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Comparison of Deformation in Tunnel along Thrust Zone using Different Approaches: Case Study of BBDMP

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Abstract

When tunnel excavation is done, the deformation of tunnel occurs along with stress redistribution as rock mass relaxes showing movement from it position. In the event that a catastrophe such as a cave-in, rock burst, or water invasion occurs near the tunneling site in a fully mechanised, full-face excavation, the tunnel boring machine (TBM) might get twisted upon departing, becoming stuck, and in fact damaged.The misshapen mass is distorted after excavation emptying of the thrust zone, making it vital to research the misshapen shake mass within the break zone under conditions including excavation upsetting influence. There are different approaches for deformation calculation,among which analytical method and numerical model (2D model and 3D model) using Rocscience software is adopted for comparison of deformation along thrust zone (Bheri Thrust and Babai Thrust)of Bheri Babai Diversion Multipurpose Project's headrace tunnel.The result of the research demonstrate that the total displacment for higher overburden is not affected by intermediate stress whereas it has greater impact for lower overburden.

Keywords

Thrust zone, analytical method, 2D model, 3D Model.

1. Introduction

Nepal lies in north central part of South Asia sandwiched between two giants: India in three sides and China in North. Nepal is a mountainous country, which has very young and fragile geological formation which results challenges in tunneling. The tunneling might be more complicated when the region is within the thrust zone as the rock mass is highly disintegrated and if it has high groundwater conditions that will be case of concern. Poor rock mass, faults and folds, weathering and disintegration, high overburden etc. are major challenge to overcome while performing underground excavation. Bheri Babai Diversion Multipurpose Project (BBDMP), is one of such project which passes through two thrust zone lying in Lesser Himalaya.

The Babai Thrust extends up to 100m near to entry portal and Bheri Thrust extends up to 400m in central part .The deformation of ground while excavation using Tunnel Boring Machine (TBM) is essential to avoid tunnel jamming risk due to huge deformation of rock mass.Due to the presence of thrust zones in Tuzla tunnel, TBM work should have been economical and simpler to support if the rock was of poor or fair quality. However, the deformation was so high that the fault zone prevented TBM from following the tunnel alignment and deviation occurred [1].Driving a tunnel through a faulted rock mass is likely to be problematic because of the difficulty of deforming, swelling, and breaking the face excessively, as well as the instability of the face[2]. The models show that during the early phase of deformation, faults in the hinterland exhibit high activity, which is facilitated by increased out-of-sequence thrusting. In contrast, the models predict that forward-propagating thrusts will dominate the latter stages of deformation when erosion is less efficient[3].

The mining tunnel along thrust zone must be assessed to determine if thrust has an important impact on mining tunnels. The vertical displacement at the crown decreases as lateral stress increases, but the horizontal displacement increases in the both right and left sidewalls. The degree of excavation defines and limits curvature, the quality of mining tunnel surrounding the rock mass, and the initial stress all affect the critical distance [4]. Chen Hao has done studied the deformation study in the 56 tunnels passing through fault zone and concluded that longitudinal settlement escalate with the rise of overburden depth, and the railway fault tunnels show a clear concentration of displacement with respect to change in height-span ratio [5]. The time effect on rock deformation surrounding fault tunnels can be separated into three phases: rapid growth, slow growth, and stabilization. Within 15 days, 80% of the surrounding rock deformation rapid growth phase was over, and 64.2% of the vertical settlement and 65.6% of the horizontal convergence were accomplished. 70% of the surrounding rock deformation tends to be stable within 30 days.

