KN/m$^2$ | 0 | 10 | 0 |
| Angle of friction | 20° | 26° | 30 |
| Young's Modulus(MN/m$^2$) | 10 | 12 | 30 |
| Poisons ratio | 0.4 | 0.35 | 0.35 |

**Table 2:** Characteristics of the tunnel lining(Mazek S.A et al)

| Properties | Value |
|---|---|
| Unit Weight(KN/m$^3$) | 25 |
| Young's Modulus(MN/m$^2$) | 21000 |
| Thickness of lining(m) | 0.4 |
| Poisons ratio | 0.2 |

**Table 3:** Geotechnical properties of 3 different case in Kathmandu Valley

| Layer | Case 1 | Case 2 | Case 3 |
|---|---|---|---|
| Bulk density (KN/m3 | 17.73 | 17.15 | 18.0 |
| Cohesion(KN/m$^2$ | 7.5 | 10 | 0 |
| Angle of friction | 20° | 28° | 28 |
| Young's Modulus(MN/m$^2$) | 60 | 60 | 35 |
| Poisons ratio | 0.4 | 0.4 | 0.4 |

**Table 4:** Parameters for study and ranges

| Parameters | Values |
|---|---|
| Tunnel spacing(m) | 0.5D,1D,2D,3D |
| Volume Loss(Vl) | 0.5,1,1.5,2 |

## 4. Results and Discussion

The study is carried out in two parts:

i)Validation of numerical model with field measurement and numerical model of reference paper.
ii)Using Validated model to carry out the parametric study.

### 4.1 Numerical Model and its Validation

The case study of Greater Cairo Metro Line 2 is modeled in 2D finite element model. The measured settlement at the site and numerical analysis of the referenced paper when compared to the computed settlement of model is in good agreement with error of 3.5%. Hence the numerical model is reasonably accurate enough to predict the behaviour of tunnel under various changes in parameters.

