Study on the Effect of Surface Subsidence Due to Tunneling Under Various Loading Conditions

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Research Article

Keywords: Tunneling, Subsidence, Surface Displacements, Stresses

Posted Date: April 14th, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-344891/v1>

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Version of Record: A version of this preprint was published at Geotechnical and Geological Engineering on July 12th, 2021. See the published version at <https://doi.org/10.1007/s10706-021-01936-3>.

Abstract

The subsidence caused on the surface due to the construction of subsurface tunnels for various purposes in urban areas is a major concern for both the tunnel and the overlaid buildings. Seeing the importance of study, different models has been created keeping reference of commercial and residential buildings. The amount of surface deformation and the stresses so generated are calculated, which plays a paramount role before construction. These models are analyzed on circular and semicircular tunnels with various loading conditions and varying litho. In this paper, two software's namely STAAD Pro and Rocscience were used for structural design and analysis respectively. The study gives the basic idea of behavior of these two shapes of tunnels with varying loading condition and strata which shows a path for predicting unforeseeable displacements in real life situations.

1 Introduction

Underground Tunnels are majorly used for transportation or passage of water, sewerage, and utilities. Due to the exponential growth of population in urban areas, there are lot of space constraint, so the other way left is to go with sub surface. But because of the skyscrapers in cities, if the tunnels are constructed beneath it, huge stress is created around the tunnel. Due to this Stress, there may be a loss of ground volume and due to uneven displacement on the surface, building gets cracked and even may be collapsed. So before the construction of tunnels, displacement and stresses around the tunnel are to be calculated. This calculation involves soil properties, loading condition, depth of the tunnel and many other factors.

There are three methods for the calculation of ground displacements like empirical method, analytical method, and numerical method. The empirical method involves simple calculations like ground volume loss and its displacements. The empirical method is best suited if the tunnel conditions are known well. Analytical method is limited only to circular tunnels in homogeneous soil conditions. Numerical methods such as FEM, FDM can be used for different shapes of tunnels under heterogeneous soil conditions and is capable to consider soil-structure interaction, nonlinear behavior of soils and construction methods.

This paper mainly focus on the study of surface displacements in urban areas due to different shapes of tunnel namely circular and semi circular under various loading conditions and varying litho. For this displacement calculation, Rocscience Phase 2 which works on FEM is used.

2 Background

From the literature survey, only single litho with varying loading condition having a particular distance from center line of tunnel was analyzed. Shape of tunnel considered was circular. Comparison of surface displacements due to different shapes of tunnels and varying litho was not analyzed. Graphical representation of surface displacements with varying conditions is not done. The stresses produced

around the tunnel are not properly analyzed and compared. Varying litho in a single site condition is also not considered.

3 Calculation Of Loads

For the structural design, STAAD Pro software has been used which analyses in limit state method as it is designed for ultimate loads and serviceability is also considered. To relate this paper with live life conditions, a 5-storied residential building and a 10-storied commercial building are preferred as the models for analysis. A load combination of dead load, live load, wind load and earthquake load are considered. These models are constructed using STAAD Pro software and the vertical forces on the footing are calculated. To give the uniform design load, the vertical forces on each column are divided by the area of the footing. The column section with maximum loading on footing is used in the final models.

3.1 5-Storied Residential building

To understand the impact caused by various loading condition, a 5 storied residential building is considered so that it can relate to live life condition. The column section with node 3-10-14-18-22 is taken for the analysis

Table 1 UDL values of column strip of residential building

Column Node	Loading (MN)	Area (1.5m*1.5m) (m ²)	UDL (MN/m ²)
3	2.00817	2.25	0.892
10	1.75679		0.780
14	1.24704		0.554
18	1.67032		0.742
22	0.51355		0.228

3.2 10- Storied Commercial Building

To understand the impact caused by various loading condition, a 10 storied commercial building is considered so that it can relate to live life condition. The column section with node 3-6-9-13-17-21 is taken for the analysis.

Table 2 UDL values of column strip of commercial building

Column Node	Loading (MN)	Area (1.5m*1.5m) (m ²)	UDL (MN/m ²)
3	13.176	2.25	5.856
6	12.174		5.410
9	22.265		9.895
13	27.288		12.128
17	21.678		9.634
21	25.824		11.477

4 Loading Conditions

The ground displacements increase as the load applied on the centre line of tunnel increases and vice versa. For this, six different types of loading conditions are considered for the analysis which are detailed as follows:

4.1 No loading

In this no load is applied on the tunnel and analyzed for the surface displacements.

