Proceedings of 8th IOE Graduate Conference
Peer Reviewed
ISSN: 2350-8914 (Online), 2350-8906 (Print)
Year: 2020 Month: June Volume: 8

Geotechnical Analysis of Tunneling for Metro Rail in the Ground Condition of Kathmandu-Patan Line (Bhrikutimandap to Satdobato Section)

Pawan Babu Bastola [a], Binod Lal Amatya [b], Akal Bahadur Singh [c]

[a, c] *Department of Civil Engineering, Pulchowk Campus, IOE, TU, Nepal*
[b] *Arcadis London, U.K*
Corresponding Email: pawanbabubastola@gmail.com [a] ,blamatya@hotmail.com [b]

Abstract

This paper gives an account of the Geo-technical analysis and Tunnel Support System Design of Kathmandu Metro Rail from Bhrikutimandap to Satdobato Section.Construction has to be done in very difficult condition through the congested urban areas passing below the Bagmati River and Bishnumati River.Modern design techniques and field instrumentation has to be used precisely to cope this challenging project. Twin tunnel each of 6m diameter is prefered to be bored by Highly mechanised EPB TBM. 6.3Km long onstreet underground alignment of tunnel is mostly preferred at the depth of 30m station level as per settlement criteria. It will be one of the pioneer mass rapid transit projects on soft,lacustrine deposit of Kathmandu Valley Soil. Determination of the extent of feasilbility of Metro Rail facility in Kathmandu is the ultimate aim of this project.

Keywords

Support System, Geo-technical, Design, Finite Element Method Analysis, Station, Formation, Lining

1. Introduction

1.1 Background

Increasing traffic congestion in cities has serious effects on urban ecosystems, especially due to the increased atmospheric pollution and changes in land use patterns. Kathmandu Valley is facing this problem.An ecologically sustainable and environment friendly urban transport system has to be obtained as an appropriate alternative modes of transport for the betterment of Kathmandu transport system. Transport, because of its pervasive nature, occupies a central position in the fabric of modern urbanized society. In most of the countries, this has been a story of evolutionary change with new transport development replacing the old transport system in response to perceived socio-economic needs of the people. Geo-technical Study and Implementation of such modern transport system of Metro Rail facility to Kathmandu city is the goal of this project. Kathmandu Basin consists of full of unplanned settlement, temples and buildings of archaeological importance.This will result the selection of the alignment of Metro-Rail more challenging and daring. Further,settlement criteria should be precisely monitored to ensure high safety to the superstructures and traffic in during and after the construction of Tunnel.

In this modern era, Mass Rapid Transport has been an initial epitome for the development and prosperity of nation. People traveling from one place to another in more safer, faster and convenient way is the need of this time in Kathmandu which can be possible due to Metro Rail.For this, metro route alignment is to be selected as per traffic volume study.On road underground alignment is selected to minimize the induced settlement and seismic effects.Best alignment from all possible alternatives is selected and then evaluated in accurate manner by using GIS, Global Mapper.Google Earth and GIS is used to trace the alignment and to determine the altitude of the points of ground level. Preliminary Desk study followed by the ground characterization and the detail geo-technical analysis are the essence of the project to drive to success within the permissible limit of subsidence and failure. After the successful breakthrough of tunnel of Bheri Babai Diversion Multiple Project (BBDMP) , i.e. 12.34Km (Hydro

Tunnel) in difficult land terrain , Tunnel Boring Machine(TBM) has been introduced in the land of Nepal for the 1st time. There will be TBM launching portal beyond NAST (Satdobato) and Stations will be of 120m length(L) and at 30m depth(Z) from the natural ground level allowing twin tunnels of 6m diameter(D) each separating at the distance of 12m center to center.

1.2 Statement of Problem

Kathmandu is being incapable of providing smooth and speed mode of transport system.In Kathmandu Valley, population increase million in next two decades(Feasibility Study of MRT system in Kathmandu Valley). Thus, growing cities, growing population and growing traffic has invariably called for a shift from private modes of conveyance to effective mass transit system. Similarly, Nepal lags its own non- renewable fuels and it is concluded that Metro Rail requires 1/5th energy per passenger km compared to road-based transport system. Thus, it will be better alternative for fuel importing country. Increasing air pollution due to vehicles, time lag of passengers, accidents and traffic congestion of the Capital will drastically be reduced after this Mass Transport System. After the implementation of Metro-Rail Project there will be incremental benefits to a number of economic agents: government, private transporters, passengers, general public and unskilled labor. Four Millions of people at a city needs to sift to reliable Mass Transport System. In Kathmandu, time has called to move underground and living on the ground. This might be the game changer project in the journey of Nepal to Prosperity.

