Behavioural Aspect of Tunnel by Soil Structure Interaction

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Abstract. Tunnels are the underground passages used for transportation and other purposes. Tunnel lining adds the structural strength and saves the rock from air slakes. This paper contains study of ground conditions which includes variation in stratification and effect of ground water table. Based on these conditions of stratification and ground water the problem of deformation of tunnel and stresses developed on tunnel are solved considering field situations. For this purpose, 3D analysis is done by Midas GTS NX software. Various parameters of soil/rock such as porosity, cohesion, friction angle, Poisson's ratio, Young's modulus, Geological Strength Index, etc. have been used. Various cases tried for concrete lining and its effect on deformation is studied at key points of tunnel. By taking iterations and comparing results of all the cases, final conclusion is drawn. Thus, the soil structure interactive analysis for various conditions have been tried and results obtained at selected key points on the tunnel lining are tabulated graphically which are useful for the preliminary design of tunnel lining under appropriately selected conditions. This work is useful to the practitioners, design engineers, consultants, researchers and construction professionals to decide the preliminary thickness of lining with certain approximations.

Keywords: Soil-structure interaction, Midas GTS NX, Tunnel deformation.

1 Introduction

Tunnels are underground passages which serves mainly in transportation purposes. These are of different types according to its shape and utility. Tunnels are constructed with different types of lining such as steel, rock bolts, concrete etc. in various kinds of strata. Here Midas GTS NX software is used for analysis.

K. Szechy has given the analysis and design aspects of various shapes of tunnel [1]. In this paper circular shaped tunnel is used for analysis. The lining provided here is a concrete lining. 3D analysis is done in Midas GTS NX.

1.1 Stratification

Geology plays an important role in design, construction and to determine the feasibility of tunnel. One fixed stratum is taken here throughout for all cases executed in Midas GTS NX software. This is 30m deep stratum having layers as alluvial soil, clay, weathered rock, limestone, marble, and basalt. Fig. 1 shows circular tunnel of diameter, 6.5m at the depth of 13m from ground level. Water level is also shown at depth 25.5m.
Depth of each layer is tabulated in Table 1 and shown in Fig. 1.

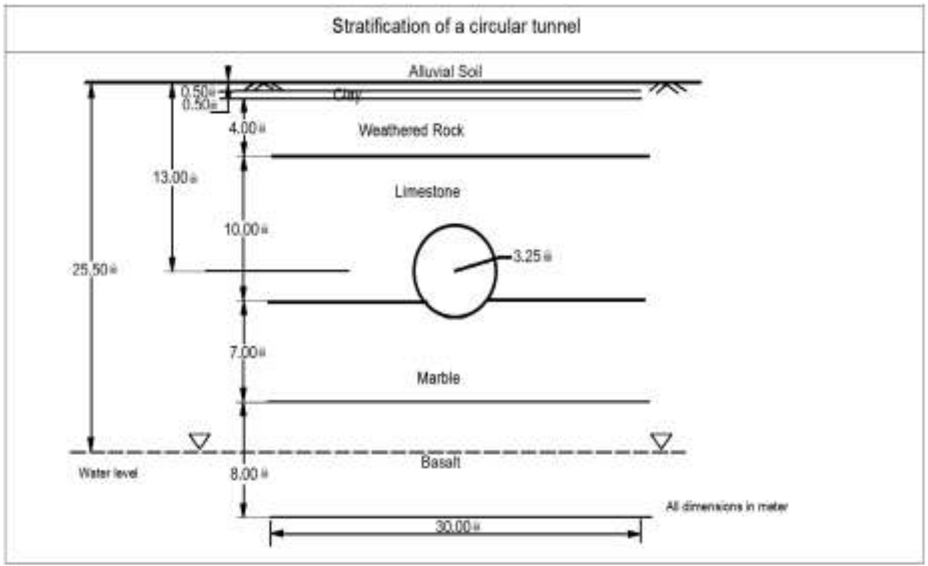

Fig. 1. Stratification of a circular tunnel

Table 1. Depth of each layer in stratum

Sr. No.	Soil/ Rock	Depth (in m)
1	Alluvial soil	0.5
2	Clay	0.5
3	Weathered rock	4
4	Limestone	10
5	Marble	7
6	Basalt	8
	TOTAL	30

1.2 Modeling of tunnel in software

Modeling of tunnel includes geometric modeling, addition of geometrical parameters, meshing of tunnel, adding of constraints, defining of construction stages and analysis.

