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Stability Evaluation of Lanedada Twin Tunnel in KTFT

Subodh Sapkota[1]
Sandeep Shrestha[2]
Nabaraj Neupane[3]

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Abstract

The construction of underground tunnels, particularly in roadway systems, is a highly complicated and demanding process, necessitating careful consideration of geological variability, environmental impact, and safety concerns. This thesis emphasizes the critical importance of determining the optimal separation between twin tunnels, balancing the need for environmental conservation, economic efficiency, and structural stability. The study particularly focuses on the Kathmandu Terai/Madhesh Fasttrack (KTFT), a major expressway project in Nepal, which includes twin tunnels at three different sites under varying geological conditions. A detailed case study is conducted on the Lanedada Twin Tunnel, spanning 1.430 kilometers through the Siwalik Hill. Various methodologies, including empirical, analytical, and numerical approaches, are employed to assess tunnel stability. The findings reveal discrepancies in predictions of tunnel squeezing, with Singh et al.'s method indicating no squeezing potential, while Goel et al.'s method identifies squeezing in half of the evaluated sections. Additionally, the approaches by Hoek and Marino (2000) and Shrestha and Panthi (2015) are applied to estimate tunnel deformation at six specific locations. An analysis of rock support systems using the Rock Mass Rating (RMR) classification and the Q system is presented. Special attention is given to the section at 34+160, where the RS2 software is utilized to simulate varying pillar widths between the twin tunnels, allowing for a comparative analysis of different scenarios. This research aims to contribute to the understanding and implementation of safer, more feasible twin tunnel constructions, thereby enhancing the effectiveness of large-scale infrastructure projects.

Keywords: Twin tunnel, Squeezing, Tunnel deformation, Pillar width

[1]Rock and Tunnel Engineering, Department of Civil Engineering, IOE, Pashchimanchal Campus, Tribhuvan University, Nepal
[2]Akara Materials testing Laboratory - Pvt. Ltd, Tinkune, Kathmandu, Nepal
[3]Department of Civil Engineering, IOE, Pashchimanchal Campus, Tribhuvan University, Nepal
Corresponding Author: rameshpt02@gmail.com

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Stability Evaluation of Lanedada Twin Tunnel in KTFT

Tunnels serve as essential man-made underground structures designed to facilitate the movement of people, vehicles, water, and utilities by traversing obstacles like mountains, rivers, or urban areas. During excavation, Tunnel may encounter with soil, weak rock mass or hard rock mass depending on the location where tunnel is being excavated. The stability of the underground structure in weak rock mass depends predominantly on the materials themselves whereas in hard rock mass the stability is controlled by the major discontinuities (Ulusay et al., 2013; Selen, 2020). Depending on the purpose of underground structure, the shape, size, orientation and alignment can be different. It is common engineering practice to construct deep, parallel-twin tunnels with conventional methods (Sequential Excavation Method, Observational Method (Kova´ri and Lunardi 2018), etc.) within weak rock masses in highway and railway networks. However, stability of such tunnels and maintaining optimal separation between twin tunnels is critical. If the separation is too wide, it leads to higher construction costs due to increased excavation needs and the elongation of connecting access tunnels (crosscuts) between the twins, which can negatively affect the project economically. Conversely, reducing the distance between the tunnels increases stress on the support systems due to stress concentration and the formation of a plastic zone, necessitating a more robust support framework.

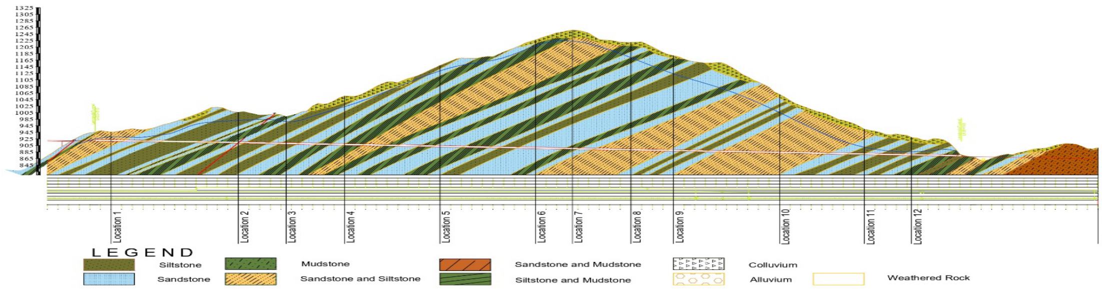
Tunneling projects in the Himalayas have faced significant stability issues, leading to delays and cost overruns (Panthi, 2006). Thus, stability assessment of tunnels is essential for each unique case of tunneling in Himalayas. Twin tunnel in case of Himalayas of Nepal is new as most of the tunnels built here are single tube tunnel only recently some twin tunnel projects are being under construction. Twin tunneling projects may face similar issues thus proper study of such project is essential. This study aims to evaluate stability and suitable separation of twin tunnel in Siwalik zone of Nepal Himalaya. For this purpose case study on Lanedada tunnel of Kathmandu-Terai/Madhesh Fasttrack (Expressway) (KTFT) is selected.

Study Area

KTFT projects stretches between Kathmandu and Nijgadh in Central Nepal. The project consists of tunnels at three different locations namely Mahadevtar, Dhedre and Lane Dada. Mahadevtar and Dhedre tunnel are situated in Lesser Himalaya region while Lane Dada tunnel passes through Siwalik zone. The Lanedada tunnel lies in Makwanpur district of Bagmati province. The entry portal of Lanedada tunnel lies at 27° 25’ 54.9529” and 85° 11’ 54.33198” while the exit portal area lies at 27° 25’ 1.79098” and 85° 11’ 50.79624”.