1.3 Study Objectives

The detail objective of this study are:

- Study on various tunneling risks of Patan Line such as ground condition, settlement, ground movement below ground
- Establish alignment of Patan Line
- TBM selection for the ground condition of Patan Line
- Propose tunnel size, length for Patan Line
- Establish tunnel/station box induced ground settlement of Patan Line
- Study on sustainability aspect of Patan Line such as impact on local heritage, environmental risks (such as waste, ecology, resource use), tunnel size

2. Literature Review

Elastic Continuum Method,Bedded Beam Method and Muir Wood Method are three methods for the calculation of the Bending Moment and the thrust on the wall of the tunnel.Amount of stress release and radial displacement in the walls of tunnel is analyzed [1].

Range of minimum permissible horizontal radius, minimum gradient(0.2-0.3 percent for drainage) and maximum gradient of the tunnel has been selected as per STRASYA Code. Circular Tunnel is found to be most effective [2].

Ground Behavior at different soil conditions and their soil Stabilization techniques are shown. Selection criteria of TBM and tunnel induced settlement is analysed [3].

New Austrian Tunneling Method (NATM) allows the estimation of moments and thrusts acting on the liner for the range of commonly encountered conditions. Design values are shown to be preliminary dependent on soil deformation properties, initial stress conditions and the amount of stress release in the ground prior to concreting [4, 5].

Different types formation on the Kathmandu Valley, their respective depths can be studied. In the metro alignment from Bhrikutimandap to Satdobato section, Kalimati Formation is found to be encounter in the 1st Kilometer and last Kilometer of alignment while the middle portion encounter Chapagaun Formation [6, 7].

Kolkata Metro Construction includes the construction of Metro rail below the Ganga River.This can be important while driving tunnel under Bagmati River in Kathmandu Metro Project [2, 8].

Seismic response of the tunnels,Damping and its amplification are analyzed in this paper [9].

Measurements of soil deformation during the extension of Madrid Metro is analyzed. Application of numerical and analytical solutions to the soil deformations measured during the construction of 30Km of new tunnels is shown [10].

Typical Compaction grouting above tunnels and below building foundation in Los Angeles Metro is shown which can be basis for Kathmandu Metro [11].

3. Materials and Methodology

3.1 Study Area

Kathmandu Valley and in peculiar Section from Bhrikutimandap to Satdobato is the study area of this paper. Kathmandu Valley is where mythology and geology intertwined. Geological study has shown that the Kathmandu Valley is an ancient lake deposit and is made of thick layers of clay, silt, sand and gravel. The maximum thickness of the valley soil is 500-550 m at the center of the valley[6]. Southern part of the valley consists of boulders and gravel with a clayey and silty matrix derived as debris flows from southern hill, while typical riverbed layered deposit of clays , silts, sand and gravels are found in the valley north and the central basin consists of open lacustrine facies(i.e. thick organic mud, and the black clay). As the soil deposited in irregular layers, soil properties and basin thickness vary from place to place.

3.2 Methodology

To achieve the objectives of the study, following approach are taken:

3.2.1 Selection of Alignment

After the detail study of traffic movement,geological,archaeological and geotechnical study,alignment of the Metro Rail has been selected to facilitate maximum population density. Starting from the Bhrikutimandap Central Station, there will be Metro stations near Tripureshowr Chowk (1+100Km), Sajha Petro Pump (Pulchowk ,2+700Km), Patan Industrial Gate. (4+600Km)and Launching Portal at Khumaltar respectively. Alignment is 6.2Km in Length and designed using Google Earth, Global Mapper and Smart Road Software. Similarly, alignment is selected to encounter minimum settlement and avoiding the super structured area that is why most of the alignment is on road underground.

