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Tunneling in Various Shapes Using Numerical Analysis

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Abstract:** Tunnelling has gained popularity in the recent times due to lack of space and the rapidly increasing population. Thus, going underground is the only option to provide the infrastructure facilities which will meet the need of increasing population. The shape and dimensions of the tunnel cross section usually depends on certain parameters like purpose for which the tunnel is provided, drainage & maintenance requirements, requirement of escape route, etc. Geology plays an important role in deciding the shape of the tunnel. The ground behaves in a complex manner, when a tunnel is excavated in it as new stresses are developed. Based on the ground types, the shape is selected in such a waythat the stresses developed in the ground should distribute properly around the tunnel periphery and should not cause convergence of the tunnel boundary. Also, requirement of support systemshould not be too heavy, as it will increase the cost. Apart from the above parameters, the availability of the equipment & the construction method also decides the shape of the tunnel. There are various shapes of tunnels like D-shape, Circular, Elliptical, Egg-shape, Box type, Horseshoe & Modified Horseshoe shape. In the present course of work three shapes of tunnels viz. Horseshoe Shape, Modified Horseshoe Shape & D-Shape tunnels are considered. By hypothetical assumption the geology and overburden are taken into account for the tunnels and the tunnels are simulated for roof collapse and shear failure case by using RS^2 FEM based software.

***Keywords:** Horse Shoe, Modified Horseshoe, D-shape Tunnel, Failure Simulation, Roof collapse, Shear failure, RS^2.*

I. INTRODUCTION

The purpose of tunnel for which it is to be constructed primarily govern the choice for shape of tunnel. There are other factors like the availability of equipment, construction method, site conditions, etc which also play an important role in fixing the shape of the tunnel. The selected shape of the tunnel based on the above parameters should be such that it should be stable enough during tunnelling in the surrounding geology i.e., the stresses should be properly distributed, and the support requirement should be minimal which ultimately helps to complete the project economically. In the present course of work the failures like roof collapse and shear failure are simulated and the three tunnel shapes viz. D-shape, Horseshoe & Modified Horseshoe tunnels are compared from stability point of view.

II. ROOF COLLAPSE FAILURE

For roof collapse failure simulation, it is assumed that the tunnel is passing through Gneiss rock which has very weak properties and the tunnel has 400m overburden. For failure simulation full face excavation models are modelled in RS2. Modelling is done for D-shape, Horseshoe & Modified Horse shoe shape tunnel by considering roof failure case.

A. Rock Mass Properties

Gneiss	
Initial Conditions	
Initial Element Loading	Field Stress Only
Unit Weight	0.027 MN/m3
Stiffness Properties	
Elastic Type	Isotropic
Loading	
Poisson's Ratio	0.3
Young's Modulus	1000 MPa
Use Residual Young's Modulus	No
Strength Properties	
Failure Criterion	Mohr-Coulomb
Material Type	Plastic
Peak Strength	
Peak Tensile Strength	5 MPa
Peak Friction Angle	35 degrees
Peak Cohesion	1 MPa
Residual Strength	
Residual Tensile Strength	5 MPa
Residual Friction Angle	35 degrees
Residual Cohesion	1 MPa
Dilation Angle	0 degrees
Hydraulic Properties	
Material Behaviour	Drained
Porosity Value	0.5
Static Water Mode	Dry

Figure 2.1: Rock Mass properties (Gneiss rock)

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B. Field Stress

Overburden	400m
Sigma 1	10.8 MPa
K_0	0.4
Sigma 3 & Sigma Z	4.32 MPa
Angle to sigma 1	90˚

Table 2. 1: Field Stress (Roof collapse)

The above Rock mass properties and the Field stress parameters are considered same for all three shapes of tunnels and analysis is done.

1) Modified Horseshoe Shape Tunnel

a) Tunnel Geometry

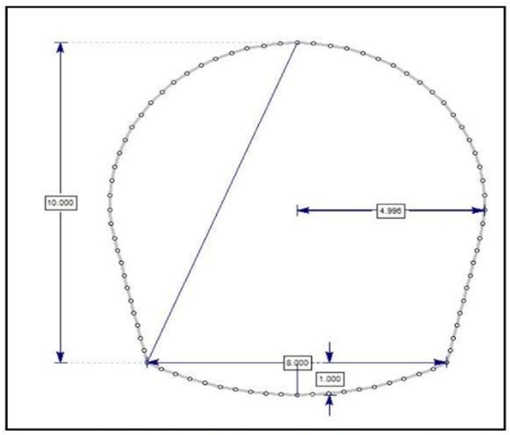

Figure 2.2: Modified Horseshoe Shape Tunnel c/s

Shape	Modified Horseshoe
Radius	5m
Overall height to corners	10m
Invert width	8m
Invert Dish	1m