Figure 1

Geological Profile of Lanedada Tunnel (Source: KTFT project)



Geology of the site mainly consists of intercalation of Sandstone, Siltstone and Mudstone. Intermittent occurrence of Mudstone, Siltstone and Sandstone will also be a challenge because it increases the unpredictability of the ground condition ahead of the tunnel face. Also the presence of less competent rocks in project location makes excavation of tunnel challenging. Hence, stability analysis of these twin tunnels of Lane Dada is of great importance and challenging as well.

The twin tunnels are Horseshoe shaped with 14.5 meter excavation width and 10.5 meter excavation height. The pillar width is variable at different sections. For ease of assessibility the separation distance between two tunnels is kept small near the Portal. At section of study the pillar width of 23.2 meter is adopted in field.

Objectives of Study

The main objective of this project work is to determine the optimal separation distance between twin tunnels that balances safety, economic efficiency, and structural integrity, minimizing stress concentrations and the potential for geological instability while controlling construction costs.

This objective will be pursued through a comprehensive analysis of the Lanedada twin tunnels within the Kathmandu-Terai/Madhesh Fasttrack (Expressway) project.

The specific objectives of the study are:

- To access stability of Tunnels by using Empirical Methods
- Analytically evaluate the stability of Tunnel at specific locations
- To evaluate the Plastic deformation characteristics at specific Locations
- To assess the optimal pillar width of twin tunnels through 2D numerical

modeling, by varying the pillar width and comparing the impact of different pillar widths on various parameters.

Literature Review

Rock Mass Classification and Support System

Rock Mass Rating (RMR)

Z.T. Bieniawski (1973) developed the Rock Mass Rating (RMR) system initially using 49 case histories and expanded later including additional case histories from coal mining and tunneling. The RMR method assesses rock mass based on six measurable field parameters, which may also be assessed using borehole data. These include:

- Uniaxial compressive strength of the intact rock
- Rock Quality Designation (RQD)
- Spacing of discontinuities
- Condition of discontinuities, which looks at persistence, roughness, separation, infilling, and weathering of discontinuities
- Groundwater conditions
- Orientation of discontinuities

The cumulative score of these parameters forms the RMR, which is instrumental in guiding support system decisions for underground excavations, specifically formulated for horseshoe-shaped tunnels 10 meters in width, undergoing drilling and blasting under a vertical stress of less than 25 MPa.

Rock Mass Quality (Q)

Barton et al. (1974) developed Q-system at Norwegian Geotechnical Institute to classify rock masses based on a quantitative assessment using parameters such as the degree of jointing, joint set number, joint roughness, joint alteration, water inflow/pressure, and stress reduction factors. This system scales logarithmically from 0.01 up to 1000 and is pivotal for the empirical design of rock reinforcements and tunnel supports.

$$Q = \frac{RQD}{Jn} * \frac{Jr}{Ja} * \frac{Jw}{SRF}$$

By incorporating the Equivalent Dimension (De), calculated as the span, diameter, or wall height divided by the excavation support ratio (ESR), this method allows engineers to tailor the support design based on Q values, offering a detailed support chart for practical guidance.

Geological Strength Index (GSI)

Hoek (1994) introduced the Geological Strength Index (GSI) that serves as an alternative to the RMR for assessing rock mass strength and deformability in jointed rock masses. The GSI is particularly useful when employing the Hoek-Brown failure criterion and has been integral in advancing the understanding of heterogeneous rock masses, such as flysch, through the use of tailored GSI charts and the RocLab software. There are several correlations developed by different researchers between Q value and GSI as well as RMR value and GSI.

Plastic Deformation

Singh et al. (1992)

The empirical method developed by Singh et al. (1992) uses rock mass quality (Q-value) and plots it in log-log plot with tunnel depth. It draws a clear boundary to predict whether the section of tunnel under study has squeezing potential or not.

$H > 350Q^{1/3}$ ……………………..Squeezing Condition
$H < 350Q^{1/3}$ …………..Non-Squeezing Condition

Goel et al. (1995)

Goel et al. (1995) introduced an empirical technique that utilized a rock mass number known as "N," which closely parallels the "Q" value used in other methods. The key simplification in Goel's approach is setting the Support Requirement Factor (SRF) to 1. This modification was implemented to simplify the process and to mitigate the difficulties and uncertainties involved in accurately determining the SRF value in the Q-method classification system.

$H>275N^{1/3} B^{-0.1}$…………………….Squeezing Condition

$H<275N^{1/3} B^{-0.1}$……………Non-Squeezing Condition

Hoek and Marinos (2000)

Semi-analytical method developed by Hoek and Marinos (2000) focuses on calculating the behavior of circular tunnels under hydrostatic stress conditions. The approach assumes that support is uniformly distributed around the tunnel's perimeter. Its main goal is to predict the likelihood and intensity of squeezing in tunnel environments. Hoek and Marinos demonstrate this by plotting the strain experienced by the tunnel against the ratio of uniaxial compressive strength (σcm) to in-situ stress (Po)

Shrestha and Panthi (2015)

Shrestha and Panthi's 2015 research focused on analyzing the sustained squeezing in three different hydropower tunnels in Nepal's Himalayas. They utilized a convergence equation from Sulem et al. (1987) to establish a link between time-dependent and time-independent strain. Their study sought to determine correlations between various factors such as instantaneous and final strains experienced by the tunnels, vertical gravitational stress (σv), the ratio of horizontal to vertical stress (k), support pressure (Pi), and the rock mass's shear modulus (G). The goal was to clarify how these factors interact, enhancing the understanding and prediction of tunnel behavior under squeezing conditions.