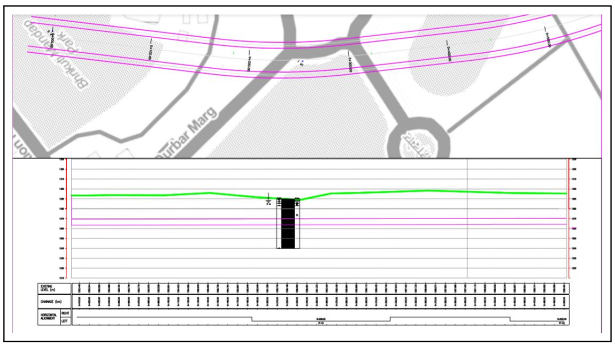

Figure 2: Alignment of Bhrikutimandap Central Station 0+500Km.

3.2.2 Collection of Bore hole data

Geo-technical Report of different points of the alignment are collected. Geo-technical Report of Bhrikutimandap Central Station and Lagankhel Intermediate Stations are of 50m depths while Pulchowk Intermediate Station is of 30m depth. Geo-technical Report of Satdobato and Khumaltar are of around 15m depths.Index properties of soil,Ground Water Table,soil types and their respective properties are analyzed.

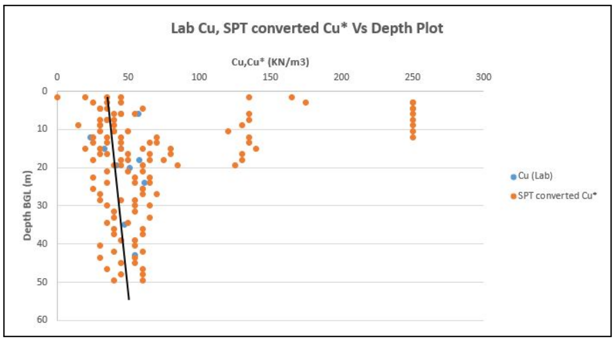

Figure 3: Lab Cu and SPT converted Cu plot.

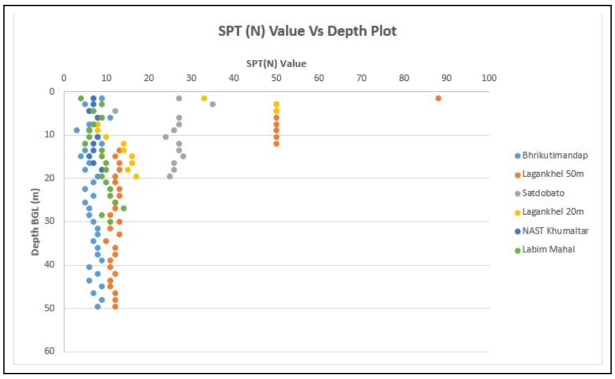

Figure 4: Total SPT Plot

3.2.3 Ground Characterization

Kathmandu valley is synclinal basin filled up by fluvio lacustrine deposit of Pleistocene age.Ground Water level at Bhrikutimandap is at 4.5m below ground level.Ground Water Level decreases towards Kupondole around 1.5 m below ground level and increases towards Lagankhel near at 7.8 m from ground surface. Bhrikutimandap Central Station consits of sandy silty upper layer while Kupondole area consist of organic clay and peats.Satdobato area near to the launching portal is made up of gravelly particles up to 10m from ground surface. From the study of the deep bore hole logs it is seen that tunnel passes through the Clayey Silt layer.