Table 2. 2: Modified Horseshoe Shape Tunnel c/s Details

b) Modelling Stages

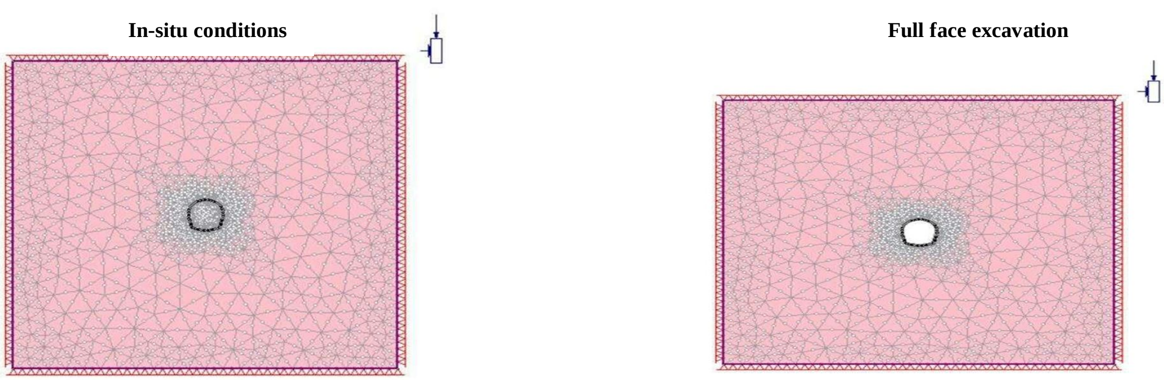

Figure 2.3: Modelling Stages (Roof collapse) – Modified Horseshoe

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c) Interpretation Stages

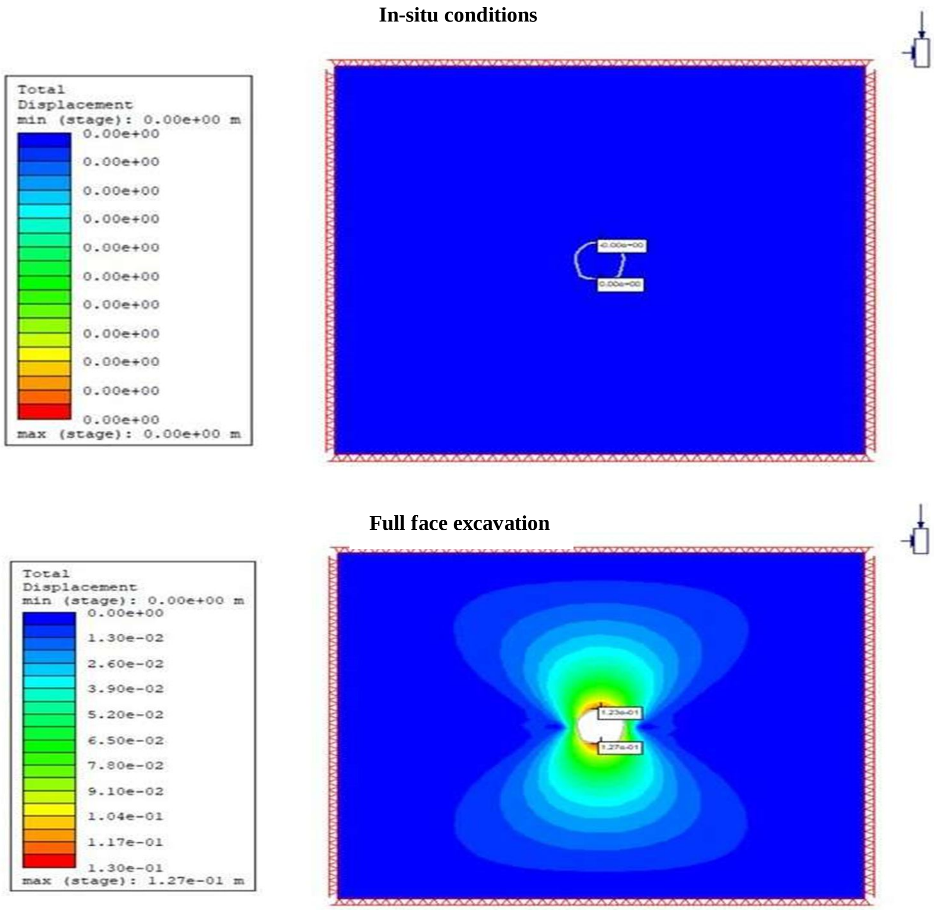

Figure 2.4: Interpretation Stages (Roof collapse) – Modified Horseshoe

After interpretation, as seen above the total displacement in the in-situ stage is zero as the stress field is undisturbed as there is no excavation carried out. In the full-face excavation stage, the maximum total displacement observed at the roof and invert is 123mm and 127mm respectively. The huge displacement at the crown of the tunnel results in to failure/collapse of roof.