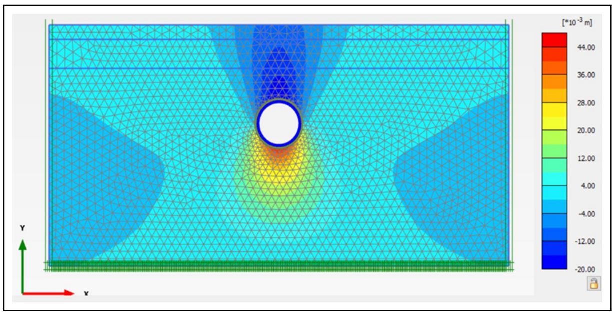

**Figure 2:** Numerical Analysis of Greater Cairo Metro

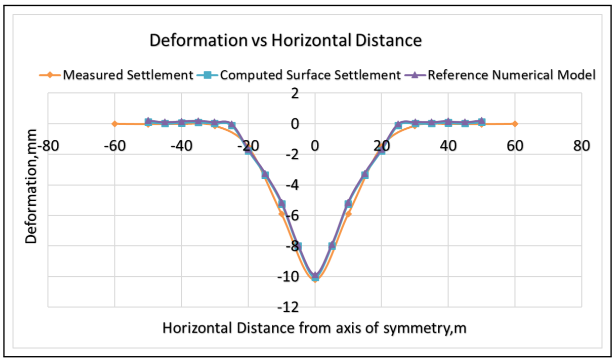


**Figure 3:** Settlement curve of Greater Cairo Metro

## 4.2 Parametric study analysis

### 4.2.1 Effect of Distance between tunnel

The effect of tunnel spacing on ground displacement and tunnel lining forces are presented in Figure 5, 7, 9, 11 and 12. For a constant volume loss as presented in Figure 4,ground displacement increases with the decrease in distance between tunnel. It illustrates that maximum interaction between tunnels occurs on close positioning but once the spacing reaches 3D it becomes negligible. For 3 different cases it is observed that there is decrease in ground displacement with increase in distance as indicated in figure 5,7 and 9. The maximum settlement is observed at cohesionless soil for same Volume loss and decreases as the cohesion between soil goes on increasing. The figure 6,8 and 10 indicates the settlement pattern of three different soil cases. As the characteristics of soil changes from plastic to non plastic movement of soil is restricted to wider to narrower region. Similarly the effect of tunnel spacing on internal lining forces is shown in figure 11 and 12 for Case 1. There is decreasing trend in ratio of Bending moment and Axial force in tunnel lining A due to excavation of Tunnel B as the spacing of tunnel decreases. It shows that the interaction between tunnel becomes less significant for spacing of three times tunnel diameter. Similar cases were observed for Case 2 and 3. Based on the ground displacement and tunnel lining forces the interaction between tunnel becomes almost negligible for tunnel spacing of 3D.