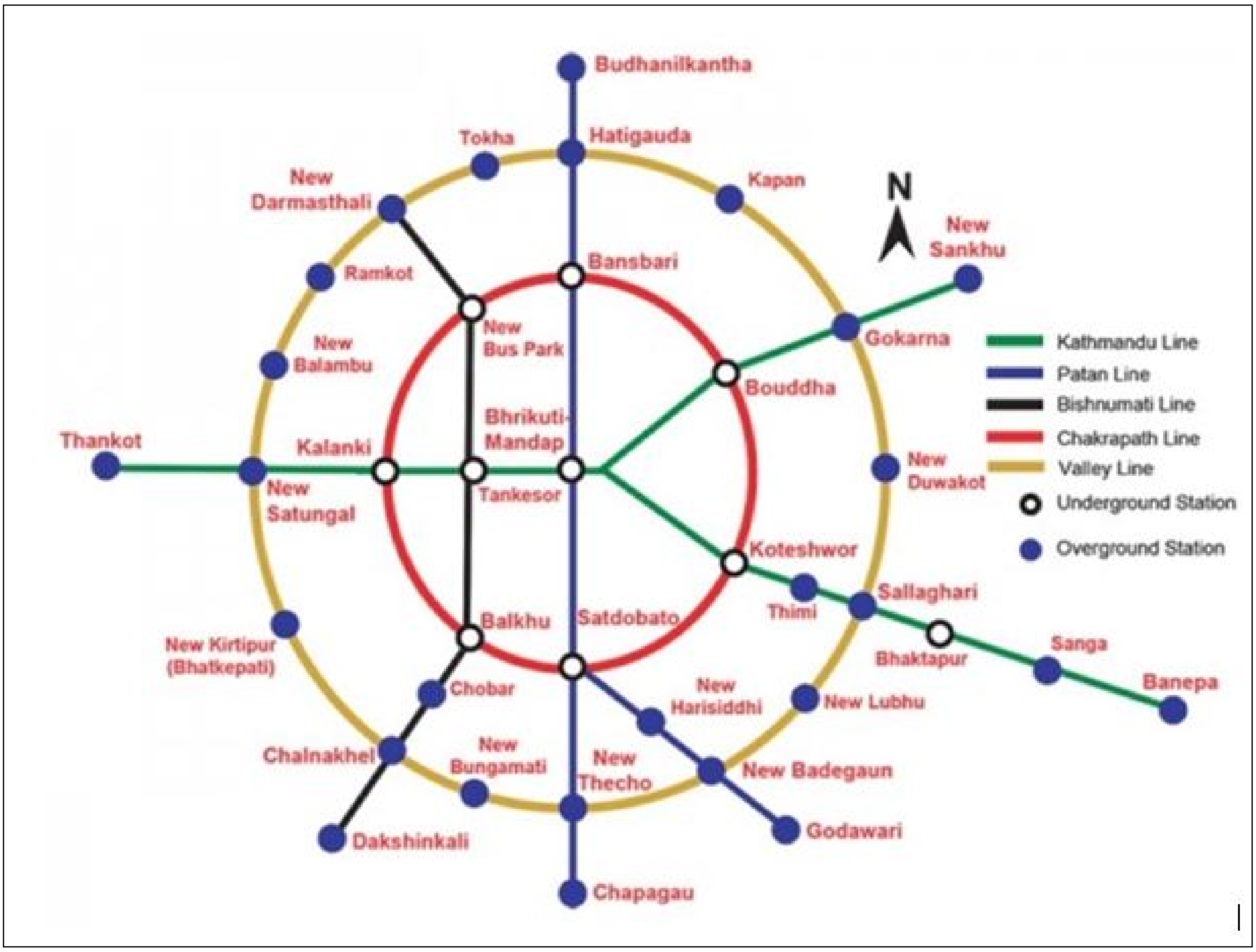

Figure 1: Proposed Metro Alignment of Kathmandu Valley[8]

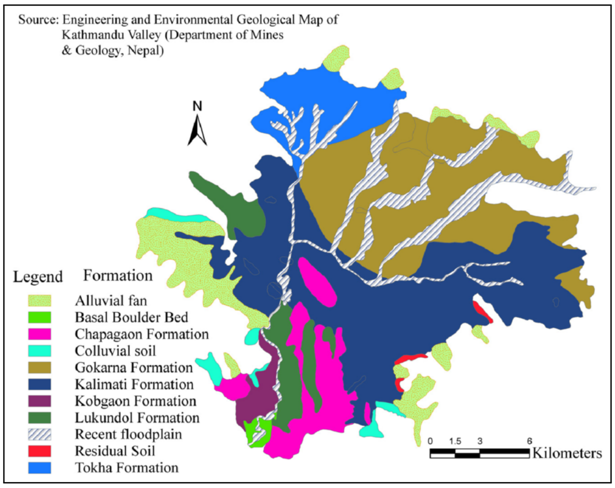

Figure 5: Soil Map of Kathmandu Valley[6]

S. N	Geological Unit	Symbol	Unit	Made Ground	Kalimati Clay/Silt
1.	Weight Density (Above GWT)	γ	KN/m^3	20	18
2.	Weight Density (Below GWT)	γ_s	KN/m^3	21	19
3.	SPT N Value	N_{60}		5	8
4.	Plasticity Index	PI	%	6(20 taken)	6(20 taken)
5.	Liquidity Index	LL	%	38	40
6.	Plastic Limit	PL	%	32	32
7.	Natural Moisture Content	NMC	%	30	40
8.	Drained Angle of Shearing Resistance (Peak)	ϕ'_p	°	20	20
9.	Coefficient of compressibility	m_v	m^2/MN	52	50
10.	Drained Cohesion	c'	KPA	20	20