2) Horseshoe Shape

a) Tunnel Geometry

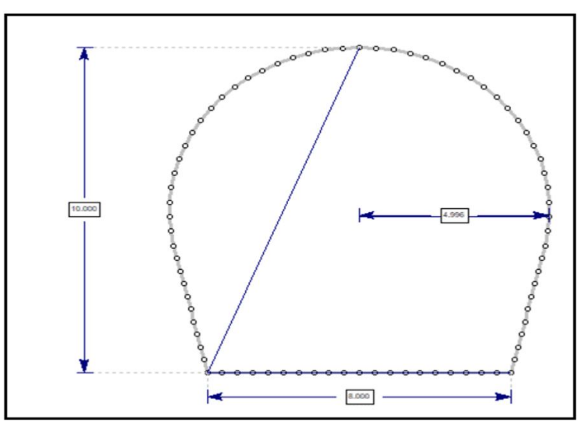

Figure 2.5: Horseshoe Shape Tunnel c/s

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b) Modelling Stages

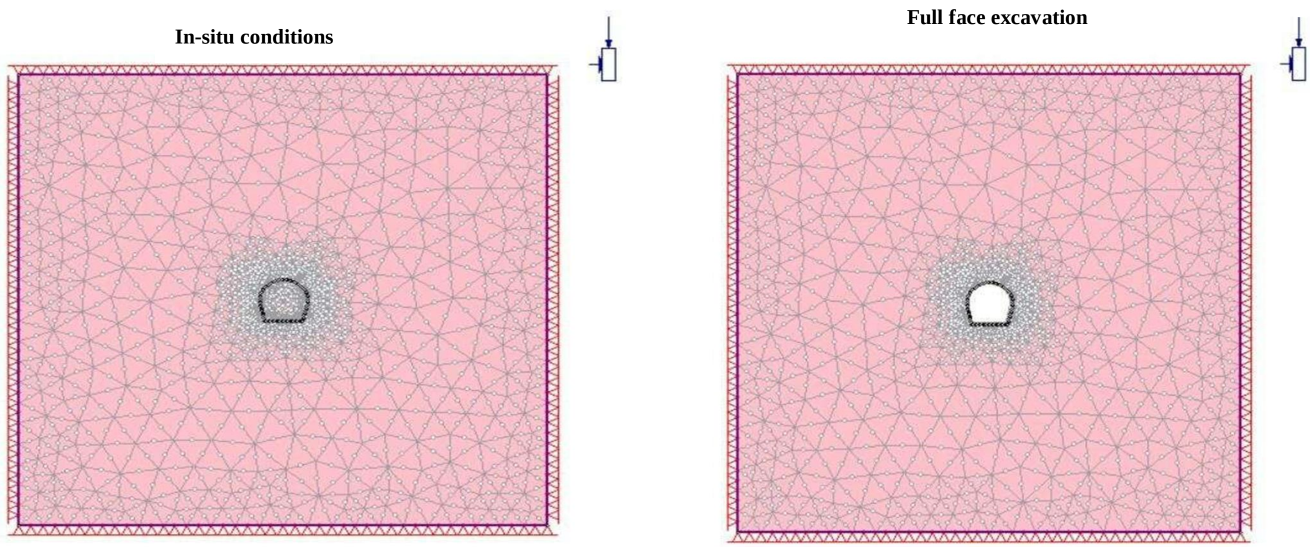

Figure 2.6: Modelling Stages (Roof collapse) – Horseshoe

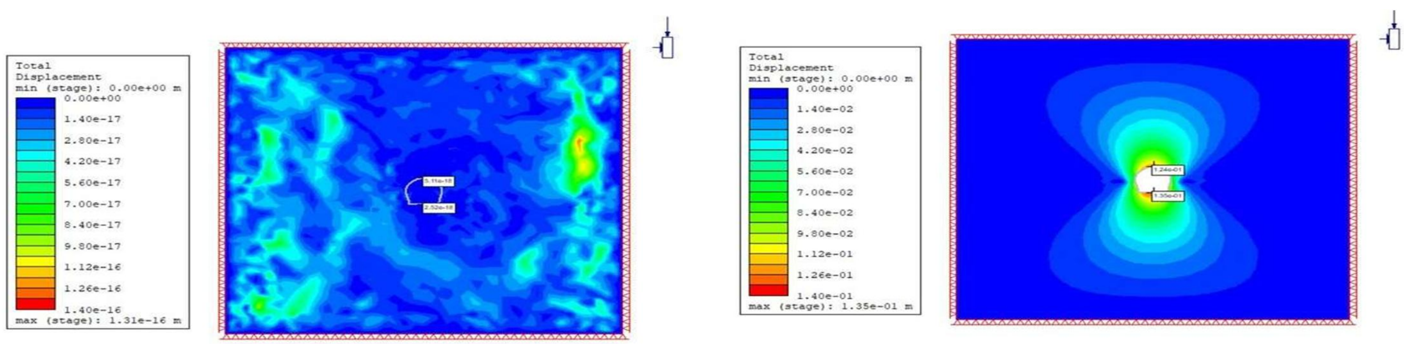

Figure 2.7: Interpretation Stages (Roof collapse) – Horseshoe

After interpretation, as seen above the total displacement in the in-situ stage is minimal as the stress field is undisturbed as there is no excavation carried out. In the full-face excavation stage, the maximum total displacement observed at the roof and invert is 124mm and 135mm respectively.