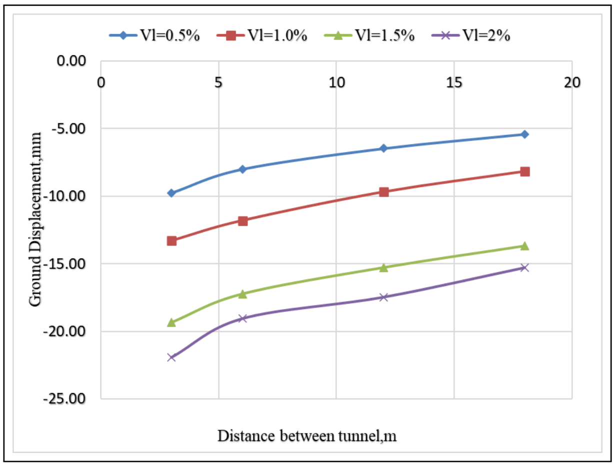


**Figure 5:** Effect of distance between tunnel on Ground displacement Case 1

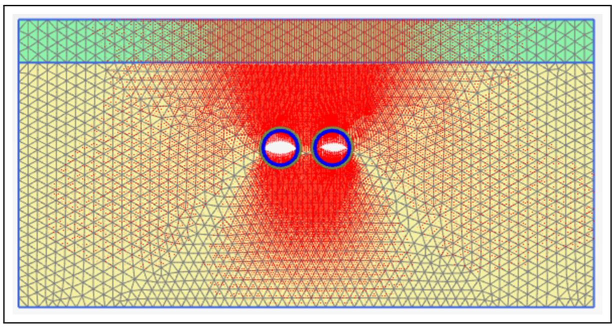

**Figure 6:** Displacement vector for Case 1

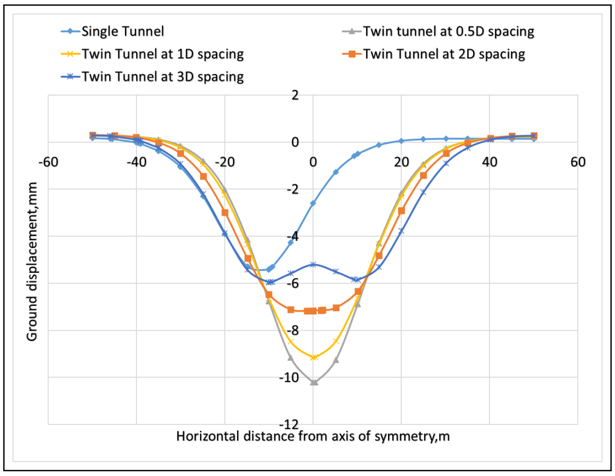


**Figure 4:** Ground displacement vs Horizontal distance at different tunnel spacing

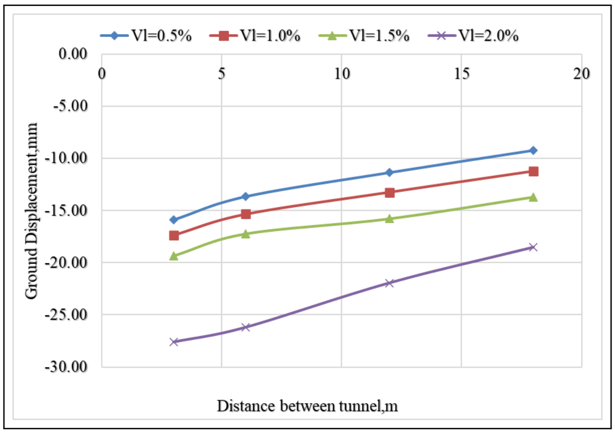


**Figure 7:** Effect of distance between tunnel on Ground displacement Case 2

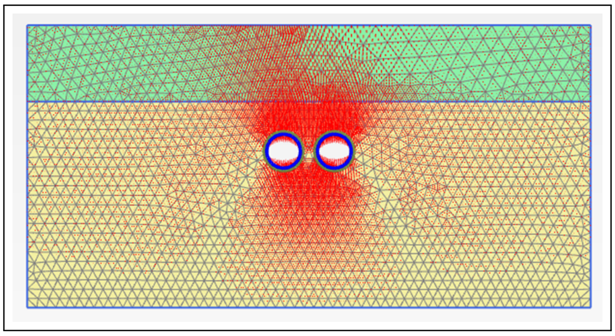

**Figure 8:** Displacement vector for Case 2

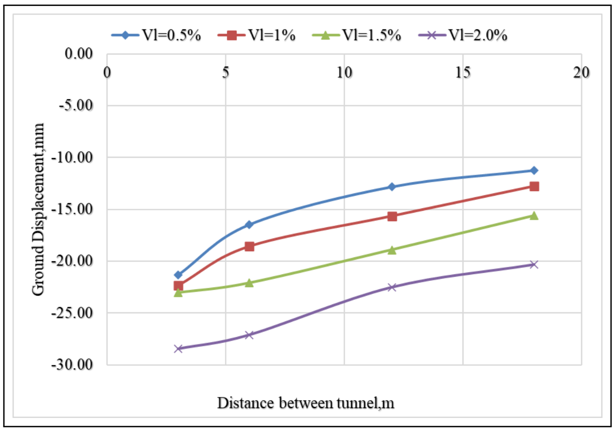


**Figure 9:** Effect of distance between tunnel on Ground displacement

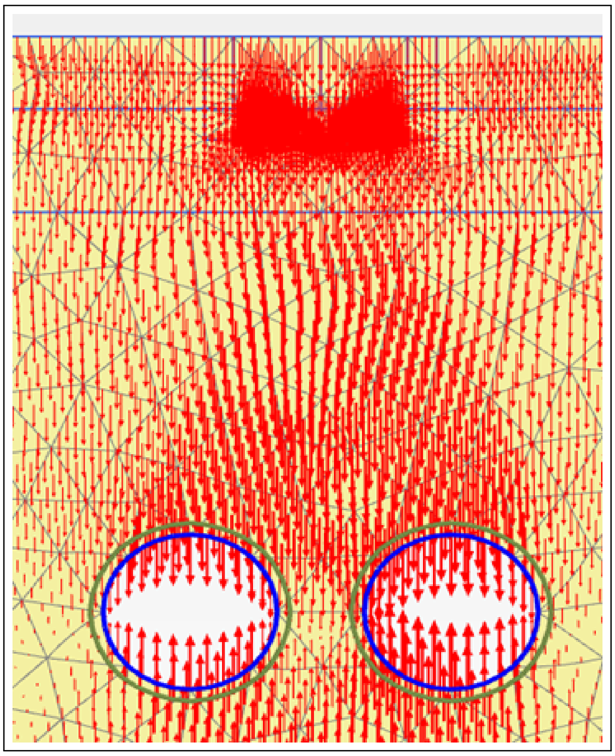

**Figure 10:** Displacement vector for Case 3

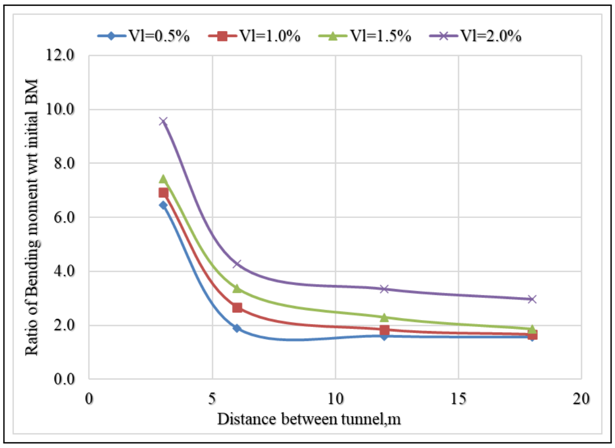