4.2 Residential structure away from tunnel

In this condition, the load of the column strip ends at a distance of radius from the centre line of the tunnel.

4.3 Residential structure on top of tunnel

In this model the load of the column strip is placed above the center line of the tunnel.

4.4 Commercial structure away from tunnel

In this condition the load of the column strip ends at a distance of radius from the centre line of the tunnel.

4.5 Commercial structure on top of tunnel

In this model the load of the column strip is applied above the centre line of the tunnel.

4.6 Commercial structure on top with tunnel lining

In this model the load of the column strip is applied above the centre line of the tunnel. To reduce the ground displacement, liner around the tunnel is applied and analyzed for the reduction in displacements

and compared it with the previous case.

5 Material Properties

In this paper, different types of litho with varying loading conditions on different shapes of the tunnels are analyzed for surface displacements. For this elastic property of soil & rock based on the Mohr Coulomb failure criterion is considered.

The table below shows the various litho along with respective properties required for the compilation of the model.

Table 3 Properties of different soil strata

S. No.	Strata	Material Properties					
		Unit Weight (MN/m ³)	Poisson's Ratio	Young's Modulus (MPa)	Tensile Strength (MPa)	Cohesion (MPa)	Friction Angle (degree)
1	Sandy Gravel	0.02059	0.25026	40.0083	0	0.001	35
2	Lime Stone	0.02648	0.2906	28393.4	1.58	6.72	42
3	Sand Stone	0.027	0.3	140	3.25	3	32
4	Shale	0.027	0.3	150	1.22	8.04	14.4
5	Marble	0.02711	0.35	70000	1.8	25.3	21.2
6	Granite	0.0264	0.2	45000	11.7	55.1	51
7	Basalt	0.02768	0.17	60000	13.1	66.2	31
8	Quartzite	0.02612	0.23	75000	11	70.6	48

6 Liner Properties

Liner is provided in the last case of commercial structure on the top of tunnel. This is done to compare the reduction in the displacement in same condition without liner. In this paper liner properties are assigned according to the situation and applied on the periphery of the tunnel.

Reinforced concrete liner was used and the properties of it are given below:

Table 4 Liner Concrete Properties

Concrete		
S. No.	Properties	Values
1	Thickness(m)	0.3
2	Young's Modulus (MPa)	26713.1
3	Poisson's Ratio	0.15
4	Compressive Strength (MPa)	25
5	Tensile Strength (MPa)	3
6	Unit Weight (MN/m ³)	0.024

Table 5 Liner Reinforcement Properties

Reinforcement		
S. No.	Properties	Values
1	Spacing (m)	0.6
2	Section Depth (m)	0.254
3	Area (m ²)	0.0004
4	Moment of Inertia (m ⁴)	6.458e ⁻⁰⁰⁶
5	Young's Modulus (MPa)	200000
6	Poisson's Ratio	0.25
7	Compressive Strength (MPa)	415
8	Tensile Strength (MPa)	415
9	Weight (kg/m)	3.112

M25 grade precast concrete and Fe 415 grade steel of 15.875 mm diameter are used as liner reinforcement.

7 Development Of Displacement Models

A model of 70 m wide and 40 m height is contrived and a tunnel of radius 5m is excavated at the centre and the soil properties of the strata are assigned. The boundaries of the models are restrained from

forces except for vertically downward forces. Load is applied on the surface according to the required condition. Uniform mesh of 3 noded triangles with an approximate of 10000 mesh elements is chosen. More the mesh elements, accuracy of the displacement is more. Then the model is discretized and mesh is applied. The model is computed and interpreted. From the interpreted model, total surface displacement values are captured. The obtained values are tabulated. The process is repeated with change in soil strata, loading condition and tunnel shape. The ground displacement values are compared with various combinations and are figuratively represented.

7.1 No Loading Condition

7.1.1 Lime Stone

In no loading condition, the overburden is considered to be 20 meters in both the circular and semi circular tunnel with lime stone as the litho. The surface displacements due to both the shapes of tunnels are as follows:

The surface displacement from Fig. 11 is about 0.061 mm and from Fig. 12, it is 0.071mm from which circular results in slightly lesser ground displacement than semi circular in lime stone litho with no loading condition.