Figure 6: Calculated Parameters of Kathmandu Soil(a)

S. N	Geological Unit	Symbol	Unit	Made Ground	Kalimati Clay/Silt
11.	Undrained Cohesion	C_u	KPA	50	50
12.	OCR	OCR		1.8	0.4
13.	Undrained Young's Modulus	E_u	MPa	40	35
14.	Drained Young's Modulus	E'	MPa	35	30
15.	Ratio of Horizontal to Vertical Modulus	E_h/E_v		1.3	1
16.	Undrained Poisson's Ratio	v_u	-	0.5	0.5
17.	Drained Poisson's Ratio	v	-	0.3	0.3
18.	Permeability	k	m/s	10^{-8}	10^{-8}
19.	Shear Wave Velocity	Vs	m/s		
20.	Reference Level	Z	MoD	1293	1290
21	Reference Depth	z	m	3	24

Figure 7: Calculated Parameters of Kathmandu SOil(b)

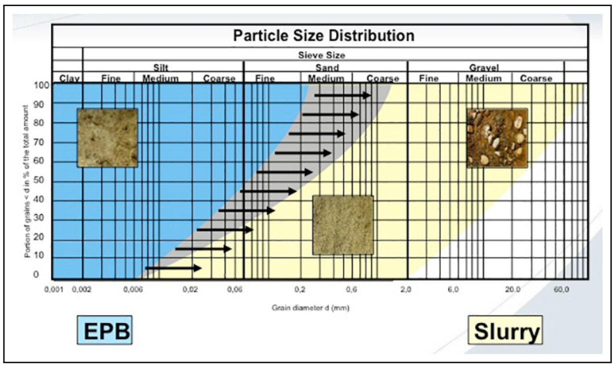

Figure 8: TBM selection criteria as per Herrenect TBM Company

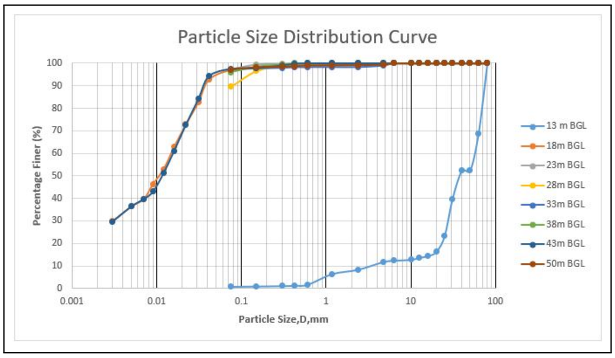

Figure 9: Particle Size Distribution of Lagankhel Intermediate Station for TBM selection

3.2.4 Preleminary Sizing

Circular tunnel is most common in subways and best in soft and medium soils.[2]As TBM are used for driving the tunnels, tunnel will be cicular[2] In TBM Method, minimum of 1D of cover is required and particularly in alluvial soil minimum of 2D cover.[1]If the tunnel passes under buildings then it should be below the zone of influence of superstructure.Twin Tunnel of 6m diameter at 30m station depths are initially taken as per settlement criteria and geo-technical analyis[2]. Soil Analysis is done considering the average soil properties from surface as ratio of cover to diameter is not much more than 5.[2]

3.2.5 Selection of TBM

Selection of TBM is done on the basis of the soil encountered within the tunnel alignment. After the ground characterization, tunnel is seen to drive through the clayey silt layer . Thus, EPB TBM machine is best suited for this soil condition as per Herrenect graph [12].

3.2.6 Lining Design

Lining has to withstand the load of overburden (and water if water table is above), Horizontal pressure, Self-weight of lining and track road, Live load transmitted to base, Uplift pressure from base.[1] There are several analytical methods for determination of soil pressure at tunnel and lining design.Among them most suited and widely used for soft ground tunneling is Elastic continuum Model that is based on excavation and lining of a hole in a stressed isotropic and homogeneous elastic medium.[3] This is used simply and quickly to determine loads and defections in the lining system, and for carrying out parametric sensitivity studies. Bedded Beam models has difficulty in application for the determination of tunnel lining as spring constant of soil of Kathmandu is undiscovered yet.