3) D-Shape

a) Tunnel Geometry

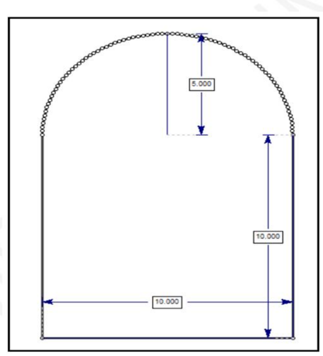

Figure 2.8: D-Shape Tunnel c/s

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b) Modelling Stages

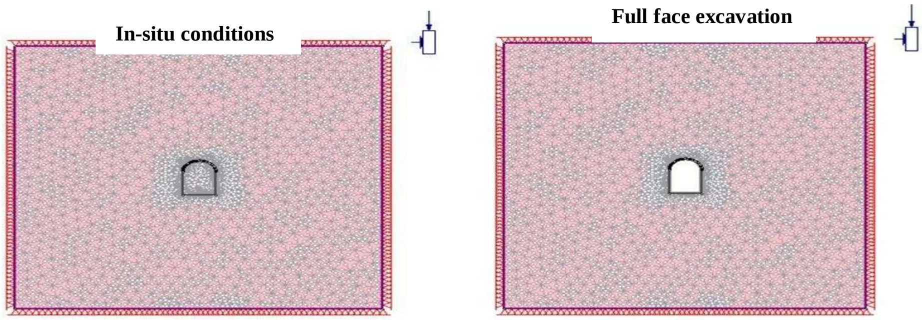

Figure 2.9: Modelling Stages (Roof collapse) – D Shape

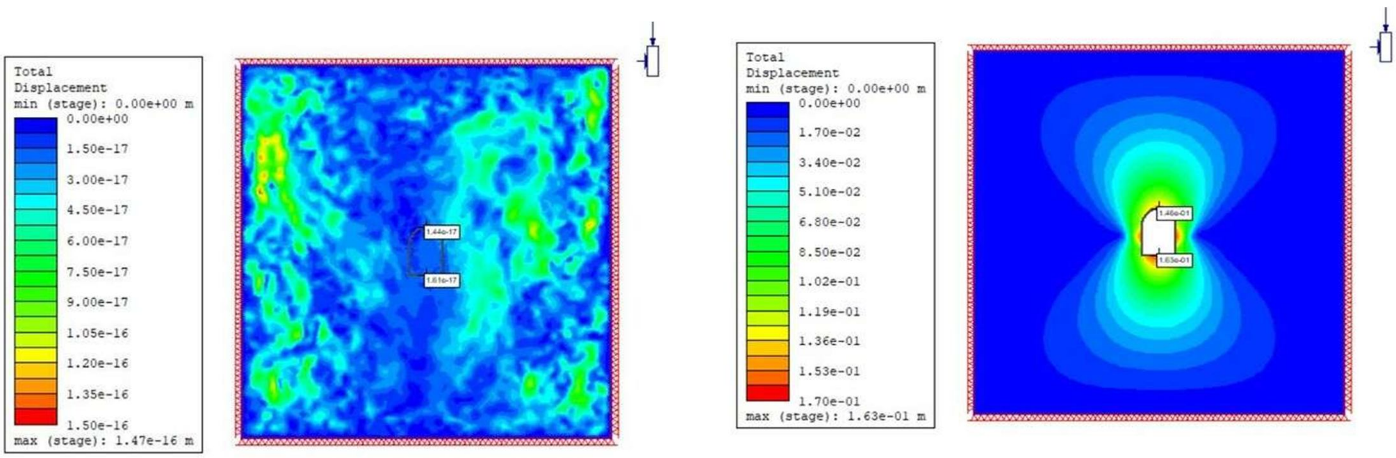

Figure 2.10: Interpretation Stages (Roof collapse) – D Shape

After interpretation, as seen above the total displacement in the in-situ stage is minimal as the stress field is undisturbed as there is no excavation carried out. In the full- face excavation stage, the maximum total displacement observed at the roof and invert is 146mm and 163mm respectively.

III. SHEAR FAILURE

For failure simulation full face excavation models are modelled in RS2. Modelling is done for D-shape, Horseshoe & Modified Horseshoe shape tunnel by considering shear failure case. Brief comparison is done between three shapes of tunnels from the stability point of view.

A. Modified Horseshoe shape

1) *Tunnel Geometry:* The tunnel geometry is same for all the three shapes as taken in roof collapse case.

2) *Rock Mass Properties*

Phyllite	
Initial Conditions	
Initial Element Loading	Field Stress Only
Unit Weight	0.027 MN/m3
Stiffness Properties	
Elastic Type	Isotropic
Loading	
Poisson's Ratio	0.3
Young's Modulus	20000 MPa
Use Residual Young's Modulus	No
Strength Properties	
Failure Criterion	Mohr-Coulomb
Material Type	Plastic
Peak Strength	
Peak Tensile Strength	5 MPa
Peak Friction Angle	35 degrees
Peak Cohesion	1 MPa
Residual Strength	
Residual Tensile Strength	5 MPa
Residual Friction Angle	35 degrees
Residual Cohesion	1 MPa
Dilation Angle	0 degrees
Hydraulic Properties	
Material Behaviour	Drained
Porosity Value	0.5
Static Water Mode	Dry

Figure 3. 1: Rock Mass Properties (Phyllite rock)

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3) Joint Network

Network Type	Parallel Deterministic
Inclination	36˚
Spacing	1.2m
Joint ends	All closed
Slip Criterion	None
Normal Stiffness	100000 MPa/m
Shear Stiffness	10000 MPa/m

Table 3. 1 Joint Network Properties

4) Field Stress

Overburden	1500m
Sigma 1	40.5 MPa
K_0	1.0
Sigma 3 & Sigma Z	40.5 MPa
Angle to sigma 1	0˚

Table 3. 2: Field Stress (Shear failure)

In shear failure simulation, it is assumed that the tunnel is passing through phyllite rock which is heavily jointed. The tunnel is passing through a high overburden of about 1.5km. The above joint network properties, rock mass properties and the field stress conditions are taken same for all three shapes i.e., Horseshoe, Modified Horseshoe and D-shape tunnel.