**Figure 11:** Effect of distance between tunnel on Bending moment of tunnels' lining Case 1

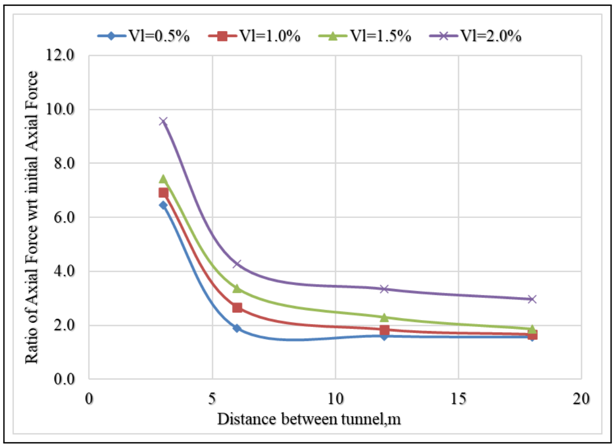


**Figure 12:** Effect of distance between tunnel on Axial Force of tunnels' lining Case 1

### 4.2.2 Effect of Volume Loss

As the volume loss in tunnel increases the displacement observed at ground goes on increasing as illustrated in Figure 13,14 and 15. Similarly for Case 1 the figure 16 and 17 indicates the trend of ratio of bending moment and axial force with respect to initial bending moment and axial force respectively. It illustrates that the ratio goes on decreasing as the volume loss goes on increasing. Similar trends were observed for different soil types of Case 2 and 3. Hence the interaction between tunnel and ground displacement goes on increasing as the volume loss goes on increasing irrspective of different soil types.