Twin Tunnel Interaction

One of the critical determinants of twin tunnel stability is the integrity of the pillar that separates them. The distance between the tunnels plays a pivotal role in the extent of deformation they experience. Finite Element Method (FEM) simulations have demonstrated key correlations between tunnel spacing, dimensions, and resultant deformations (Singh et al., 2018).

Innovative experiments by Jiang et al. (2020) involved testing 3D printed models of twin tunnels in materials mimicking sandstone properties. Their findings identified a critical zone at the partition wall between the tunnels, where crushing failure is most likely to initiate.

Observations by Karakus et al. (2007) revealed differential displacement responses in twin tunnels constructed through Ankara clay, where the tunnel built second experienced up to three times more displacement than the first. Additionally, Chakeri et al. (2011) noted that in soft ground, spacing at least three times the tunnel diameter generally mitigates significant interaction effects, though their study was limited to a specific tunnel diameter.

Lee (2009) studied the role of temporary supports at tunnel portals using FEM analysis, finding that support removal and subsequent excavation increased earth pressures and crown displacement.

The research by Shen and Barton (1997) identified three primary disturbance zones around excavations: failure, open, and shear zones. Each zone requires specific management strategies, from immediate support in failure zones, to long-term stabilization in open zones.

Zhou et al. (2017) investigated the dynamic responses of rock surrounding twin tunnels during seismic events, noting that closer tunnel spacing resulted in higher relative displacements among rock monitoring points, especially when the spacing was less than the tunnel diameter. For spacing between two and three diameters, the deformation remained relatively stable.

When reinforced with horizontal steel pipe reinforcement grouting, it is judged to have played a role in supporting the upper load applied to the upper part of the pillar part and increasing the stability of the upper part of the pillar part. It was confirmed that when the upper part of the pillar was stabilized by horizontal steel pipe reinforcement + grouting reinforcement, the vertical displacement of the pillar part was smaller than when it was not.

You, K. H., & Kim, J. G. (2011) studied pillar stability of twin tunnel with different overburden and suggested that regardless of the cover height, as the pillar width increases and the lateral pressure coefficient increases.

Recent studies by Zhang et al. (2023) compared vertical (up-down) and horizontal (side-by-side) orientations of twin tunnels. They found that the stability of rock pillars in vertically oriented tunnels is predominantly influenced by pillar cross-sectional area, whereas in horizontally oriented tunnels, it is more sensitive to the spacing-to-radius ratio. They suggested enhancing pillar stability by modifying construction methods to adjust the spacing-to-radius ratio or by optimizing the rock pillar thickness relative to the tunnel diameter.

Ağbay, E., & Topal, T. (2020) evaluated twin tunnel induced surface ground deformation by empirical and numerical analysis and concluded that Twin tunnel-induced surface settlement is mainly controlled by geomechanical factors and engineering factors. Hence, the determination of rock mass parameters is a vital step to be undertaken during the numerical analysis of the tunnel structure. The study also suggested that friction angle and cohesion parameters had less effect on the twin tunnel-induced surface settlement.

Method

Rock mass classification

Different Rock mass classification system were applied for quantifying the rock mass quality. The classification is based on field observation at accessible sections and based on predicted data obtained from project. RMR and Q system were implemented to classify the rock mass quality and estimate tunnel support. GSI value of rock mass were derived for different location using correlation between RMR and GSI for Nepal Himalaya proposed by Chaulagai K. and Dahal R.K. (2023).

$$GSI = 0.547RMR + 26.47$$

The GSI values thus obtained are used for different analytical as well as numerical analysis.

Evaluation of Plastic Deformation

Tunnel plastic deformation is commonly analyzed using empirical approaches, with methods such as those proposed by Singh et al. (1992) and Goel et al. (1995). Additionally, two valuable semi-empirical techniques have been introduced by Hoek and Marinos (2000) and Panthi and Shrestha (2018). Analytical methods, such as the Convergence Confinement Method (CCM), as developed by Carranza-Torres and Fairhurst (2000), and numerical methods employing finite element software like Rocscience, are widely recognized for their effectiveness in quantifying the phenomenon of squeezing around tunnel contours. Numerical modeling is utilized for study of Pillar stability while other methods are utilized for plastic deformation without considering twin tunnel.

Numerical Modeling

Finite Element Analysis (FEA) serves as an integral computational resource in the realm of rock and tunnel engineering, employing advanced numerical modeling to simulate and evaluate the structural integrity of underground constructions. This aspect of the thesis uses the sophisticated FEA software RS2, which is specifically developed for geotechnical applications, to investigate the twin tunnel systems that are part of the Kathmandu Terai/Madhesh Fasttrack (KTFT) project.

The principle stress at field were derived from valley model using Numerical modeling in RS2. Field geography data was derived from both longitudinal section of the tunnel alignment from the project and also from Google Earth.

In the simulations, the pillar widths between the tunnels was varied to explore their influence on the tunnels' structural responses under normal operating conditions. This adjustment of pillar widths is crucial as it affects the distribution of stresses within the rock mass, which in turn affects the tunnels' deformation behaviors and stability. The FEA allowed for the detailed modeling of the interaction between the tunnels and the surrounding rock formations, providing a clear visualization of how changes in pillar width affect tunnel stability. From this detailed analysis, we were able to derive optimal pillar dimensions that would prevent structural failures and maintain safety. This FEA study enhances our understanding of the design requirements and contributes significantly to the engineering of twin tunnel systems under challenging geological conditions, as observed in the KTFT project.

Results

Rock mass classification

Rock mass classification based on RMR system and Q system showed different class at different sections. RMR suggested 59% class III rock mass, 33% class IV rock mass and 8% class V rock mass while Q system suggested 67% class B rock mass, 17% class C rock mass, 8% class D rock mass and 8% class E rock mass. The result of rock mass classification is summarized in Figure 3 for both RMR system classification and Q system classification.