7.1.2 Sand Stone

In no loading condition, the overburden is considered to be 20 meters in both the circular and semi circular tunnel with sand stone as the litho. The surface displacements due to both the shapes of tunnels are as follows:

The surface displacement from Fig. 13 is about 12.67 mm and from Fig. 14, it is 14.78 mm from which circular results in lesser ground displacement than semi circular in sand stone litho with no loading condition.

The surface displacements which are calculated for various materials with no loading condition due to circular and semi circular shape of tunnels are tabulated below.

Table 6 Max surface displacement in no loading condition

Materials	No Loading	
	Maximum surface displacement in mm	
	Circular	Semi Circular
Sandy Gravel	32.000	39.32
Lime Stone	0.061	0.071
Sand Stone	12.670	14.780
Shale	11.834	13.800
Marble	0.027	0.030
Granite	0.035	0.045
Basalt	0.026	0.035
Quartzite	0.021	0.027

7.2 Residential structure away from the top of the tunnel

7.2.1 Lime Stone

In residential away condition, the overburden is considered to be 20 meters in both the circular and semi circular tunnel with lime stone as the litho. The surface displacements due to both the shapes of tunnels are as follows:

The surface displacement from Fig. 15 is about 0.231 mm and from Fig. 16, it is 0.203 mm from which semi circular results slightly lesser ground displacement than circular in lime stone litho with residential away loading condition.

7.2.2 Sand Stone

In residential away condition, the overburden is considered to be 20 meters in both the circular and semi circular tunnel with sand stone as the litho. The surface displacements due to both the shapes of tunnels are as follows:

The surface displacement from Fig. 17 is about 46.82 mm and from Fig. 18, it is 46.57 mm from which circular and semi circular results approximately same surface displacements in sand stone litho with residential away loading condition.

The surface displacements which are calculated for various materials with residential away condition due to circular and semi circular shape of tunnels are tabulated below.

Table 7 Max surface displacement in residential away condition

Materials	Residential Away	
	Maximum surface displacement in mm	
	Circular	Semi Circular
Sandy Gravel	159.733	159.900
Lime Stone	0.231	0.203
Sand Stone	46.820	46.570
Shale	43.700	43.470
Marble	0.090	0.089
Granite	0.152	0.153
Basalt	0.116	0.118
Quartzite	0.090	0.091

7.3 Residential structure on top of the tunnel

7.3.1 Lime Stone

In residential top condition, the overburden is considered to be 20 meters in both circular and semicircular tunnel with lime stone as the litho. The surface displacements due to both the shapes of tunnels are as follows:

The surface displacement from Fig. 19 is about 0.257 mm and from Fig. 20 it is 0.262 mm from which circular results slightly lesser ground displacement than semi circular in lime stone litho with residential top condition.

7.3.2 Sand Stone

In residential top condition, the overburden is considered to be 20 meters in both the circular and semi circular tunnel with sand stone as the litho. The surface displacements due to both the shapes of tunnels are as follows:

The surface displacement from Fig. 21 is about 52.23 mm and from Fig. 22, it is 53.05 mm from which circular results in lesser ground displacement than semi circular in sand stone litho with residential top loading condition. The surface displacements which are calculated for various materials with residential top condition due to circular and semi circular shape of tunnels are tabulated below.

Table 8 Max surface displacement in residential top condition

Materials	Residential Top	
	Maximum surface displacement in mm	
	Circular	Semi Circular
Sandy Gravel	178.120	180.385
Lime Stone	0.257	0.262
Sand Stone	52.230	53.050
Shale	48.700	49.510
Marble	0.101	0.101
Granite	0.169	0.175
Basalt	0.129	0.134
Quartzite	0.100	0.103

7.4 Commercial structure away from the top of tunnel

7.4.1 Lime Stone

In commercial away condition, the overburden is considered to be 20 meters in both the circular and semi circular tunnel with lime stone as the litho. The surface displacements due to both the shapes of tunnels are as follows:

The surface displacement from Fig. 23 is about 2.783 mm and from Fig. 24, it is 2.727 mm from which semi circular results in lesser ground displacement than circular in lime stone litho with commercial away loading condition.

7.4.2 Sand Stone

In commercial away condition, the overburden is considered to be 20 meters in both the circular and semi circular tunnel with sand stone as the litho. The surface displacements due to both the shapes of tunnels are as follows:

The surface displacement from Fig. 25 is about 558.9 mm and from Fig. 26, it is 547.72 mm from which semi circular results in lesser ground displacement than circular in sand stone litho with commercial away loading condition.