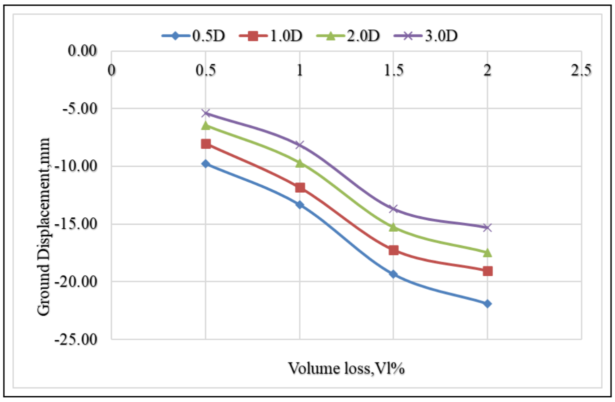


**Figure 13:** Effect of Volume Loss on Ground displacement Case 1

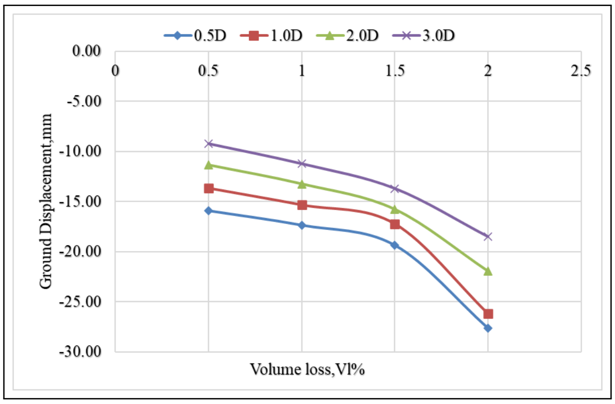


**Figure 14:** Effect of Volume Loss on Ground displacement Case 2

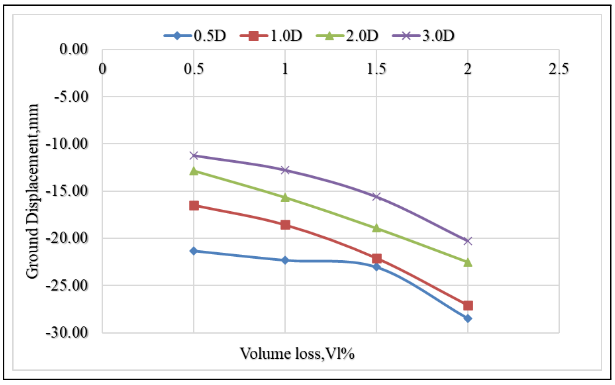


**Figure 15:** Effect of Volume Loss on Ground displacement Case 3

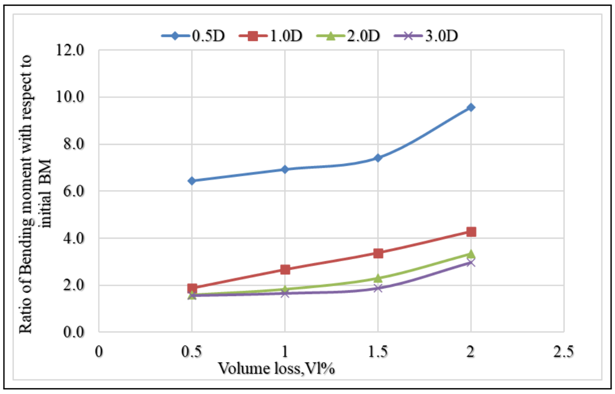


**Figure 16:** Effect of Volume Loss on Bending moment of tunnels' lining Case 1

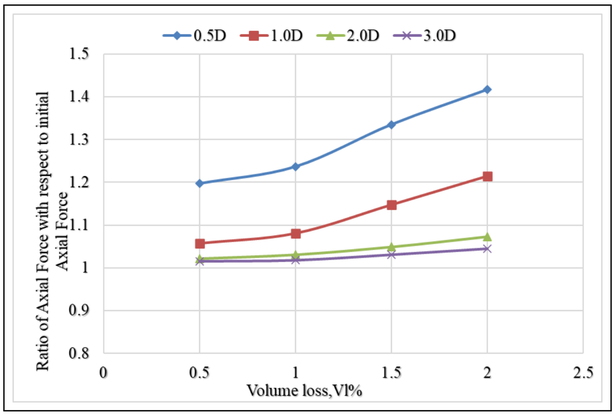


**Figure 17:** Effect of Volume Loss on Axial Force of tunnels' lining Case 1

## 5. Conclusion

From the results it can be concluded that:

1. Maximum ground settlement from numerical model when compared with referenced numerical analysis and measured settlement in field was in good agreement with error in between 3.5%.

2. With the increase in tunnel spacing ground displacement decreases. When the spacing increases to 3D the influence of second tunnel on the already existing tunnel becomes negligible in terms of displacement and lining forces.

3. The settlement case of all three casesfrom 1 to 3 were compared and maximum settlement were observed at Case 3 irrespective of different parameter changes. Greater displacement occured in cohesionless soil because the predominant force acting in granular soil is gravitational force thus it reinforces the vertical movement which is shown visually by the displacement vector. However with the

increase in cohesive nature of soil the displacement vector spread to wider region due to dominance of surface force.

4. Movement of cohesionless soil is restricted to narrower region. Hence when void is created the soil tries to move towards the void to maintain equilibrium in soil domain and as the movement is restricted to narrower region the maximum settlement is observed at the surface similar to the one proposed by Potts in 1976. Wider settlement trough is observed as the cohesive nature of soil increases as experimented by Mair in 1979 where soil moves both laterally and vertically under the influence of surface force.

5. Volume loss has direct influence on ground displacement and tunnel lining responses. The magnitude of both the parameters were dependent on type of soil and found to increase as the soil transitioned from Case 1 to Case 3.

## 6. Limitations

The major limitations are listed as:

1. The work is performed by two-dimensional finite element analysis method using Plaxis 2D as a tool. While tunnelling is a 3D procedure so 3D finite element approach could be adopted but due to restraint in time and computational cost 2D is used.

2. The study is restricted to the limited range of parameters, which may not be the only governing factors. Therefore, it is highly recommended to carry out parameter studies of other factors in order to achieve reliable result.

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