2 Methodology

2.1 Lining material

The concrete lining is provided with grades M30, M40 and M50. Poisson's ratio, unit weight and modulus of elasticity are properties of concrete which is an elastic material. These properties and its values are tabulated as follows,

Table 2. Characteristics of lining material

Sr. No.	Material Properties for lining	
1	Name	Concrete
2	Material Model	Elastic
3	Poisson's ratio	0.18
4	Unit Weight (kN/m^3)	24

Modulus of elasticity as one of the properties of concrete used in different cases for three different grades is calculated by equation (1) and shown in Table 3.

$$E=5000\sqrt{f_{ck}} \quad (1)[2]$$

Table 3. Modulus of elasticity

Sr. No.	Grade of concrete	Modulus of Elasticity (kN/m^2)
1	M30	2.74E+07
2	M40	3.16E+07
3	M50	3.54E+07

2.2 Cases in Midas GTS NX

In a fixed stratum, circular tunnel of one particular grade of concrete of lining thickness of 0.3m, 0.4m and 0.5m are taken and deformation of tunnel is observed for each lining thickness. Likewise, total nine cases are executed as three for each grade of concrete. Geometric modeling includes the basic geometry and dimensions of tunnel. Default tetrahedral element is used for meshing of tunnel. 0.5 meshing size is provided to plate material i.e. lining material of tunnel and mesh size provided for strata is 1.2. 3D modeling of tunnel in Fig. 1 is shown in Fig.3. The boundary conditions provided in this case are 'Auto'. Selection of the mesh set automatically created constraint conditions. The ground conditions for general stress analysis are set automatically. The X-direction displacement is constrained for the left/right side, the Y-direction displacement is constrained for the front/back side and the Z-direction displacement is constrained for the up/down of a model. Direction of axes is shown in Fig. 2. Construction stages are defined and finally analysis is done followed by extraction of results at key points of tunnel shown in Fig. 4.

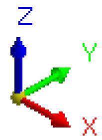

Fig. 2. Axes directions

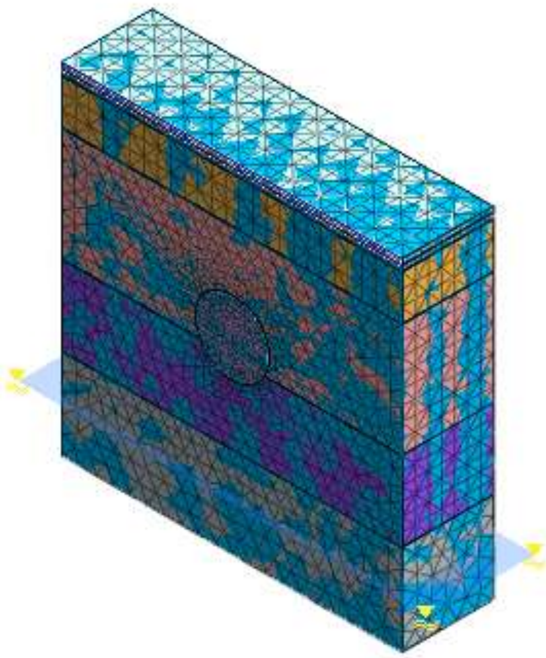

Fig. 3. 3D modeling in GTS NX

3 Geotechnical parameters used for materials in stratum

Geotechnical parameters with their constants [3] of soil and rocks present in a stratum are tabulated in Table 4 and Table 5 respectively. The values of modulus of elasticity and other constants are given by Goodman, Brown and others [4][5].