Support system obtained from RMR system classification is presented in Table 1 and support system obtained from Q system classification is presented in Table 2.

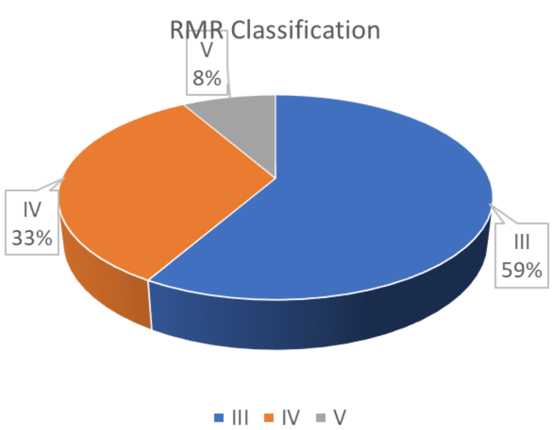
Table 1

Support Estimation by RMR system

<table>
<tr><th rowspan="2">Location</th><th rowspan="2">RMR</th><th rowspan="2">Rock Mass Class</th><th rowspan="2">Description</th><th colspan="3">Support Required</th></tr>
<tr><th>Rock Bolts 20mm fully bonded</th><th>Shortcrete</th><th>Steel Sets</th></tr>
<tr><td>Location 1</td><td>19</td><td>V</td><td>VERYPOOR</td><td>Systematic bolts 5-6 m long, spaced 1-1.5 m in crown and walls with wire mesh. Bolt invert.</td><td>150-200 mm in crown, 150 mm in sides, and 50 mm on face.</td><td>Medium to heavy ribs spaced 0.75 m with steel lagging and forepoing if required. Close invert.</td></tr>
<tr><td>Location 3</td><td rowspan="4">21-40</td><td rowspan="4">IV</td><td rowspan="4">POOR</td><td rowspan="4">Systematic bolts 4-5 m long, spaced 1-1.5 m in crown and walls with wire mesh.</td><td rowspan="4">100-150 mm in crown and 100 mm in sides</td><td rowspan="4">Light to medium ribs spaced 1.5 m where required</td></tr>
<tr><td>Location 4</td></tr>
<tr><td>Location 9</td></tr>
<tr><td>Location 12</td></tr>
<tr><td>Location 2</td><td rowspan="7">40-50</td><td rowspan="7">III</td><td rowspan="7">POOR</td><td rowspan="7">Systematic bolts 4 m long, spaced 1.5 - 2 m in crown and walls with wire mesh in crown.</td><td rowspan="7">50-100 mm in crown and 30 mm in sides.</td><td rowspan="7">None.</td></tr>
<tr><td>Location 5</td></tr>
<tr><td>Location 6</td></tr>
<tr><td>Location 7</td></tr>
<tr><td>Location 8</td></tr>
<tr><td>Location 10</td></tr>
<tr><td>Location 11</td></tr>
</table>

Figure 2

Rock mass classification as per a) RMR system and b) Q system



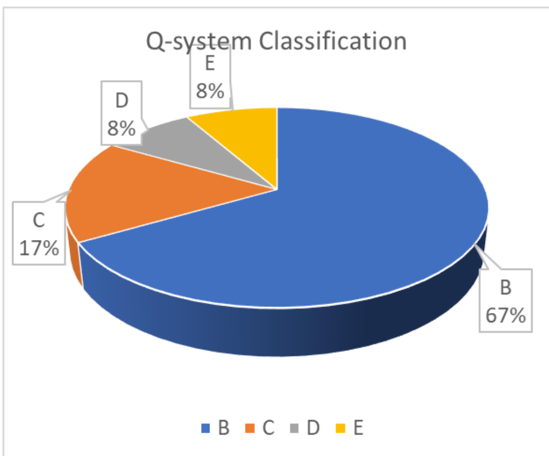


Table 2

Support Estimation by Q-system

Location	Q-Value	Rock Mass Class	Description	Support Required ESR:1.6, Bold Length:2m
Location 3	0.82-2.00	B	GOOD	9 cm thick steel fiber reinforced shotcrete and 20 mm diameter 2 m long grouted rock bolts @ 2.4 m spacing.
Location 4				
Location 6	1.5-2.22	B	GOOD	
Location 7				
Location 8				
Location 9				
Location 10	1.11-1.92	B	GOOD	
Location 11				
Location 5	0.6-1.5	B-C	GOOD-FAIR	12 cm thick steel fiber reinforced shotcrete and 20 mm diameter 4 m long grouted rock bolts @ 2.1 m spacing.
Location 12	0.459	C	FAIR	
Location 2	0.23-0.8	C-D	FAIR-POOR	
Location 1	0.062	E	VERY POOR	Fiber Reinforced shotcrete >15 cm, Reinforced ribs of shotcrete and bolting, 20 mm dia, 4 m length @1.5 m spacing

Empirical Methods

Squeezing prediction from Singh et al. (1992) is presented in Table 1 and Figure 3. The findings indicate no Squeezing potential at any of considered sections of Tunnel. Squeezing prediction from Goel et al. (1998) is presented in Table 2 and Figure 3. The findings indicate Squeezing at three sections among twelve sections considered.