Thus, analytical approach by Muir Wood modified by DJ Curtis has been followed to determine the Relative flexibility factor,Bending Moment (BM), Axial

Load(N), Radial deflection respectively as below:

$$Q2 = \frac{Esoil * Ro^3}{Esoil * 12 * (1+v)Ie} \tag{1}$$

$$B.M = \frac{Po * Ro^2(3-4v)}{2(5-6v+4Q2)} \tag{2}$$

$$N = (Pav * Ro) \pm \frac{Po * Ro(3-4v)}{2(5-6v+4Q2)} \tag{3}$$

$$\delta = \frac{B.M * Ro^2}{3Econc * Io} \tag{4}$$

3.2.7 Settlement Calculation

At different chain-age of Tunnels excavation corresponding values of the settlement is compared to the permissible range of settlement as per defined by Wahls, 1981 [13]. Settlement Contour of 10mm settlement is calculated by Gaussian Curve Method and the enclosed zone will be evacuated for the construction of the tunnel.

Settlement curve has been calculated using the relation:

$$VoluumeLoss(V.L) = \frac{i}{Smax} \tag{5}$$

Where,i=trough width,

Smax=Maximum Settlement

$$MaximumSettlement = Smax * e^{\frac{-x^2}{2*i^2}} \tag{6}$$

Where,x=Horizontal Distance from the axis of tunnel.

If the permissible range is exceeded the either alignment might be changed of ground or support modification can be done to attain surplus pressure.

4. Results and Discussion

4.1 Lining

Calculation of Maximum Bending Moment and Axial Load of the Tunnel has been done.Interaction curve is plotted and analyzed.Points within the curve shows it is on safe zone else the lining segment fail to withstand the pressure. In the latter case,if the lining in any section fail to withstand the load then the reinforcement on segment is to be increased and soil is to modified to more stable state.

M50 grade concrete and steel of reinforcement Fe500 is taken. Tunnel of 6m diameter and 30cm structural thickness with 4 segments is obtained as safe. After the calculation of Bending Moment and Maximum Shear force from Muir Wood approach the respective values are plotted and analyzed in the interaction diagram. It is evident from above figure that the designed sections are safe because all the respective points fall inside the interaction diagram.

4.2 Settlement

Surface effects of tunnel construction is calculated. Diameter of tunnel(D)of 6m, trough width parameter(k)of 0.5and Volume loss is 1.5percent is taken as per the ground condition of Kathamandu Metro-Patan Line. Center to center distance of tunnel is taken as 12m that is 2D spacing. Overburden of each location is taken from the tunnel alignment and the maximum settlement of each tunnel and combined settlement is obtained as shown in the graph below.During the crossing of the Bagmati River,ground experiences maximum settlement of 40mm.Special considerations of ground modifications should be considered here to mitigate the induced settlement.Rest of the points experience settlement within permissible limit.

Tunneling induced surface settlement increases on increasing the diameter of the tunnel and vice-versa for the overburden.