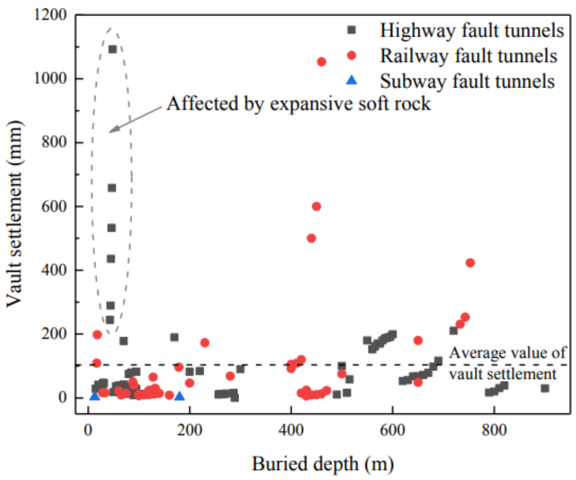

Figure 1: Relationships between vault settlement of surrounding rock and buried depth in fault tunnels [5]

The key geo-mechanical and hydrological features of brittle faults are critical to tunnel feasibility, and can make or break a project.The nature of the fault and the associated geo-mechanical properties are closely linked to the rock's viscoelastic behaviour, age of faulting and depth of formation. [6].The location and mechanical properties of the fault determine the failure pattern of the surrounding rock and support. Structural components, such as tunnels, are affected by ground stresses within the vicinity of faults and introductory ground stresses. Variety exists within the ground stresses and affects their behaviour.

2. Project Description

The project area is located between the Bheri and Babai rivers in Surkhet and Bardiya districts, about

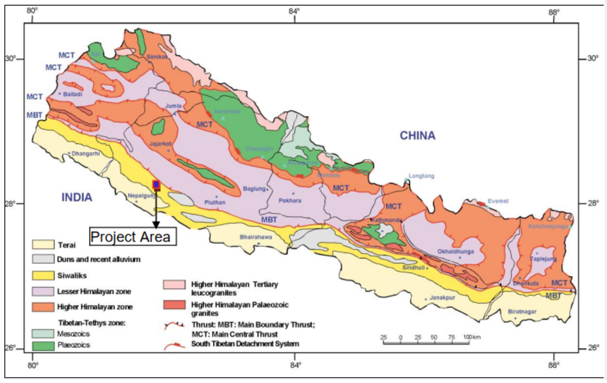

Figure 2: Project Location Map modified from [7]

560 km southwest of Kathmandu, capital city of Nepal. The Ratna Rajmarg (Highway) is nearest road head for the project. Geologically, the project area lies in Siwalik zone of western Nepal. It is sandwiched between Main Boundary Thrust (MBT) in the north and Main Frontal Thrust (MFT) in south. MBT lies about 3km north of TBM exit and MFT lies about 10km south of TBM entry portal. Seismically, the entire project falls within Seismic Zone Four of Seismic Zoning Map of India, which corresponds to Zone factor of 0.24 (effective ground acceleration in terms of 'g'). According to Indian seismic hazard classification system, there is possibility of an earthquake of magnitude between 6 and 7 in every 100 years.

The project are has mainly rocks of Siwalik Group and soils above it. It comprises mainly sedimentary rocks of fluvial origin belonging to Neogene age. The Siwalik group rocks can be categorized into Lower Siwalik, Middle Siwalik and Upper Siwalik. The region mostly contains pebble, cobbles and boulder conglomerates with intercalation of sandstone and mudstone. BBDMP project passes through two thrust zone in which the rockmass is highly crushed and gauge filling is prominent.

3. Objective

The objective of this research work is to compare how the tunnel deformation vary with overburden and rockmass properties along thrust zone using different approaches. Two locations, Bheri thrust and Babai thrust zone are selected as region of study. Analytical solution with Convergence Confinement Method and numerical model 2D and 3D are created using Rocscience Inc. software which uses finite element method for analysis. The deformation along the