Figure 3

Squeezing analysis by Sing et al. (1995) and Goel et al. (1998)

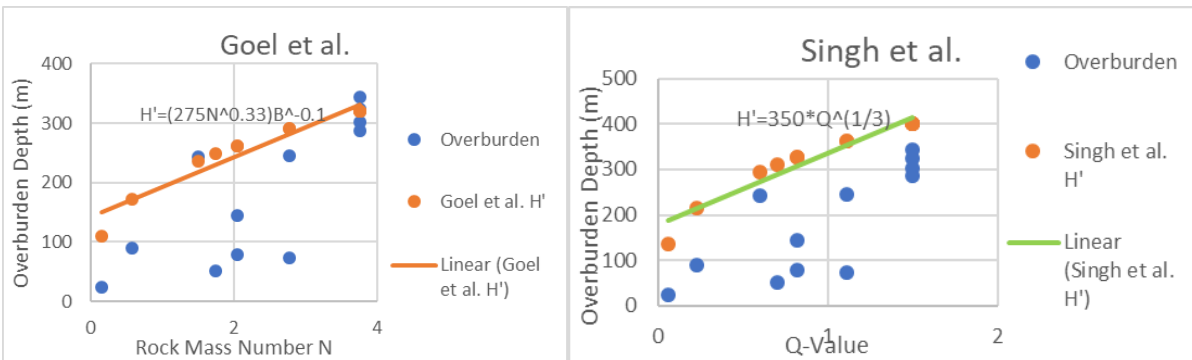


Table 3

Squeezing prediction by Singh et al. (1995)

Chainage	Q Value Predicted	Overburden (Meter)	Singh Et. Al. H' (Meter)	Squeezing Prediction
33+540	0.06	23.16	137.02	No
33+780	0.23	89.52	214.44	No
33+870	0.82	79.16	327.60	No
33+980	0.82	145.18	327.60	No
34+160	0.6	243.54	295.20	No
34+300	1.5	301.1	400.65	No
34+370	1.5	343.54	400.65	No
34+520	1.5	324.54	400.65	No
34+600	1.5	286.68	400.65	No
34+800	1.11	245.3	362.39	No
34+960	1.11	72.78	362.39	No
35+050	0.7	50.9	310.77	No

Table 4

Squeezing prediction by Goel et al. (1998)

Chainage	N Value (Q with SRF=1)	Overburden (Meter)	Goel Et. Al. H' (Meter)	Squeezing Prediction
33+540	0.15	23.16	109.87	No
33+780	0.575	89.52	171.87	No
33+870	2.05	79.16	262.45	No
33+980	2.05	145.18	262.45	No
34+160	1.5	243.54	236.52	Yes
34+300	3.75	301.1	320.91	No
34+370	3.75	343.54	320.91	Yes
34+520	3.75	324.54	320.91	Yes
34+600	3.75	286.68	320.91	No
34+800	2.775	245.3	290.29	No
34+960	2.775	72.78	290.29	No
35+050	1.75	50.9	248.98	No

Semi-Analytical Method

The results from semi-analytical methods of plastic deformation prediction are presented in this section.

Table 5

Outcome of Hoek and Marinos (2000) approach

Chainage	Po (Mpa)	σcm	Strain, ϵ (for Pi=0)	Strain, ϵ (for Pi=0.5)	Strain, ϵ (for Pi=1)	σcm/Po	Total deformation (mm)
33+540	0.586	7.005	0%	0.2%	28.53%	11.954	0.203
33+780	2.256	10.694	0.01%	0.02%	0.04%	4.741	1.290
33+870	1.892	3.020	0.08%	0.1%	0.13%	1.596	11.384
33+980	3.659	8.230	0.04%	0.05%	0.06%	2.250	5.730
34+160	6.137	10.791	0.06%	0.07%	0.08%	1.758	9.380
34+300	7.196	4.213	0.58%	0.53%	0.48%	0.585	84.622
34+370	8.657	10.791	0.13%	0.13%	0.13%	1.247	18.664
34+520	8.211	9.402	0.15%	0.15%	0.16%	1.145	22.116
34+600	7.224	8.230	0.15%	0.16%	0.16%	1.139	22.343
34+800	6.206	9.310	0.09%	0.1%	0.1%	1.500	12.885
34+960	1.739	3.984	0.04%	0.07%	0.11%	2.291	5.528
35+045	1.283	10.222	0%	0.02%	0.14%	7.969	0.457

Table 6

Outcome of Shrestha and Panthi (2015) approach

Chainage	Po (Mpa)	Rock shear modulus, G (Mpa)	σtec (MPa)	σh	Strength anisotropy (K)	Initial closure Strain, ϵI	Final closure Strain, ϵF	2G/(σv (1+k)/2)
33+540	0.586	334.277	3	3.183	5.432	0.011	0.021	354.784
33+780	2.256	1171.010	3	3.631	1.610	0.002	0.004	795.640
33+870	1.892	232.511	3	3.591	1.898	0.055	0.099	169.621
33+980	3.659	697.476	3	4.024	1.100	0.011	0.020	363.163
34+160	6.137	1191.929	3	4.717	0.769	0.007	0.014	439.240
34+300	7.196	397.342	3	5.248	0.729	0.100	0.179	127.714
34+370	8.657	1191.929	3	5.422	0.626	0.013	0.023	338.626
34+520	8.211	571.251	3	5.562	0.677	0.057	0.103	165.904
34+600	7.224	697.476	3	5.021	0.695	0.029	0.053	227.826
34+800	6.206	561.225	3	4.937	0.795	0.038	0.069	201.469
34+960	1.739	390.368	3	3.543	2.037	0.017	0.031	295.569
35+045	1.283	1071.283	3	3.359	2.619	0.001	0.003	923.204

Table 5 shows different outcome of Hoek and Marinos (2000) semi analytical approach performed whereas Table 6 is summary of different outcome of semi analytical method developed by Shrestha and Panthi (2015).