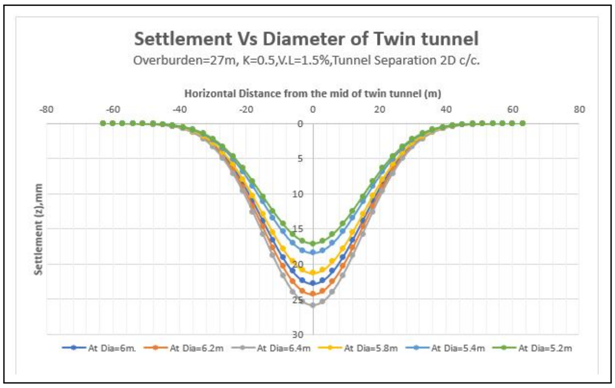

Figure 11: Settlement Vs Diameter Plot

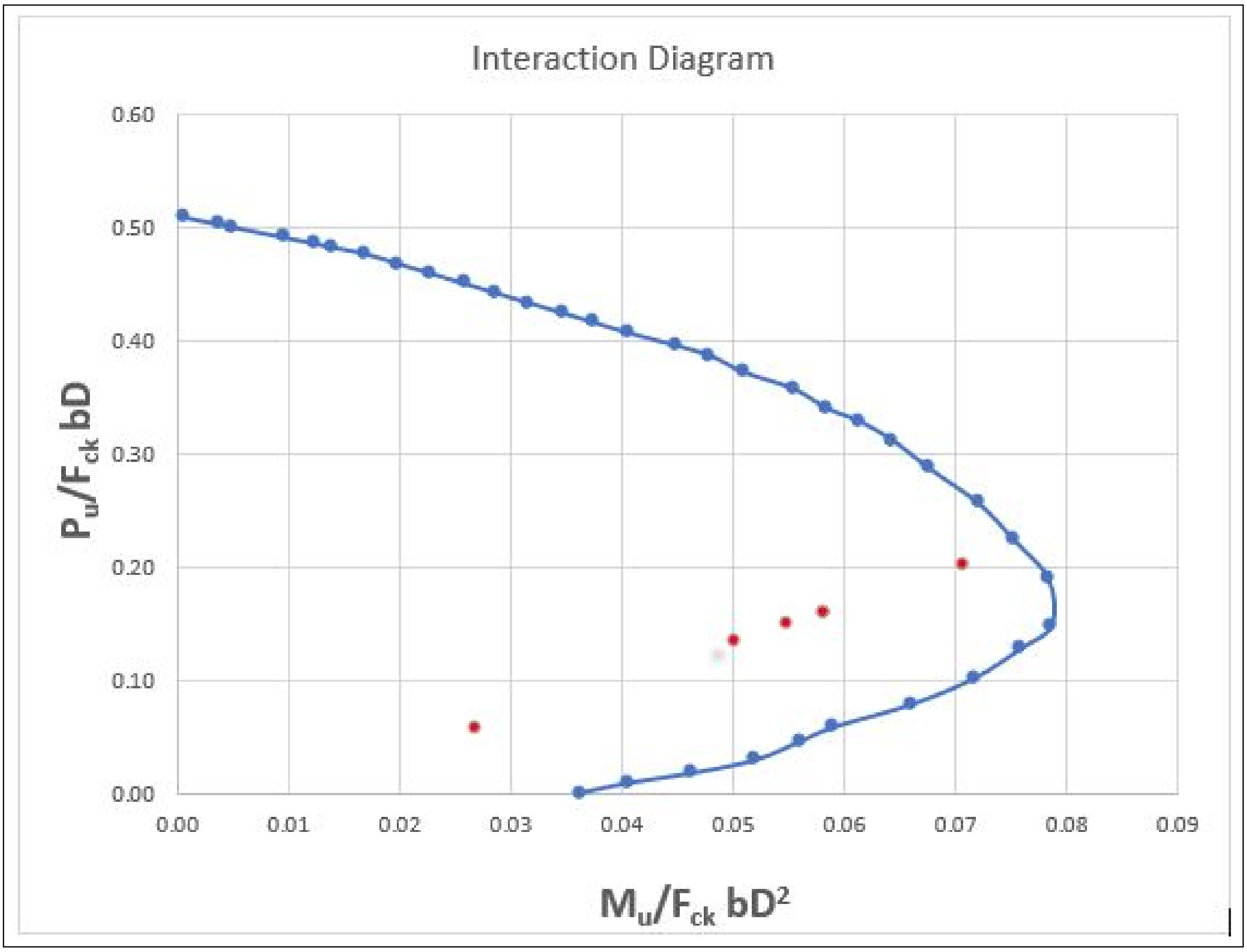

Figure 10: Interaction Curve

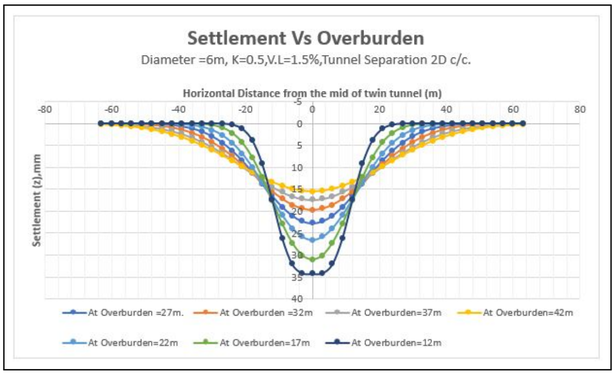

Figure 12: Settlement Vs Overburden Plot

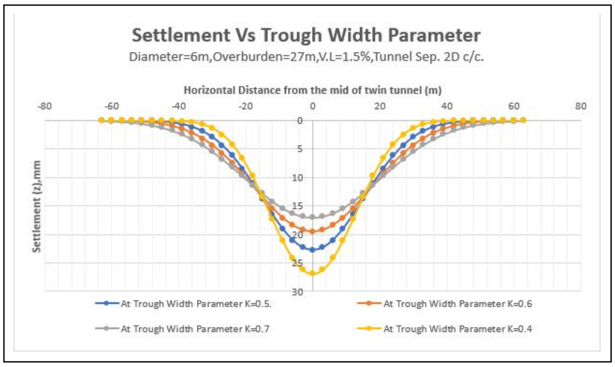

Figure 13: Settlement Vs Troughwidth Parameter

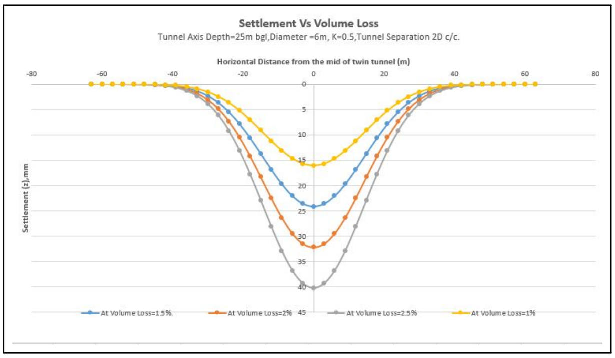

Figure 14: Settlement Vs Volume Loss

5. Conclusion

Kathmandu,being a synclinal basin with deposited silty-clay and clayey silt demands soft ground tunneling. This paper demonstrates that Kathmandu Metro Tunnel is technically feasible.Twin Tunnel of 6m internal diameter and precast segments of 30cm structural thickness is proposed at depth 30m in the station levels. On road underground twin tunnels are proposed to be separated at 2D(12m) center to center distance considering the existing roads of Kathmandu. Earth Pressure Balance(EPB)Tunnel Boring Machine(TBM) is proposed as per the insitu ground condition and particle size distribution curve [14].

Acknowledgement

The authors acknowledge MULTI Lab Disciplinary Consultants (P) Ltd. (Nepal) and Department of Railway, Nepal for their support.

References

[1] Karoly Szechy. *The art of tunnelling*. 1967.

[2] N Som. Geotechnical Challenges of Kolkata Metro Construction. 48(2):72–79, 2017.

[3] S Ponnuswamy and D Johnson Victor. *Transportation Tunnels*.

[4] Thomas R Kuesel, Elwyn H King, and John O Bickel. *Tunnel engineering handbook*. Springer Science & Business Media, 2012.