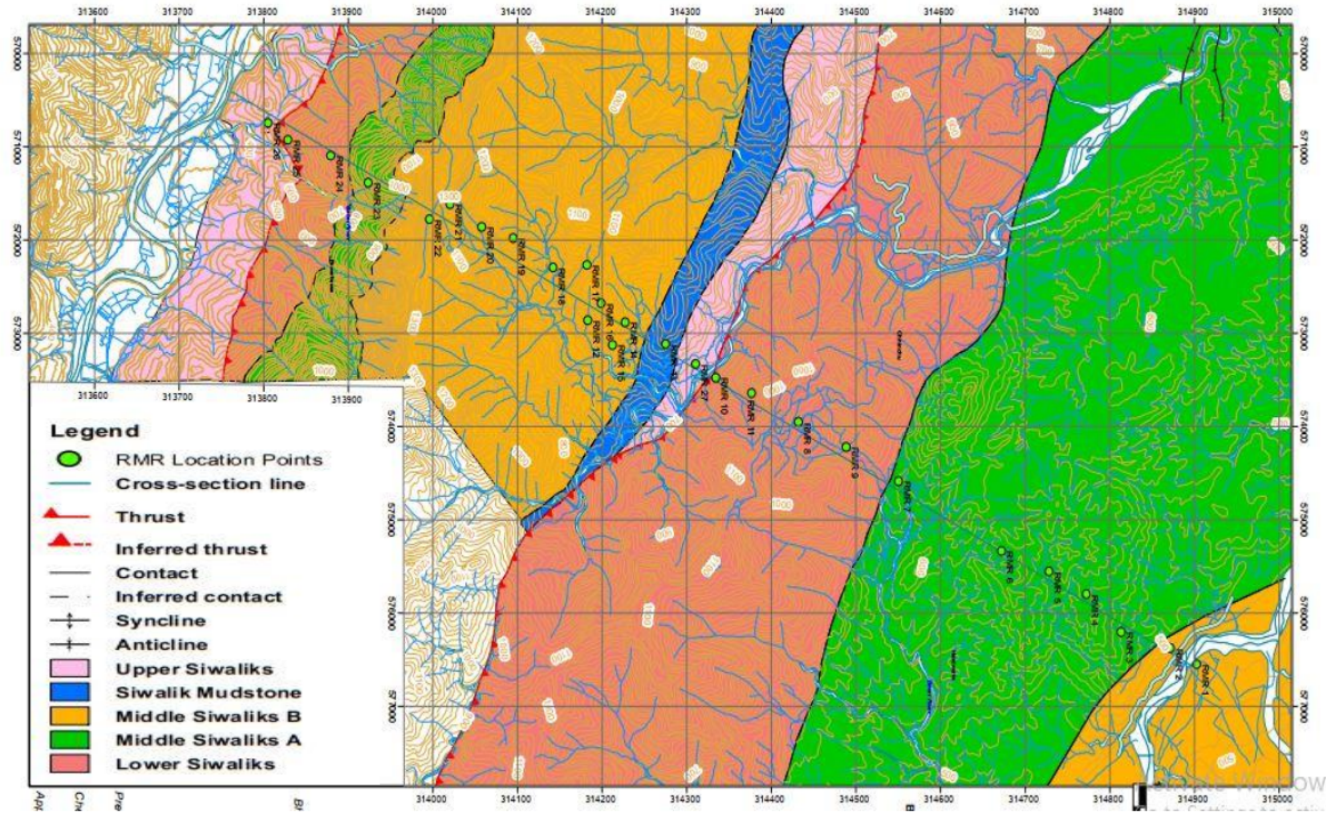

Figure 3: Geological Map Along tunnel Alignment modified from [8]

length of tunnel from face is computed and compared.

4. Methodology

The methodology steps followed during the study is given in Figure 4. The research work was initiated

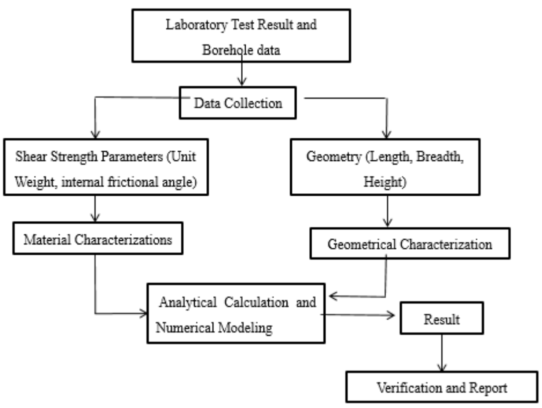

Figure 4: Methodology

with collection of data from field with the lab test report and along with borehole data. The continuous work of desk study followed by literature review, field visit, consultation with expertise and numerical modeling, interpretation, and compilation was done for report preparation. The necessary data for the analysis like type of rock mass,depth of overburden, and Q-values have been recorded field work and reports. Modulus of elasticity, poisson's ratio, and UCS have been taken from laboratory testing of rock core sample. Deformation modulus, rock mass strength, cohesion, frictional angle etc has been estimated through literature reviews and are given in Table 4.