Numerical Modeling

Valley Model

Using RS2 software, a two-dimensional topographical valley model is designed to analyze the confined model and ascertain the in-situ principal stresses at the tunnel cross-section's center. This model is anchored at the bottom boundary in the Y direction and at the left and right boundaries in the X direction, while the top remains unrestricted. The loading uses field stress combined with gravity effects, based on the actual ground surface topography. The rock mass is considered elastic in this model to allow for the development of stresses without leading to rock failure. This approach helps in examining stress conditions within the rock mass, providing essential data for analyzing the confined model. Specific parameters and calculations for the valley model are tabulated in Table 7.

Table 7

Input Parameters for Valley Model

S.N.	Rock Type	Intact UCS	GSI	Mi	Disturbance Factor	Elastic Modulus	Unit Weight	Poisson's Ratio
1	Sand Stone	60.37	48.897	17	0.5	18120	0.0252	0.22
2	Silt Stone	32.5	48.35	7	0.5	6090	0.0239	0.23
3	Sand and Silt Stone	60	48.897	12	0.5	8826.67	0.0253	0.24

Figure 4

Valley Model simulation and Stress Distribution Longitudinally to Tunnel Alignment

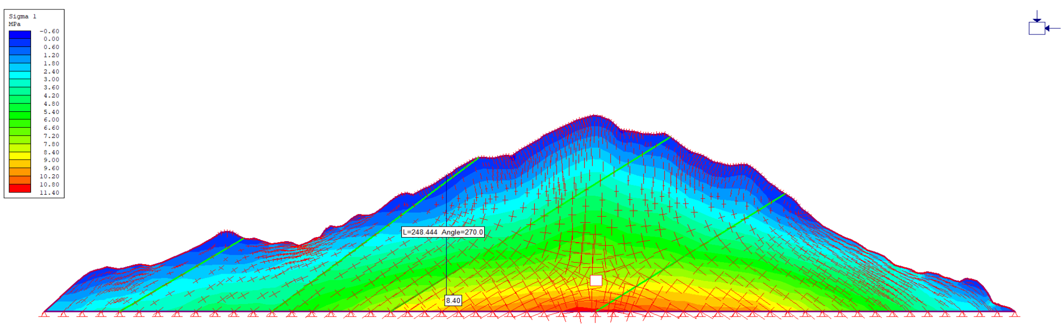
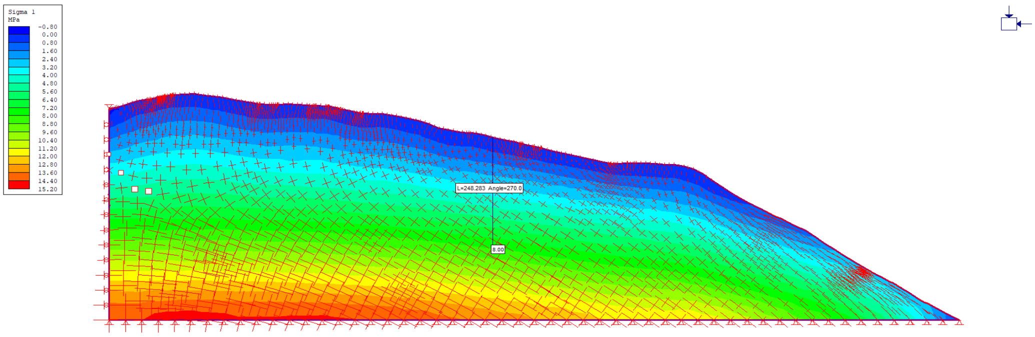


Figure 5

Valley Model simulation Perpendicular to Tunnel Alignment at Chainage 34+160



Valley model simulation for longitudinal tunnel section and perpendicular to Tunnel alignment at chainage 34+160 is shown in figure 8 while same for perpendicular to Tunnel alignment at chainage 34+160 is shown in figure 9. The Table 8 are the result obtained from valley model.

Table 8

Result of Stress analysis from Valley Model at Chainage 34+160

σz	5.00
σ1	8.2
σ3	5.025
σ1 Angle with Horizontal	35

RS2 Model

To conduct an analysis on a critical tunnel section, a 2D box model is created with a width Ten times that of the excavation span. The model is segmented into 13 stages, with stage factors decreasing from 1 to 0, and its boundaries are fixed in both directions. Material properties within the 2D model are defined by initial loading elements of field stress and body force. Strength parameters and the failure criterion utilize the Generalized Hoek-Brown method.

The RS2 software models an Inverted Horse Shoe-shaped tunnel, adopting the 14.5 m Span. The model sets the loading condition to a constant field stress, with parameters derived from the previously mentioned valley model, detailed in Table 4.8. The modeling includes four phases: pre excavation (stage 1), the initial tunnel excavation (stage 2), relaxation of the surrounding rock mass (stage 3), and support installation (stage 4). The analysis evaluates the tunnel's response under both elastic and plastic conditions, with and without support in each scenario.

Additionally, to address the impact of using the drill and blast method for tunnel excavation, a disturbed zone is included in the model with a disturbance factor of 0.5. This factor accounts for the alterations in rock properties due to blasting effects.

Table 9

Results from RS2 Simulation

Pillar Width (M)	Dia (M)	PW/Dia	Plastic Zone Radius (M)	Plastic Zone Overlap	Distance from Tunnel Face (M)	Plastic Radius/ Tunnel Radius	Dist. From Face/ Tunnel Radius
	14.5	0	14	N/A	2	1.93	0.28
3.625	14.5	0.25	50.6	Yes	2	6.98	0.28
7.25	14.5	0.5	31	Yes	2	4.28	0.28
14.5	14.5	1	14.5	Yes	2	2.00	0.28
21.75	14.5	1.5	18.125	Yes	2	2.50	0.28
23.2	14.5	1.6	18.4	No	2	2.54	0.28
29	14.5	2	15	No	2	2.07	0.28
36.25	14.5	2.5	15.43	No	2	2.13	0.28