The surface displacements which are calculated for various materials with commercial away condition due to circular and semi circular shape of tunnels are tabulated below.

Table 9 Max surface displacement in commercial away condition

Materials	Commercial Away	
	Maximum surface displacement in mm	
	Circular	Semi Circular
Sandy Gravel	2041.610	2000.900
Lime Stone	2.783	2.727
Sand Stone	558.900	547.720
Shale	521.700	511.249
Marble	1.046	1.024
Granite	1.884	1.848
Basalt	1.435	1.408
Quartzite	1.109	1.088

7.5 Commercial structure on top of the tunnel

7.5.1 Lime Stone

In commercial top condition, the overburden is considered to be 20 meters in both the circular and semi circular tunnel with lime stone as the litho. The surface displacements due to both the shapes of tunnels are as follows:

The surface displacement from Fig. 27 is about 3.060 mm and from Fig. 28, it is 2.952 mm from which semi circular results in lesser ground displacement than circular in lime stone litho with commercial top loading condition.

7.5.2 Sand Stone

In commercial top condition, the overburden is considered to be 20 meters in both the circular and semi circular tunnel with sand stone as the litho. The surface displacements due to both the shapes of tunnels are as follows:

The surface displacement from Fig. 29 is about 615.23 mm and from Fig. 30, it is 592.65 mm from which semi circular results in lesser ground displacement than circular in sand stone litho with commercial top

condition.

The surface displacements which are calculated for various materials with commercial top loading condition due to circular and semi circular shape of tunnels are tabulated below.

Table 10 Max surface displacement in commercial top condition

Materials	Commercial Top	
	Maximum surface displacement in mm	
	Circular	Semi Circular
Sandy Gravel	2254.680	2168.440
Lime Stone	3.060	2.952
Sand Stone	615.230	592.650
Shale	562.730	539.505
Marble	1.147	1.103
Granite	2.087	2.009
Basalt	1.593	1.533
Quartzite	1.227	1.181

7.6 Commercial structure on top of the tunnel with lining

7.6.1 Lime Stone

In commercial top with lining condition, the overburden is considered to be 20 meters in both the circular and semi circular tunnel with lime stone as the litho. The surface displacements due to both the shapes of tunnels are as follows:

The surface displacement from Fig. 31 is about 3.014 mm and from Fig. 32, it is 2.912 mm from which semi circular results slightly lesser ground displacement than circular in lime stone litho with commercial top with lining condition.

7.6.2 Sand Stone

In commercial top with lining condition, the overburden is considered to be 20 meters in both the circular and semi circular tunnel with sand stone as the litho. The surface displacements due to both the shapes of tunnels are as follows:

The surface displacement from Fig. 33 is about 515.178 mm and from Fig. 34, it is 526.84 mm from which circular results in lesser ground displacement than semi circular in sand stone litho with commercial top with lining condition. The surface displacements which are calculated for various materials with commercial top with lining loading condition due to circular and semi circular shape of tunnels are tabulated below.

Table 11 Max surface displacement in commercial top with lining condition

Materials	Commercial top with lining	
	Maximum surface displacement in mm	
	Circular	Semi Circular
Sandy Gravel	1869.700	1899.140
Lime Stone	3.014	2.912
Sand Stone	515.178	526.840
Shale	484.672	487.681
Marble	1.138	1.097
Granite	2.063	1.889
Basalt	1.578	1.521
Quartzite	1.218	1.174

8 Development Of Stress Models

Stress models are developed similar to the displacements models. But after the interpretation we select the mean stress from the tool bar instead of total displacement. Then the model with stress contours are displayed. We capture the required stress values at surface and around tunnel and are tabulated. Comparison of stresses with different conditions is figuratively represented.

8.1 No Loading Condition

8.1.1 Lime Stone

In no loading condition, the overburden is considered to be 20 meters in both the circular and semicircular tunnel with lime stone as the litho. The stresses developed around the tunnel in both the circular and semicircular tunnels are as follows:

The stress from Fig. 35 is about 1.05 MPa and from Fig. 36, it is 1.59 Mpa. From the figures, circular results in lesser stress around the tunnel than semi circular in lime stone litho with no loading condition.