4.1 Material Characterization

The rock mass property for a section is considered homogeneous, isotropic and free of discontinuities as the section is highly fractured and for easy modeling process and calculation. The value were obtained from test result in lab as shown in Table 1.

These value of rock core properties has been selected for the further analysis. The generalized Hoek–Brown criterion for the estimation of rock mass strength, introduced by Hoek Brown [9].

$$\sigma_1 = \sigma_3 + \sigma_{ci}(mb\frac{\sigma_3}{\sigma_c i} + s)^a \tag{1}$$

where mb, s and a are rock material constants defined

Table 1: Properties of Rock mass [8]

Location	σ_{ci} in MPa	E_{ci} in MPa	ν	ψ	c in KPa	γ in KN/m3	Overburden(m)
Babai Thrust Zone	16.00	1200	0.300	0	186	25	100
Bheri Thrust Zone	13.00	550	0.325	0	268	24	350

by

$$mb = mi \exp\left[\frac{GSI - 100}{28 - 14D}\right] \quad (2)$$

$$s = \exp\left[\frac{GSi - 100}{9 - 3D}\right] \quad (3)$$

$$a = \frac{1}{2} + \frac{1}{6}(e^{\frac{-GSI}{15}} - e^{\frac{-20}{3}}) \quad (4)$$

The thrust zone at Babai consist of sheared and jointed rock mass containing conglomerate, sandstone and mudstone. Bheri thrust zone comprises of fault gouge and fault breccias in conglomerates, mudstones and sandstones.This is the most critical zone of tunnel alignment as water from Bharleni Khola may penetrate in to tunneland create adverse conditions.

4.2 Geometrical Characterization

The geometry of tunnel along the whole section is same for part in which the TBM was used. In the entry portal, there is use of drill and blast technique which is not the area of study. The geometrical characteristics of tunnel is tabulated below:

Table 2: Geometrical characteristics of tunnel

Tunnel parameter	Value(mm)
Diameter of Excavation	5060
Diameter of Segment (Internal)	4200
Diameter of Segment (External)	4800
Thickness of Segment	300
Length of Shield	12000

5. Analysis and Results

5.1 Analytical Method: Convergence Confinement Method

The convergence-confinement method helps to simulate the excavation of a tunnel and the installation of the support using a simple plane strain model.The 3D problem is simplified by means of a 2D plane-strain assumption where the tunnel excavation is simulated by a progressive reduction of a 'fictitious' internal support pressure Pf applied at the tunnel wall given by

$$Pf = (1 - \lambda)\sigma_0 \quad (5)$$

where, σ_0 is initial stress state and $\lambda$is deconfining rate.

The idea of employing a deconfining rate lambda in order to simulate the support effect of the face advance was introduced by [10]. It takes the value of 0 at the initial state and grows until reaching the value of 1 when the tunnel is completely excavated.There are two basic assumptions in CCM: 1. Hydro-static stress conditions 2. Circular cross section of the opening. [11] have presented CCM of tunnel design rock masses that satisfy the Hoek-Brown failure criterion.