5) Modelling Stages

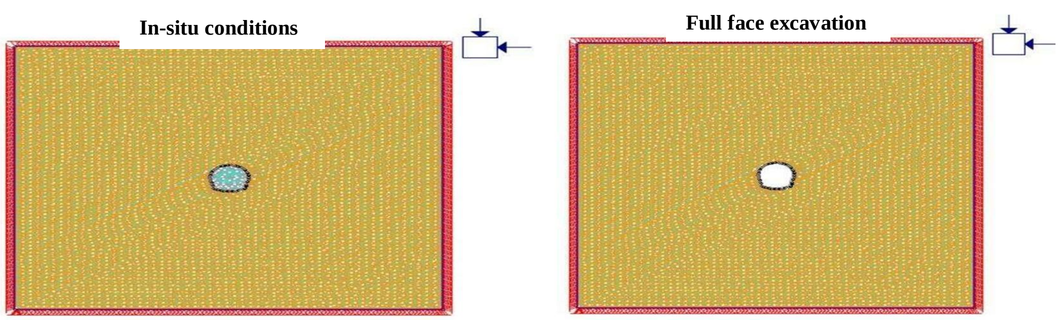

Figure 3. 2: Modelling Stages (Shear failure) – Modified Horseshoe Shape

6) Interpretation Stages

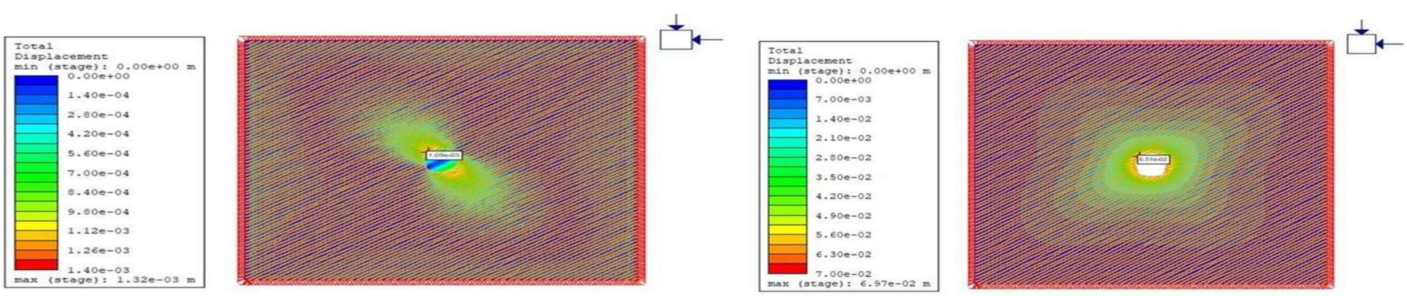

Figure 3. 3: Interpretation Stages (Shear failure) – Modified Horseshoe Shape

After interpretation, as seen above the total displacement in the in-situ stage is negligible as the stress field is undisturbed as there is no excavation carried out. In thefull-face excavation stage, the maximum total displacement observed is 65.1mm. The displacement at the top corners of the tunnel results into shear failure case.

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B. Horseshoe Shape

1) Modelling Stages

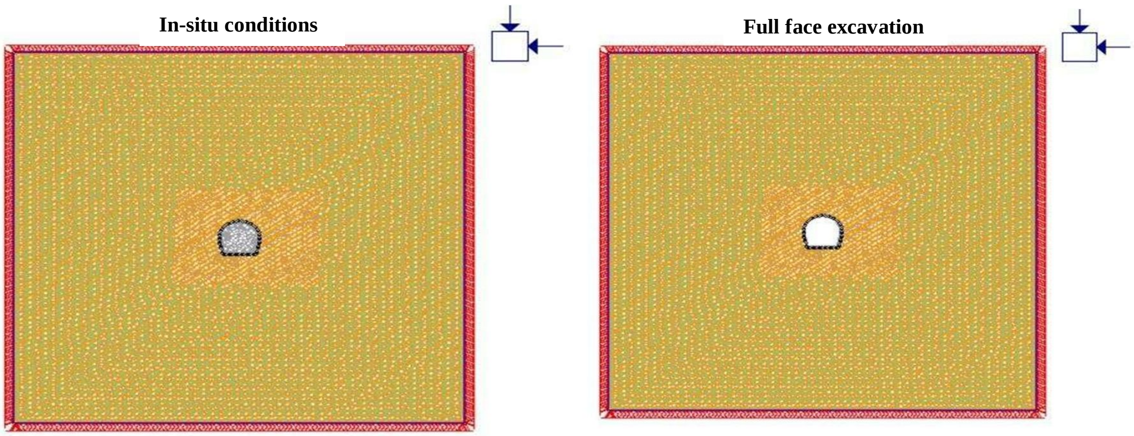

Figure 3. 4: Modelling Stages (Shear failure) – Horseshoe Shape

2) Interpretation Stages

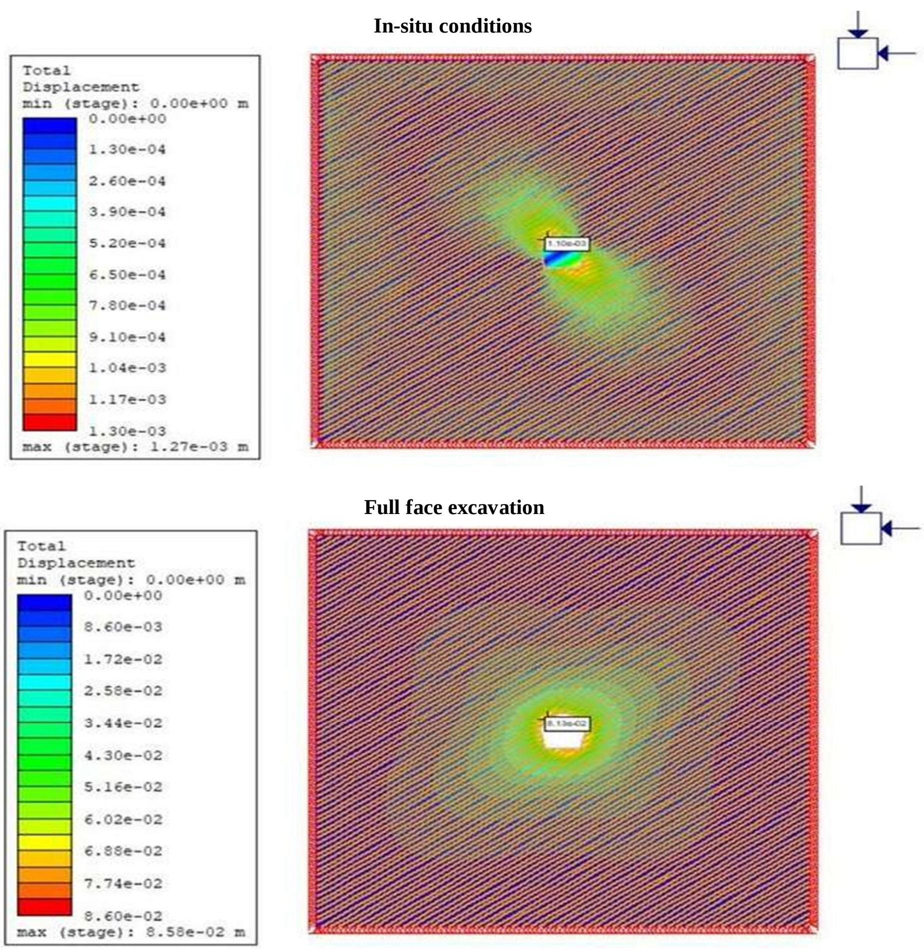

Figure 3. 5: Interpretation Stages (Shear failure) – Horseshoe Shape

After interpretation, as seen above the total displacement in the in-situ stage is negligible as the stress field is undisturbed as there is no excavation carried out. In the full-face excavation stage, the maximum total displacement observed is 81.3mm.