8.1.2 Sand Stone

In no loading condition, the overburden is considered to be 20 meters in both the circular and semi circular tunnel with sand stone as the litho. The stresses generated around the tunnel in both circular and semi circular tunnels are as follows:

The stress from Fig. 37 is about 1.07 MPa and from Fig. 38, it is 1.64 MPa. From the figures, circular results in lesser stress than semi circular in sand stone litho with no loading condition.

The stresses which are calculated for circular and semi circular tunnels with different materials in no loading condition are tabulated below.

Table 12 Mean stress in no loading condition

Materials	No Loading	
	Mean Stress in Mpa	
	Circular	Semi Circular
Sandy Gravel	0.820	1.170
Lime Stone	1.050	1.590
Sand Stone	1.070	1.640
Shale	1.070	1.640
Marble	1.070	1.780
Granite	1.050	1.420
Basalt	1.100	1.440
Quartzite	1.040	1.450

8.2 Residential structure away from top of the tunnel

8.2.1 Lime Stone

In residential away loading condition, the overburden is considered to be 20 meters in both the circular and semi circular tunnel with lime stone as the litho. The stresses developed around the tunnel in both the circular and semi circular tunnels are as follows:

The stress from Fig. 39 is about 1.08 MPa and from Fig. 40, it is 1.71 MPa. From the figures, circular results in lesser stress around the tunnel than semi circular in lime stone litho with residential away loading condition.

8.2.2 Sand Stone

In residential away condition, the overburden is considered to be 20 meters in both the circular and semi circular tunnel with sand stone as the litho. The stresses generated around the tunnel in both circular and semi circular tunnels are as follows:

The stress from Fig 41 is about 1.1 MPa and from Fig. 42, it is 1.76 MPa. From the figures, circular results in lesser stress than semi circular in sand stone litho with residential away condition.

The stresses which are calculated for circular and semi circular tunnels with different materials in residential away condition are tabulated below.

Table 13 Mean stress in residential away loading condition

Materials	Residential Away	
	Mean Stress in MPa	
	Circular	Semi Circular
Sandy Gravel	0.850	1.320
Lime Stone	1.080	1.710
Sand Stone	1.100	1.760
Shale	1.100	1.760
Marble	1.110	1.870
Granite	1.070	1.550
Basalt	1.120	1.570
Quartzite	1.060	1.580

8.3 Residential structure on top of the tunnel

8.3.1 Lime Stone

In residential top condition, the overburden is considered to be 20 meters in both the circular and semi circular tunnel with lime stone as the litho. The stresses developed around the tunnel in both the circular and semi circular tunnels are as follows:

The stress from Fig. 43 is about 1.07 MPa and from Fig. 44, it is 1.66 MPa. From the figures, circular results in lesser stress around the tunnel than semi circular in lime stone litho with residential top loading condition.

8.3.2 Sand Stone

In residential top loading condition, the overburden is considered to be 20 meters in both the circular and semicircular tunnel with sand stone as the litho. The stresses generated around the tunnel in both circular and semicircular tunnels are as follows:

The stress from Fig. 45 is about 1.09 MPa and from Fig. 46, it is 1.71 MPa. From the figures, circular results in lesser stress than semi circular in sand stone litho with residential top condition.

The stresses which are calculated for circular and semi circular tunnels with different materials in residential top condition are tabulated below.

Table 14 Mean stress in residential top loading condition

Materials	Residential Top	
	Mean Stress in Mpa	
	Circular	Semi Circular
Sandy Gravel	0.840	1.280
Lime Stone	1.070	1.660
Sand Stone	1.090	1.710
Shale	1.090	1.710
Marble	1.100	1.810
Granite	1.070	1.510
Basalt	1.120	1.530
Quartzite	1.050	1.540

8.4 Commercial structure away from top of the tunnel

8.4.1 Lime Stone

In commercial away condition, the overburden is considered to be 20 meters in both the circular and semi circular tunnel with lime stone as the litho. The stresses developed around the tunnel in both the circular and semi circular tunnels are as follows:

The stress from Fig. 47 is about 4.21 MPa and from Fig. 48, it is 5.48 MPa. From the figures, circular results in lesser stress around the tunnel than semicircular in lime stone litho with commercial away loading condition.