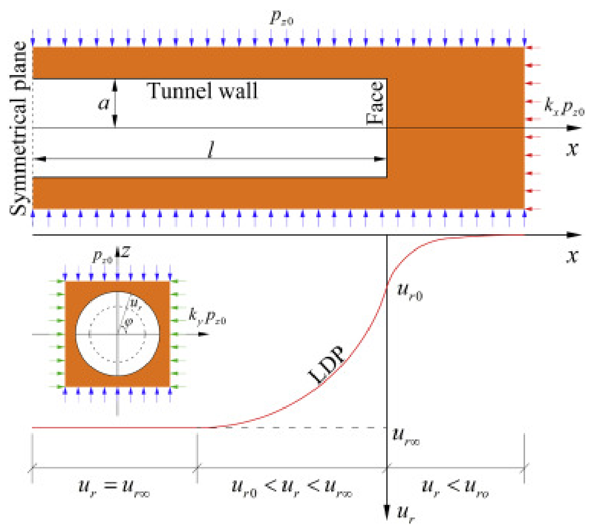

Figure 5: Longitudinal deformation profile using CCM

As Hoek-Brown criterion uses rock mass properties and utilizes UCS of intact rock to evaluate overall rock mass quality, this method provides a direct solution. Especially for jointed rock mass and highly fractured and sheared rockmass, CCM with the Hoek-Brown criterion is convenient.

The output of the analytical calculation is as shown in figure 6 and 7for location 1 and Location 2 respectively.

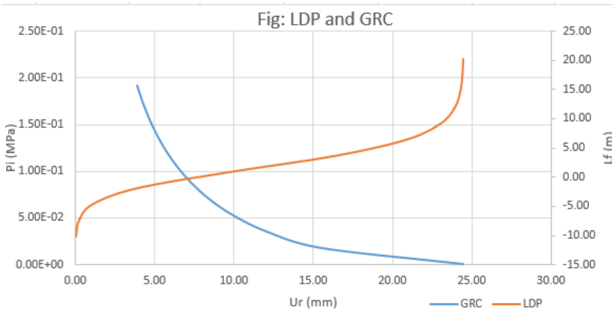

Figure 6: Longitudinal deformation profile vs Ground Reaction curve using CCM at location 1

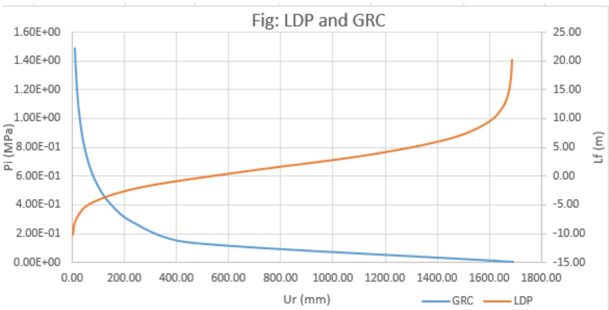

Figure 7: Longitudinal deformation profile vs Ground Reaction curve using CCM at location 2

5.2 Numerical Modeling

RS2 is a two-dimensional finite element method based numerical modeling program of the Rocscience . It is extensively used for the analysis of underground/surface excavation in rock mass or soil. Basically, it has three modules: modeler (for pre-processing which includes creation of geometry models, meshing, boundary constraints, load and support systems), compute (for processing which enables elastic and plastic analysis, plain strain and axi-symmetric analysis, static and seismic loads) and interpret (for post-processing which shows default and user defined values). Similarly, RS3 is a three dimensional finite element method based numerical modeling program of Rocscience which has same modules as RS2 package. This helps to solve the problem considering three dimensional effect.

The value of GSI is taken from the RMR rating of rockmass and borehole data given in report and disturbance factor (D) is taken zero considering the null disturbance to surrounding rockmass while excavating. The material constants were derived from above equations and other remaining parameters from lab report.

Modeling of an circular tunnel of 5.06 meter diameter has been performed in two stages :initial stage and excavation stage to study how the unsupported deformation vary calculated from different methods. The stress is assumed to be hydro-static and major and minor horizontal stress are equal. The asymmetric modeling is done in case of RS2 and 3D model is created in case of RS3. The representative model are shown in figure below:

Plain strain analysis of the defined models in the per-processing phase have been computed with 0.001 tolerance value and 500 number of iterations using Gaussian elimination methods. Absolute energy

Table 3: Summary of the input parameters for Location 1 (Babai Thrust) [8]

Description	Unit	Adopted Value
GSI	-	28
Material constant (mi)	-	5
Disturbance factor (D)	-	0
mb	-	0.382
Constant (s)	-	0.00033
Constant (a)	-	0.52556
Constant (c)	MPa	0.186
Peak frictional angle	degree	27.64
Tensile strength	MPa	0.0140
Deformation modulus	GPa	1.2
Residual frictional angle	degree	0