[5] Clough G Wayne Leca Eric. Preliminary design for NATM tunnel support in soil. 118(4):558–575, 1992.

[6] H Sakai, R Fujii, and Y Kuwahara. Changes in the depositional system of the paleo-kathmandu lake caused by uplift of the nepal lesser himalayas. *Journal of Asian Earth Sciences*, 20(3):267–276, 2002.

[7] Omkar M Shrestha, Achyuta Koirala, Busch Hanisch Jorg, Kentke Martin Klans, and Jager Stefn. Changes in the depositional system of the paleo-Kathmandu lake caused by uplift of the Nepal lesser Himilaya. *Geo Journal*, 1999.

[8] A G Bloodworth. Tunnelling and underground metro stations in the ground condition of Kathmandu. (May), 2020.

[9] Manendra Singh, Manohar Narayan, Viladkar Narendra, and Kumar Samadhiya. Seismic Analysis of Delhi Metro Underground Tunnels. *Indian Geotechnical Journal*, 2016.

[10] C Sagaseta. Madrid metro extension, 1995-99. soil deformation patterns by analytlcal solutlons. *Computers and Geotechnics*, 28:445–468, 2001.

[11] Anthony F Stirbys, Z Richard Radwanski, Richard J Proctor, and Richard F Escandon. Los Angeles metro rail project – geologic and geotechnical design and construction constraints. 51:203–224, 1999.

[12] Hyunku Park, Ju-young Oh, Dohyung Kim, and Seokbue Chang. Monitoring and Analysis of Ground Settlement Induced by Tunnelling with Slurry Pressure-Balanced Tunnel Boring Machine. 2018, 2018.

[13] E H Ghee and B T Zhu. Numerical analysis of twin road tunnels using two- and three- dimensional modelling techniques. (Nfg 2).

[14] Giovanni Barla and Sebastiano Pelizza. TBM TUNNELLING IN DIFFICULT GROUND CONDITIONS. 1993.