Pillar Width (M)	Maximum Closure (M)	Closure/ Max Closure	Closure	Deformation at Spring Max. (M)	Deformation at Crown Max. (M)	Deformation at Pillar Max. (M)
3.625	0.6186	0.17	0.1052	0.49	0.63	0.56
7.25	0.2578	0.25	0.0645	0.18	0.18	0.165
14.5	0.157	0.4	0.0628	0.12	0.136	0.096
21.75	0.1781	0.35	0.0623	0.144	0.153	0.081
23.2	0.1733	0.35	0.0607	0.153	0.144	0.081
29	0.1531	0.4	0.0612	0.096	0.136	0.048
36.25	0.1461	0.39	0.057	0.0105	0.135	0.0525

For evaluation for different pillar width between tunnels, chainage 34+160 is selected based on availability of data, possibility of stability problems that needs to be accessed. Here twin tunnel are simulated at same section with varying pillar width and their interaction is studied based on stress and deformation. The results thus obtained are presented on Table 9.

Discussion

Rock mass classification

Different rock mass classification systems applied here suggests abundance of good rock mass while at some section presence of poor rock mass is anticipated. Results from RMR system and Q system are different yet they are comparable. Among 12 sections selected for assessment, they were classified as four classes of rock mass as per RMR system while Q system evaluates the selected rock masses into three groups.

Plastic Deformation

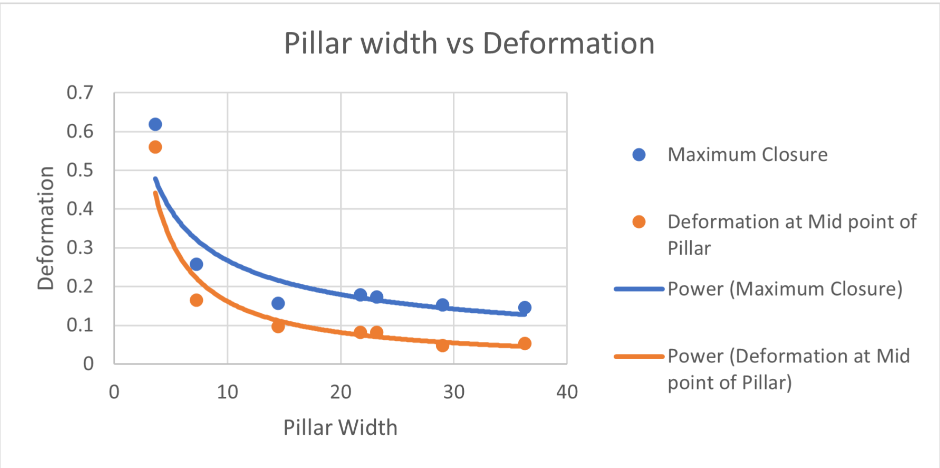
Singh et al. (1990) suggested no possibility of squeezing in twelve sections evaluated while Goel et al. (1995) suggested possibility of squeezing at three different sections. These sections are further evaluated using Semi-analytical methods like Hoek and Marinos (2000) approach and Shrestha and Panthi (2015) approach. Hoek and Marinos (2000) method shows possibility of squeezing near the entry portal due to shallow overburden. In other sections, strain value is less than 1% that means no possibility of squeezing. The maximum deformation predicted is 84 mm at chainage 34+300. Deformation at all other sections is predicted to be less than 25 mm. Shrestha and Panthi (2015) methods presents estimates for initial closure as well as final closure. It is predicted that maximum initial closure strain occurs at chainage 34+300 that 0.1 while final closure strain is maximum at the same location and can be of the order of 0.179.

Numerical Modeling

Different results are obtained from numerical modeling for different parameters as presented in result section. The results obtained shows that the deformation around the tunnel wall decreases as pillar width increases.

Figure 6

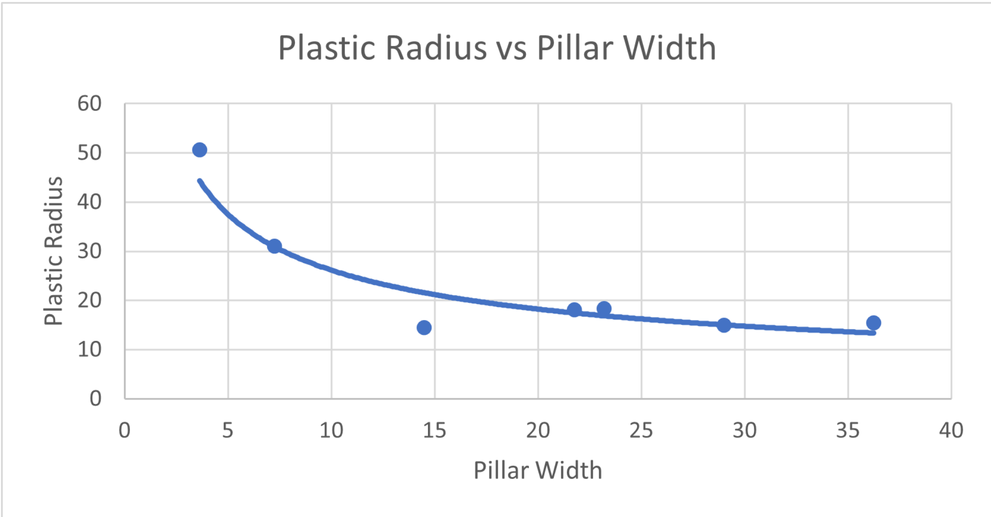
Maximum Closure and Deformation at Mid of Pillar vs Pillar Width



Initially when the pillar width is less than tunnel width, the deformation value rapidly decreases with increase in pillar width. However, when the pillar width is more than tunnel width, the deformation around tunnel decreases gradually with increase in pillar width. The trend is similar for deformation in mid span of pillar. The deformation decreases rapidly up to one tunnel width of pillar width and decreases gradually after one tunnel width of pillar width as shown in scatter chart in figure 6.