Table 4. Geotechnical parameters used for soil layers in model

Sr. No.	Properties	Alluvial soil	Weathered rock	Clay
1	Material Model	Mohr-Coulomb	Mohr-Coulomb	Modified Cam Clay
2	Modulus of Elasticity (kN/m^2)	8000	150000	10000
3	Poisson's ratio	0.35	0.3	0.45
4	Unit Weight (kN/m^3)	17	21	17
5	Saturated unit Weight (kN/m^3)	18	22	20
6	Cohesion (kN/m^2)	15	50	-
7	Friction angle (in degrees)	20	30	-
8	Over Consolidation Ratio (OCR)	-	-	1
9	Slope of Consol line (λ)	-	-	0.221
10	Slope of Over Consol line (k)	-	-	0.015
11	Slope of critical line (M)	-	-	0.18

Table 5. Geotechnical parameters used for rock layers in model

Sr. No.	Properties	Limestone	Marble	Basalt
1	Material Model	Hoek-Brown	Hoek-Brown	Hoek-Brown
2	Modulus of Elasticity (kN/m^2)	4.30E+07	6.80E+07	5.00E+09
3	Poisson's ratio	0.18	0.38	0.2
4	Unit Weight (kN/m^3)	25	25	28
5	Saturated unit Weight (kN/m^3)	25	26	30
6	Material Constant for intact rock(m)	10	9	17
7	s (impirical constant)	0.1	0.135	0.26
8	Uniaxial Compressive Strength(UCS)(kN/m^2)	1.70E+05	2.10E+05	3.30E+05
9	Geological Strength Index(GSI)	80	82	88

4 Results, interpretation and discussion

The results are obtained at key points of tunnel viz. crown, side wall and invert of tunnel. These are shown in Fig. 4.

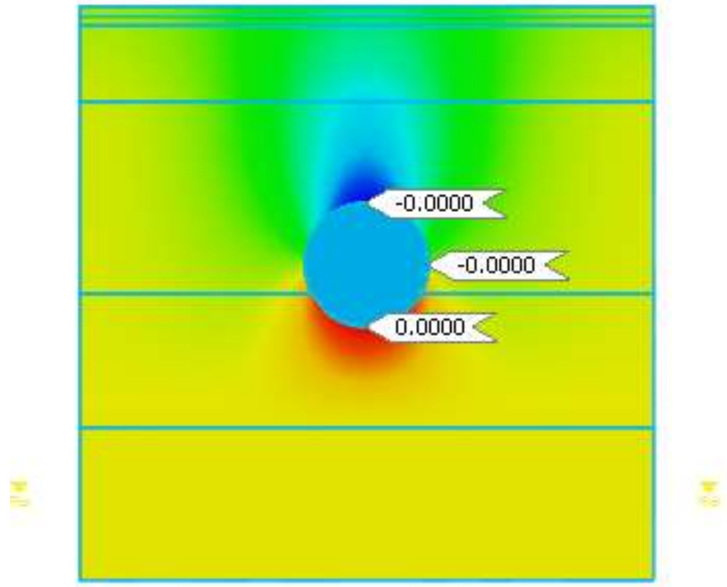

Fig. 4. Deformation at key points of tunnel

Figure 4 showed contour patterns obtained after the completion of analysis. These are the smooth contour patterns.

4.1 Deformation at crown

Vertical displacement is considered at crown of tunnel. Table 6. has shown the displacement of given tunnel at crown for M30, M40 and M50 grade of concrete for thicknesses of 0.3m, 0.4m and 0.5m.

Table 6. Crown displacement of tunnel.

Crown displacement in meter			
Lining thickness	Grade of concrete		
	M30	M40	M50
0.3m	-3.89E-05	-3.88E-05	-3.87E-05
0.4m	-3.93E-05	-3.92E-05	-3.91E-05
0.5m	-3.98E-05	-3.96E-05	-3.95E-05

Fig. 5 is a graphical representation of above table. X-axis has grade of concrete and Y-axis has displacement in meter for lining thicknesses 0.3m, 0.4m, 0.5m.