Table 4: Summary of the input parameters for Location 2 (Bheri Thrust) [8]

Description	Unit	Adopted Value
GSI	-	22
Material constant (mi)	-	5
Disturbance factor (D)	-	0
mb	-	0.308
Constant (s)	-	0.00017
Constant (a)	-	0.5382
Constant (c)	MPa	0.268
Peak frictional angle	degree	27.64
Tensile strength	MPa	0.0055
Deformation modulus	GPa	0.55
Residual frictional angle	degree	0

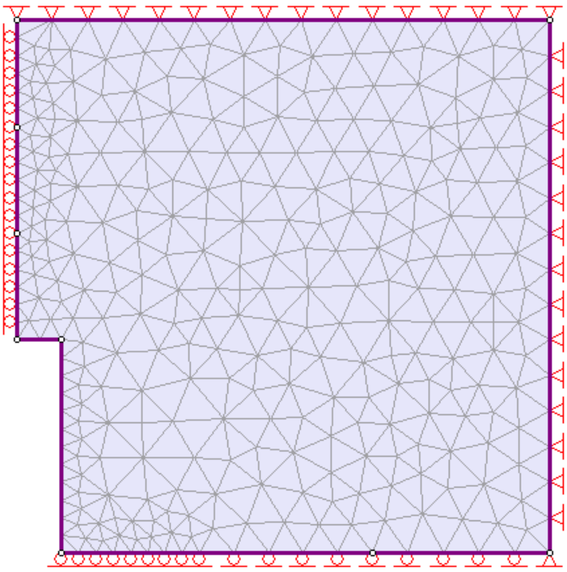

Figure 8: Axisymmetic model in RS2

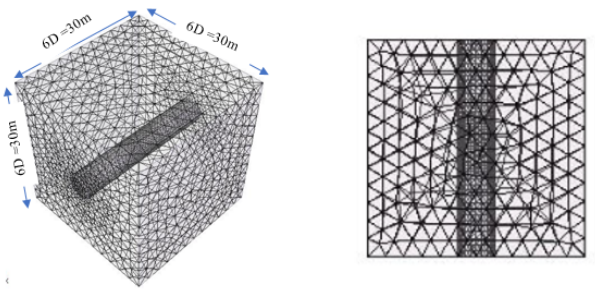

Figure 9: RS3 Model

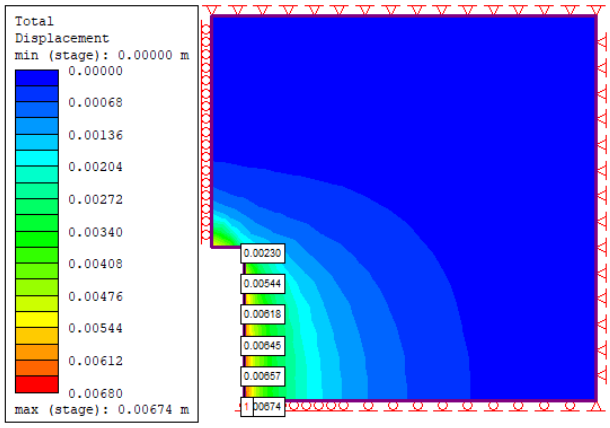

Figure 10: Total Displacement at Location 1 (RS2 Output)

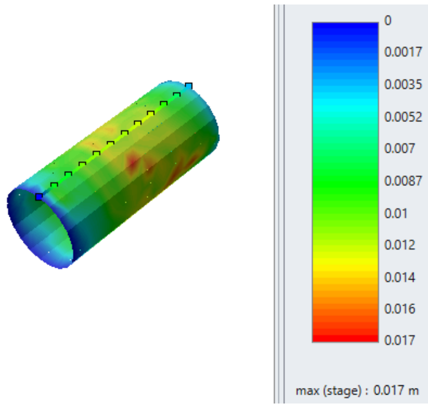

Figure 11: Total Displacement at Location 1 (RS3 Output)