Figure 7

Plastic radius vs Pillar width



The figure 7 shows the variation of plastic radius with change in pillar width of twin tunnel. For less than one tunnel width of pillar width the plastic radius decreases rapidly and for pillar width of more than tunnel width, the plastic radius decreases gradually. But at pillar width equal to tunnel width, the plastic radius is evaluated to be below the trend line because the maximum plastic deformation is seen above the tunnel for Pillar width to Tunnel width ratio less than one but when that ratio reaches one and goes up, the maximum plastic radius is observed towards pillar. But when Pillar width to Tunnel width ratio equals one, the plastic radius is small because the plastic zone on other side rather than the pillar due to effect of adjacent tunnel is diminished and available rock mass between two tunnels is small and limited.

Conclusion

From various methods of study and analysis, it is seen that the Twin Tunnel at Lanedada shows only few support problems. The support for each sections are estimated from empirical methods. The squeezing potential was evaluated by empirical methods and Goel et al. (1995) method suggested squeezing at few sections. Deformation estimated from semi analytical method like Hoek and Marinos (2000) and Shrestha and Panthi (2015) are up to acceptable range in most of the sections while some sections may need special attention during construction.

For twin tunnel, the numerical modeling and simulation showed rapid rise in deformation of tunnel wall as well as deformation of pillar between twin tunnels. From result it can also be concluded that the plastic radius of twin tunnel is also influenced by pillar width. If proper pillar width is adopted, stable Twin tunnels can be constructed through the Siwalik region of Nepal with good quality rock mass.

References

Bieniawski, Z.T. (1989) Engineering Rock Mass Classification.

Barton, N., Lien, R. and Lunde, J. (1974) 'Engineering Classification of Rock Masses for the Design of Tunnel Support.', Norg Geotek Inst, Publ [Preprint]. Available at: https://doi.org/10.1016/0148-9062(75)91319-4.

Carranza-Torres, C. and Fairhurst, C. (2000) 'Application of the Convergence-Confinement Method of tunnel design to rock masses that satisfy the Hoek-Brown failure criterion', *Tunnelling and Underground Space Technology, 15*(2), pp. 187–213. Available at: https://doi.org/10.1016/S0886-7798(00)00046-8.

Hoek, E. and Brown, E.T. (2019) 'The Hoek–Brown failure criterion and GSI – 2018 edition', *Journal of Rock Mechanics and Geotechnical Engineering, 11*(3), pp. 445–463. Available at: https://doi.org/10.1016/j.jrmge.2018.08.001.

Marinos, P. and Hoek, E. (2001) 'Estimating the geotechnical properties of heterogenous rock masses such as flysch', *Bulletin of Engineering Geology and the Environment*, 60, pp. 85–92. Available at: https://doi.org/10.1007/s100640000090.

Nilsen, B. and Thidemann, A. (1993) 'Volume No 9 by', (9), pp. 9–11

Panthi, K. (2006) Analysis of engineering geological uncertainties related to tunnelling in Himalayan rock mass conditions, Norwegian University of Science and Technology.

Palmström, A. and Singh, R. (2001) 'The deformation modulus of rock masses — comparisons between in situ tests and indirect estimates', *Tunnelling and Underground Space Technology, 16*(2), pp. 115–131. Available at: https://doi.org/10.1016/S0886-7798(01)00038-4.

Singh, B., & Goel, R. (2006). Tunnelling in weak rocks. Elsevier Geoengineering Book Series Volume 5.

Chaulagai K., & Dahal R. (2023). Correlation of Bieniawski's RMR and Barton's Q System in the Nepal Himalaya', *Indian Geotechnical Journal, 54*(1-2).

Singh, R., Singh, T. N. and Bajpai, R. K (2018). 'The Investigation of TwinTunnel Stability: Effect of Spacing and Diameter', *Journal of theGeological Society of India, 91*(5), pp.

563–568, 2018.https://doi.org/10.1007/s12594-018-0905-y

Jiang, Q., Liu, X., Yan, F., Yang, Y., Xu, D., & Feng, G. (2021). Failure performance of 3DP physical twin-tunnel model and corresponding safety factor evaluation. *Rock Mechanics and Rock Engineering, 54*, 109-128.

Ghorbani, H. and Ajalloeian, R. (2019). 'A method for selection of optimum distance between twin tunnels under static and pseudo-staticconditions, case study: Pooneh tunnel.' Geotech. Geol. Eng. 2019, 37, 4435–4446

Zhang, H.J., Liu, G.N., Liu, W.X., et al, (2023). 'Stability evaluation of rock pillar between twin tunnelsusing the YAI.' *Scientific Reports, Vol. 13, 13187*. https://doi.org/10.1038/s41598-023-40167-9

You, K. H., & Kim, J. G. (2011). Evaluation of the influence of pillar width on the stability of a twin tunnel. *Journal of Korean Tunnelling and Underground Space Association, 13*(2), 115-131.

Ağbay, E., & Topal, T. (2020). Evaluation of twin tunnel-induced surface ground deformation by empirical and numerical analyses (NATM part of Eurasia tunnel, Turkey). *Computers and Geotechnics*, 119, 103367.

Changgui Li et al (2021). 'Numerical analysis of reasonable distance between tunnel faces for twin Tunnel.' *IOP Conf. Ser.: Earth Environ. Sci. 643 012028*

(Shrestha. B. (2022). Relevancy of Three Tunnels in Kathmandu-Terai/Madhesh Fast Track (Expressway) Road Project, *KTFT Journal Vol.2*