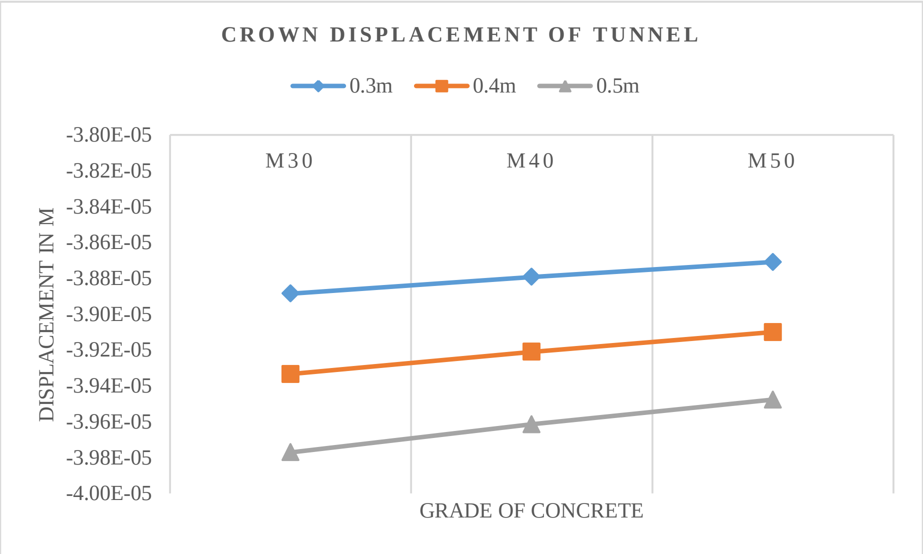

Fig. 5. Displacement of tunnel at crown

It is seen that as the grade of concrete increases, deformation of tunnel decreases at crown point. As the thickness of lining of tunnel increases deformation of tunnel at crown increases.

4.2 Deformation at side wall of tunnel

Horizontal displacement is mainly considered at side wall of tunnel. Table 7. has shown the displacement of given tunnel at side wall for M30, M40 and M50 grade of concrete for thicknesses of 0.3m, 0.4m and 0.5m.

Table 7. Side wall displacement of tunnel.

	Side wall displacement in meter		
Lining thickness	Grade of concrete		
	M30	M40	M50
0.3m	1.13E-06	1.17E-06	1.20E-06
0.4m	1.27E-06	1.32E-06	1.37E-06
0.5m	-3.88E-05	-3.92E-05	-3.96E-05

Fig. 6 is a graphical representation of above table. X-axis has grade of concrete and Y-axis has displacement in meter for lining thicknesses 0.3m, 0.4m, 0.5m.

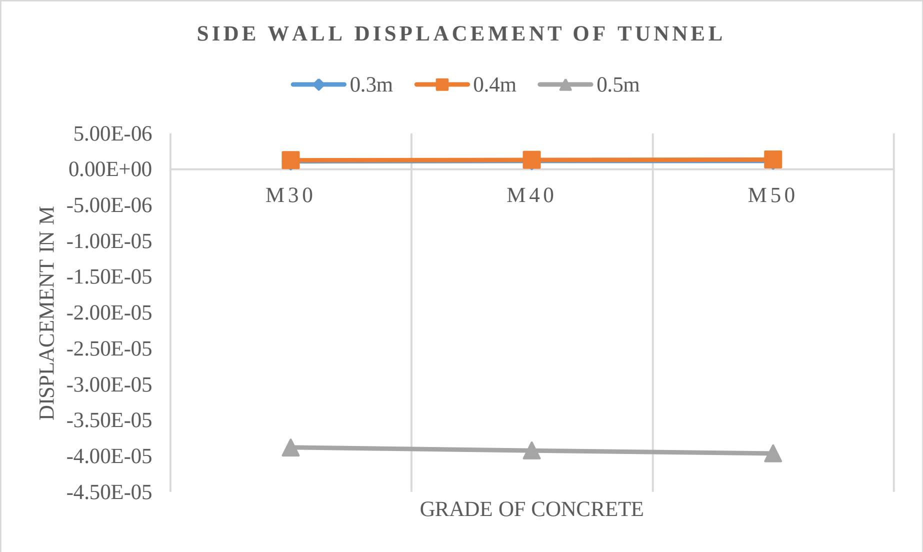

Fig. 6. Displacement of tunnel at side wall

It is seen in Fig. 6 as the grade of concrete increases, deformation of tunnel increases at side wall. The values in Table 7. of the deformation in side wall of tunnel are small so that the graph shows slightly linear trend. As the thickness of lining of tunnel increases displacement of tunnel at crown increases.