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C. D-shape

1) Modelling Stages

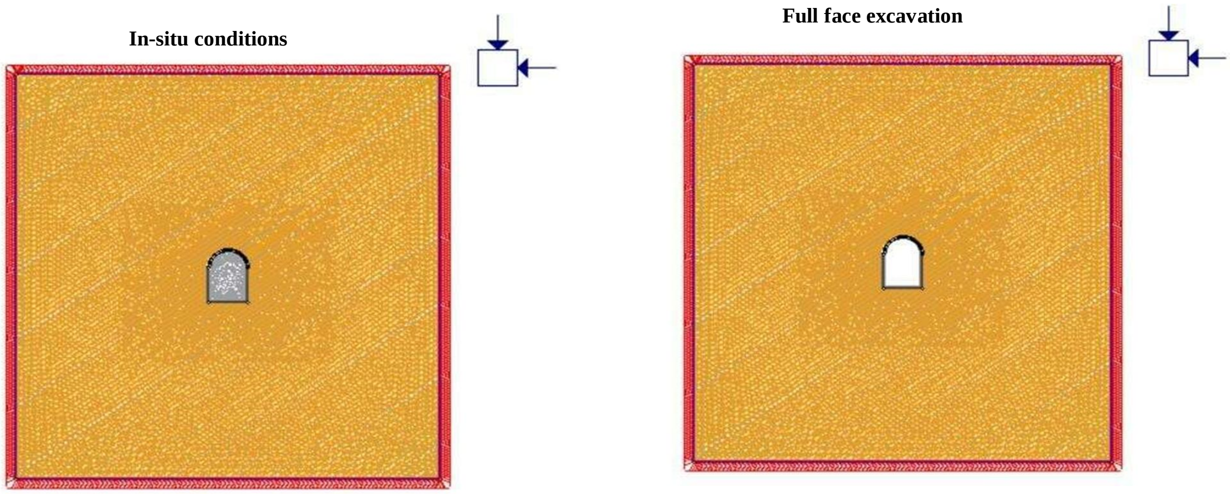

Figure 3. 6: Modelling Stages (Shear failure) – D shape

2) Interpretation Stages

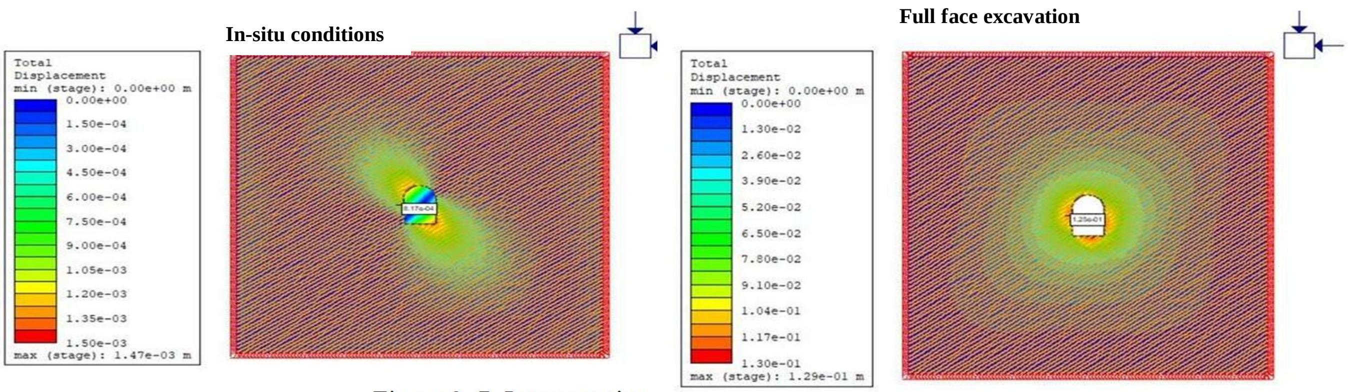

Figure 3. 7: Interpretation Stages (Shear failure) – D shape

After interpretation, as seen above the total displacement in the in-situ stage is negligible as the stress field is undisturbed as there is no excavation carried out. In the full-face excavation stage, the maximum total displacement observed is 125mm.

IV. RESULTS

A. Roof Collapse

Shape of Tunnel	Total Displacement (mm)	
	Roof	Invert
Horseshoe	124	135
Modified Horseshoe	123	127
D shape	146	163

Table 4. 1: Total Displacements (Roof collapse) – Horseshoe, Modified Horseshoe & D shape Tunnel

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From the above table, it is observed that the total displacement in the roof in Horseshoe & Modified Horseshoe tunnel is similar. The total displacement in the invert of Horseshoe tunnel (flat invert) is more than Modified Horseshoe tunnel (curved invert). As the induced stresses are distributed effectively in the curved invert the displacement is less than the flat invert. There is significant increase in the displacement in the roof and the invert of D-shape tunnel as compared to the other two shapes. Apart, from the huge displacements in the roof and invert, D-shape tunnel also shows displacements in the side walls.