8.4.2 Sand Stone

In commercial away loading condition, the overburden is considered to be 20 meters in both the circular and semicircular tunnel with sand stone as the litho. The stresses generated around the tunnel in both circular and semicircular tunnels are as follows:

The stress from Fig. 49 is about 4.24 MPa and from Fig. 50, it is 5.59 MPa. From the figures, circular results in lesser stress than semicircular in sand stone litho with commercial away condition.

The stresses which are calculated for circular and semi circular tunnels with different materials in commercial away condition are tabulated below.

Table 15 Mean stress in commercial away loading condition

Materials	Commercial Away	
	Mean Stress in Mpa	
	Circular	Semi Circular
Sandy Gravel	4.050	4.860
Lime Stone	4.210	5.480
Sand Stone	4.240	5.590
Shale	4.240	5.590
Marble	4.420	6.030
Granite	3.870	4.810
Basalt	3.760	4.680
Quartzite	3.980	5.000

8.5 Commercial structure on top of the tunnel

8.5.1 Lime Stone

In commercial top loading condition, the overburden is considered to be 20 meters in both the circular and semi circular tunnel with lime stone as the litho. The stresses developed around the tunnel in both the circular and semi circular tunnels are as follows:

The stress from Fig. 51 is about 3.99 MPa and from Fig. 52, it is 4.97 MPa. From the figures, circular results in lesser stress around the tunnel than semi circular in lime stone litho with commercial top loading condition.

8.5.2 Sand Stone

In commercial top condition, the overburden is considered to be 20 meters in both the circular and semi circular tunnel with sand stone as the litho. The stresses generated around the tunnel in both circular and semi circular tunnels are as follows:

The stress from Fig. 53 is about 4.03 MPa and from Fig. 54, it is 5.07 MPa. From the figures, circular results in lesser stress than semi circular in sand stone litho with commercial top condition.

The stresses which are calculated for circular and semi circular tunnels with different materials in commercial top loading condition are tabulated below.

Table 16 Mean stress in commercial top loading condition

Materials	Commercial Top	
	Mean Stress in Mpa	
	Circular	Semi Circular
Sandy Gravel	3.810	4.390
Lime Stone	3.990	4.970
Sand Stone	4.030	5.070
Shale	3.950	4.270
Marble	4.250	5.490
Granite	3.620	4.370
Basalt	3.500	4.260
Quartzite	3.740	4.540

8.6 Commercial structure on top of the tunnel with lining

8.6.1 Lime Stone

In commercial top with lining condition, the overburden is considered to be 20 meters in both the circular and semi circular tunnel with lime stone as the litho. The stresses developed around the tunnel in both the circular and semi circular tunnels are as follows:

The stress from Fig. 55 is about 3.97 MPa and from Fig. 56, it is 4.73 MPa. From the figures, circular results in lesser stress around the tunnel than semi circular in lime stone litho with commercial top with lining condition.

8.6.2 Sand Stone

In commercial top with lining condition, the overburden is considered to be 20 meters in both the circular and semi circular tunnel with sand stone as the litho. The stresses generated around the tunnel in both circular and semi circular tunnels are as follows:

The stress from Fig. 57 is about 3.79 MPa and from Fig. 58, it is 6.45 MPa. From the figures, circular results in lesser stress than semi circular in sand stone litho with commercial top with lining condition.

The stresses which are calculated for circular and semi circular tunnels with different materials in commercial top with lining condition are tabulated below.

Table 17 Mean stress in commercial top with lining loading condition

Materials	Commercial Top with Lining	
	Mean Stress in Mpa	
	Circular	Semi Circular
Sandy Gravel	3.570	4.810
Lime Stone	3.970	4.730
Sand Stone	3.790	6.450
Shale	3.760	5.180
Marble	4.240	5.230
Granite	3.610	3.940
Basalt	3.490	3.830
Quartzite	3.730	4.120

9 Analysis Of Displacements And Stress Models

9.1 Sandy Gravel

In sandy gravel strata, from Fig. 59 the surface displacement is more in commercial away & commercial on top condition in which circular shape tunnel results in more surface displacement when collated with semi circular. But after lining the tunnel with circular shape results in lesser surface displacement when compared to semi circular. In residential & no loading condition surface displacement due to semi circular

and circular tunnels are identical. The stresses generated is more in case of semi circular tunnel in all loading conditions when compared to circular. From Fig. 59, Fig. 60 the semi circular even producing more stresses, results in approximately identical surface displacements as circular except in commercial top condition which is a bit less than circular.