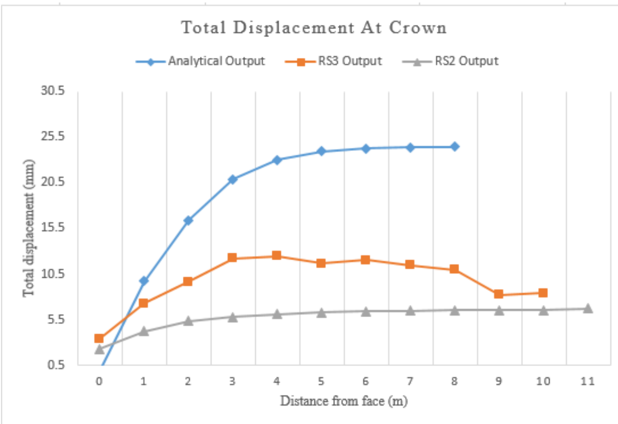

Figure 12: Comparison of total displacement variation from different outputs at location 1

convergence criterion has been adopted. Once the computation of the model gets completed, it will be ready for the interpret module.The computed parameters of the model can be visualized with the help of contour or different colors gradient or by both. The visualized parameters have been used to interpret the model. The output of RS2 model showing deformation at location 1 can be shown in Figure 10:

The deformation result output of 3D modesl of RS3 at location 1 is shown in Figure 11.

The analytical solution is done and the outputs of different models are compared and presented graphically for location 1 in Figure 12. From the graph, we see that the total displacement calculated from analytical method is very high as compared to numerical models as it cannot fully demonstrate face effect as intermediate stress is not considered which increase confinement and restricts deformation. RS2 output considering axi-symmetric analysis shows very least deformation as confinement is increased as it partially represents 3D model but its effect for causing deformation is not considered. But RS3 model output shows intermediate value as confinement is increased but also it's impact also increase stress causing deformation.

Similarly, the computation and numerical modeling results output are done for location 2 which output is shown in Figure 13.

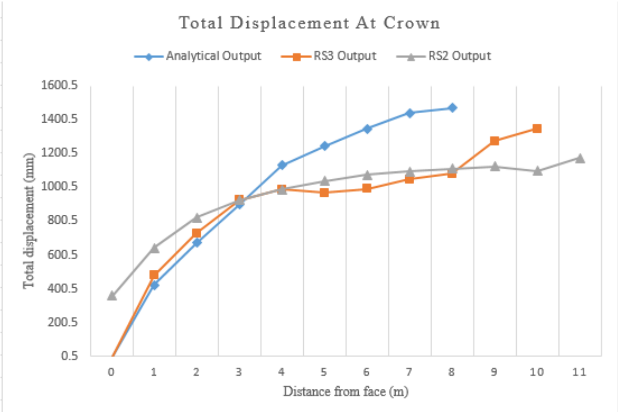

Figure 13: Comparison of total displacement variation from different outputs at location 2

It is obvious from graph that when overburden is high there is very low deviation among deformation output form different methods as the major and minor principal stress are very high which decrease the effect of intermediate stress. Intermediate stress effect for enhancing confinement effect is very low that result in similar deformation value.

6. Conclusions and Recommendations

From the above results, we can conclude the following conclusions:

- The total displacement calculation for shallow overburden using 3D modeling gives better results as it considers intermediate value that help in deciding the support installation as intermediate stress play significant role that leads to confinement as well as causing increase in deformation simultaneously in case of lower overburden.
- In case of high overburden, the 2D result of total displacement can be considered enough for calculation rather than doing 3D numerical modeling as effect of intermediate stress for lower overburden is least.

Some limitations persist in this research work. These limitations can be addressed with some more effort in the analysis. The following major points can be incorporated for the further research work.

- The groundwater effect is not included which might be included for calculation.
- Total displacement in tunnel also depends upon the dipping orientation of the joint set. Sensitivity analysis based on the spacing of joint set, frictional angle, overburden depth of the tunnel, joint normal stiffness, and joint shear stiffness should be performed.

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