4.3 Deformation at invert of tunnel

Vertical displacement is considered at invert of tunnel. Table 8. has shown the displacement of given tunnel at invert for M30, M40 and M50 grade of concrete for thicknesses of 0.3m, 0.4m and 0.5m.

Table 8. Invert displacement of tunnel.

Invert displacement in meter			
Lining thickness	Grade of concrete		
	M30	M40	M50
0.3m	1.42E-05	1.42E-05	1.42E-05
0.4m	1.41E-05	1.41E-05	1.40E-05
0.5m	1.39E-05	1.39E-05	1.39E-05

Fig. 7 is a graphical representation of above table. X-axis has grade of concrete and Y-axis has displacement in meter for lining thicknesses 0.3m, 0.4m, 0.5m.

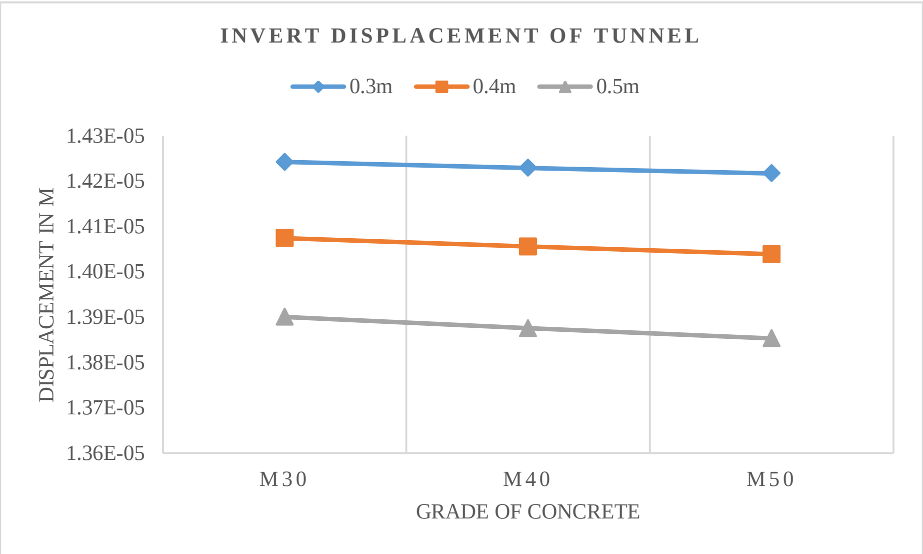

Fig. 7. Displacement of tunnel at crown

It is seen that as the grade of concrete and thickness of lining increases, deformation of tunnel increases at invert slightly decreases.

This behavior of tunnel is obtained as this tunnel is constructed in limestone and basalt rocks. As its invert lied in basalt, change in deformation observed is less compared to deformation in limestone.

The important aspects about rock support interaction analysis such as basic assumptions, analysis of stresses and deformations, equations for the required support line, allowance for the dead weight of broken rock, analysis of available supports etc. are discussed in detail by Hoek and Brown [6].

The response of deformation of tunnel opening in disintegrated geotechnical material including soils is seen [7].

5 Conclusion

Deformation analysis with different lining thickness and concrete grade for circular tunnel have been tried. However, it can be implemented and observed for any regular or irregular shape of tunnel. The geotechnical software of Midas seems to be useful for this purpose as it gives accurate results. The results can be obtained and the same concept can be used for any type of stratum for concrete lining. This soil structure interaction for tunnel with respect to type of stratum and grade of concrete is useful for structural consultants, construction engineers, designers for preliminary design of tunnel and concrete lining.

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