9.2 Lime Stone

In lime stone litho, from Fig. 61 we can see that there is virtually same surface displacements except in commercial on top and with lining conditions in which circular tunnel results in more surface displacement. From Fig. 62 the stresses in commercial away is more than the commercial on top condition and lining condition. The stresses mostly reduced in case of lining when collated with commercial on top in semi circular and in circular tunnel which remains almost constant. The surface displacement in case of residential and no loading condition is very less and almost equal. From Fig. 61, Fig. 62 the semi circular producing more stresses, results in approximately identical surface displacements as circular except in commercial top & lining condition which is a bit less than circular.

9.3 Sand Stone

From Fig. 63, the displacement in commercial top is more than commercial away but with the provision of lining, the displacement is reduced more in circular collated to semi circular. In residential condition the surface displaces more in case of semi circular followed by circular. From Fig. 64, the stresses are more in semi circular. In lining conditions, semi circular generates more stress than commercial away & on top conditions. Commercial away induces more stresses than on commercial top condition & lining in circular tunnel. From Fig. 63, Fig. 64 semi circular shape results in lesser surface displacements except in lining condition and stresses generated are more. In other cases the surface displacements are virtually same in both shapes of tunnels.

9.4 Shale

In case of shale litho, Fig. 65 shows the surface displacements due to different shape of tunnels follows the same trend as in the Sand Stone but with a little lesser values in all the loading conditions. Fig. 66 shows the stresses generated and follows the same trend as in the sand stone with approximately same values. The stresses are reduced more in commercial top than in commercial away and increased in lining condition in semi circular tunnel shape. From Fig. 65, In residential condition, surface displacements due to circular and semi circular tunnels are similar and in commercial conditions surface displacements are slightly varied except in lining condition.

9.5 Marble

In marble strata, the Fig. 67 represents displacements due to circular and semi circular tunnels are similar in all the conditions. Fig. 68 shows the stresses in case of semi circular tunnel is more. There is a trivial change in stresses in residential conditions. The stress is reduced in lining condition when collated to

commercial away & commercial top in semi circular shape of tunnel and remained constant in circular shape.

9.6 Granite

In case of granite litho, from Fig. 69, the surface displacement with circular and semi circular are almost same in all the conditions and it follows the same trend as marble. Fig.70 shows the stresses generated are slightly more in all the loading conditions in case of semi circular tunnel.

9.7 Basalt

The ground displacements and the stresses around the tunnel follows the same trend as in granite and marble litho. In Fig. 71, the surface displacements in all the loading conditions are slightly varied and is virtually same. From Fig. 72, the stresses slightly decreases in commercial on top and in lining when compared to commercial away. The stresses generated are slightly high in semi circular in all the loading conditions compared to circular.

9.8 Quartzite

Quartzite litho also follows the same trend as in the granite and basalt strata. From Fig. 73, in residential loading conditions the surface displacements is negligibly high in semi circular and vice versa in commercial & lining conditions. Fig. 74 shows, the stresses with semi circular in all the conditions are slightly more. There is negligible change in stress in both commercial top and lining conditions in circular tunnel. In semi circular, the stress is more in commercial away and reduces in commercial top & lining condition.

10 Conclusions

In the study, the displacement and stresses were analyzed on circular and semicircular tunnels with various loading conditions and varying litho.

1. In sandy gravel, sand stone & shale strata the displacements due to circular shape tunnel results is showing lesser displacement compared to semicircular in no loading, residential loading & support condition. In all the other strata, the displacements are almost similar in all the loading conditions.
2. With varying litho, in all the loading conditions, the stresses around the semicircular tunnel are more when collated with circular shape of tunnel.

Under same loading condition tunnel with liner shows reduced surface displacement when compared with tunnel without liner.

11 Declarations

Acknowledgements

The authors are thankful to VNIT, Nagpur for providing necessary support and permission to conduct and publish this research work. A special thanks to Krishna Vamsi and Aparna Unnikrishnan who helped in editing and other support for this study. The views expressed in this paper are those of the authors and not necessarily of the organization they represent. This paper forms a part of the M Tech of the first author.