Figure 4. 1: Total Displacement in Crown & Invert – Roof Collapse

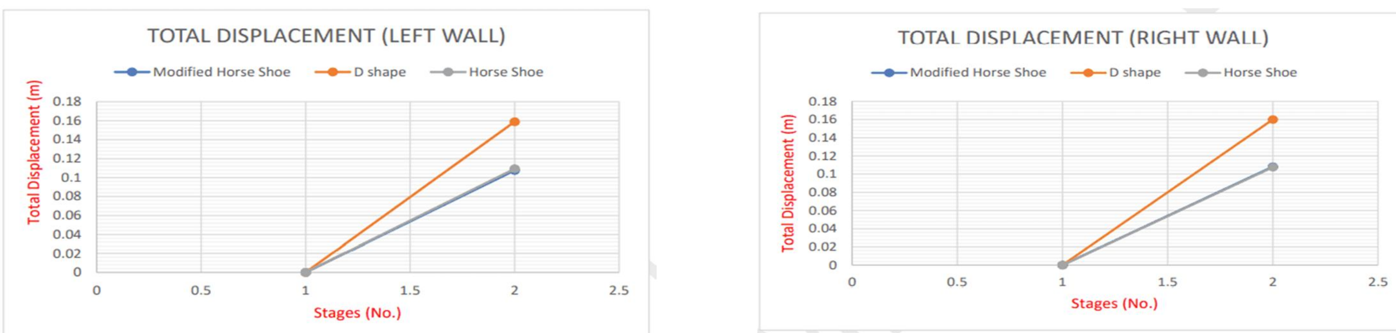

Figure 4. 2: Total Displacement in sidewalls – Roof Collapse

The two stages in the above plots represents in-situ conditions (stage1) & full-face excavation (stage2). From the above graphs, it is clear that D-shape tunnel shows more displacement in roof, invert & sidewalls than the other two shapes i.e., Horseshoe & Modified Horseshoe. Hence, it is not feasible to provide D- shape tunnel in such scenario. In case of Modified Horse shoe, the crown and sidewalls graphs are overlapped with that of Horseshoe shape. Thus, in some plots only two lines are visible. But, in the invert as the stresses vary in both the shapes viz. Modified & Horseshoe there are three lines visible each representing displacement of the respective tunnel.

B. Shear Failure

Shape of Tunnel	Total Displacement (mm)	
	Roof	Invert
Horseshoe	81.3	85.1
Modified Horseshoe	65.1	66.2
D shape	104	129

Table 4. 2: Total Displacements (Shear Failure) – Horseshoe, Modified Horseshoe & D shape Tunnel

From the above interpretation results, it is observed that the displacement in the Modified Horseshoe is quite less than that of the Horse Shoe shape tunnel. It is merely because of the curved invert in the Modified Horse shoe shape tunnel. The induced stresses are distributed effectively in the curved invert than the flat invert. Moreover, in the D-shape tunnel the displacement is almost twice than the displacement observed in the Modified Horseshoe tunnel. Hence, observing the obtained results it is clear that D-shape tunnel is not favourable in such scenario and Modified Horseshoe shape tunnel is suitable if compared to other two shapes.

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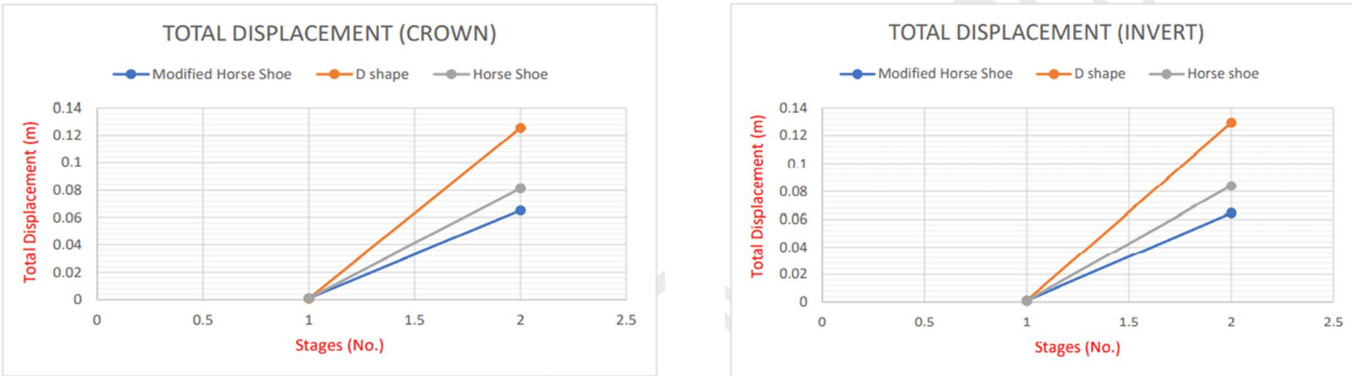