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Figures

Figure 1

Line diagram of a residential building

Figure 2

Line diagram of footing of residential building with column nodes selected for analysis

Figure 3

Line diagram of a commercial building

Figure 4

Line diagram of footing of commercial building with column nodes selected for analysis

Figure 5

Circular tunnel with no loading condition

Figure 6

Circular tunnel with residential structure away from top of the tunnel

Figure 7

Circular tunnel with residential structure on top of the tunnel

Figure 8

Circular tunnel with commercial structure away from the top of the tunnel

Figure 9

Circular tunnel with commercial structure on top of the tunnel

Figure 10

Circular tunnel with commercial structure on top of the tunnel with lining

Figure 12

Surface displacement due to semi circular tunnel

Figure 13

Surface displacement due to circular tunnel

Figure 14

Surface displacement due to semi circular tunnel

Figure 15

Surface displacement due to circular

Figure 16

Surface displacement due to semi circular tunnel

Figure 17

Surface displacement due to circular tunnel

Figure 18

Surface displacement due to semi circular tunnel

Figure 19

Surface displacement due to circular tunnel

Figure 20

Surface displacement due to semicircular tunnel

Figure 21

Surface displacement due to circular tunnel

Figure 22

Surface displacement due to semi circular tunnel

Figure 23

Surface displacement due to circular tunnel

Figure 24

Surface displacement due to semi circular tunnel

Figure 25

Surface displacement due to circular tunnel

Figure 26

Surface displacement due to semi circular tunnel

Figure 27

Surface displacement due to circular tunnel

Figure 28

Surface displacement due to semi circular tunnel

Figure 29

Surface displacement due to circular tunnel

Figure 30

Surface displacement due to semi circular tunnel

Figure 31

Surface displacement due to circular tunnel with lining

Figure 32

Surface displacement due to semicircular tunnel with lining

Figure 33

Surface displacement due to circular tunnel with lining

Figure 34

Surface displacement due to semicircular tunnel with lining

Figure 35

Max mean stress in MPa around circular tunnel

Figure 36

Max mean stress in MPa around semicircular tunnel

Figure 37

Max mean stress in MPa around circular tunnel

Figure 38

Max mean stress in MPa around semicircular tunnel

Figure 39

Max mean stress in MPa around circular tunnel

Figure 40

Max mean stress in MPa around semicircular tunnel

Figure 41

Max mean stress in MPa around circular tunnel

Figure 42

Max mean stress in MPa around semicircular tunnel

Figure 43

Max mean stress in MPa around circular tunnel

Figure 44

Max mean stress in MPa around semicircular tunnel

Figure 45

Max mean stress in MPa around circular tunnel

Figure 46

Max mean stress in MPa around semicircular tunnel

Figure 47

Max mean stress in MPa around circular tunnel

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Max mean stress in MPa around semicircular tunnel

Figure 49

Max mean stress in MPa around circular tunnel

Figure 50

Max mean stress in MPa around semicircular tunnel

Figure 51

Max mean stress in MPa around circular tunnel

Figure 52

Max mean stress in MPa around semicircular tunnel

Figure 54

Max mean stress in MPa around semicircular tunnel

Figure 55

Max mean stress in MPa around circular tunnel with lining

Figure 56

Max mean stress in MPa around semicircular tunnel with lining

Figure 57

Max mean stress in MPa around circular tunnel with lining

Figure 58

Max mean stress in MPa around semicircular tunnel with lining

Figure 59

Graph between max surface displacement and loading conditons in sandy gravel

Figure 60

Graph between mean stress and loading conditions in sandy gravel

Figure 61

Graph between max surface displacement and loading conditons in lime stone

Figure 62

Graph between mean stress and loading conditions in lime stone

Figure 63

Graph between max surface displacement and loading conditons in sand stone

Figure 64

Graph between mean stress and loading conditions in sand stone

Figure 65

Graph between max surface displacement and loading conditons in shale

Figure 66

Graph between mean stress and loading conditions in shale

Marble

Figure 67

Graph between max surface displacement and loading conditons in marble

Marble

Figure 68

Graph between mean stress and loading conditions in marble

Granite

Figure 69

Graph between max surface displacement and loading conditons in granite

Figure 70

Graph between mean stress and loading conditions in granite

Basalt

Figure 71

Graph between max surface displacement and loading conditons in basalt

Basalt

Figure 72

Graph between mean stress and loading conditions in basalt

Quartzite

Figure 73

Graph between max surface displacement and loading conditons in quartzite

Quartzite

—◆— Circular —■— Semi Circular

Figure 74

Graph between mean stress and loading conditions in quartzite