Table 4. 3: Total Displacement in Crown & Invert – Shear Failure

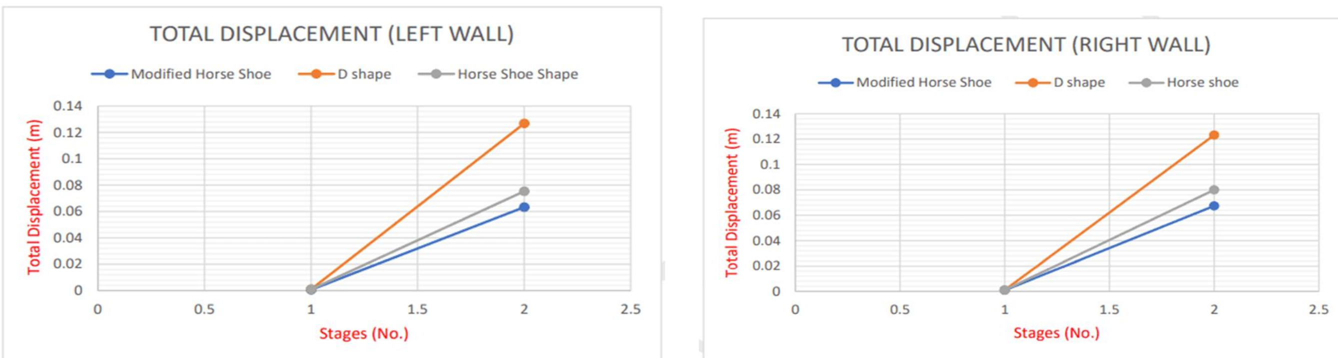

Table 4. 4: Total Displacement in sidewalls – Shear Failure

From the above graphs it is observed that D-shape tunnel shows maximum displacement in the roof, invert, and the side walls. Hence, D-shape tunnel is not suitable in this scenario. Modified Horseshoe shape tunnel shows les displacement among all the three, hence it is most suitable in such case.

V. CONCLUSIONS

A. From the above comparison, it is evident that Modified Horseshoe shape tunnel proves to be stable in ground conditions where failures like roof collapse and shear failure are expected.

B. The observed total displacement in the Modified Horseshoe tunnel is less compared to the other two shapes because of the curved invert. The stresses are effectively distributed in the Modified Horseshoe tunnel thus improving the stability in such conditions.

C. The total displacement observed in the Modified Horseshoe tunnel is less compared to Horseshoe and D-shape tunnel. But these total displacements in Modified Horseshoe tunnel are still on higher side. Hence, apart from the support system additional measures like Fore poling, Ground improvement techniques, probing, etc should be implemented according to the actual site conditions.

D. In such conditions where failures like roof collapse and shear failures are expected flexible methodology like NATM should be used for tunnelling which can be modified based on the actual conditions encountered on site.

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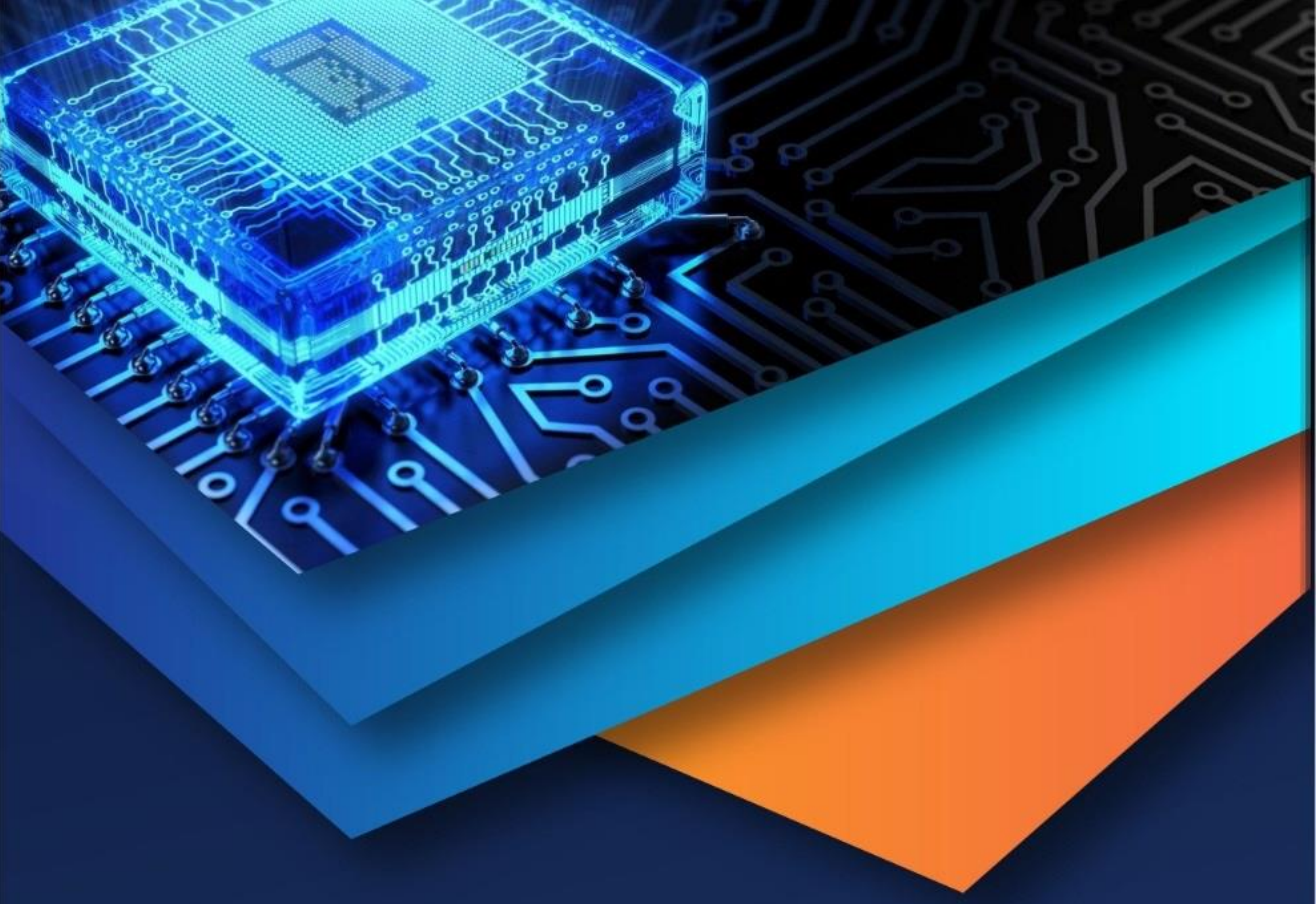

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