TUNNEL PILE INTERACTION & SETTELMENT ANALYIS OF PILES UNDER INFLUENCE OF TUNNEL USING PLAXIS 2D

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of

Master of Technology

In

Civil Engineering

(Geotechnical Engineering)

By

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CERTIFICATE

This is to certify that the project entitled "**TUNNEL PILE INTERACTION & SETTELMENT ANALYIS OF PILES UNDER INFLUENCE OF TUNNEL USING PLAXIS 2D"** submitted by **Mr. RISHIK KUMAR (Roll No. 2K20/GTE/15**) in partial fulfillment of the requirements for the award of Master of Technology Degree in Civil Engineering at **DTU** is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in this report has not been submitted to any other university/institute for the award of any degree or diploma.

Place: Shahbad, NewDelhi

Date:

Signature:

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RISHIK KUMAR

ABSTRACT

On each passing day competition for surface area/space is increasing in such situation to satisfy the target of sustainable development & utilization of subsurface/underground space turns out to be vital. Underground designs although being difficult, troublesome and uneconomical to develop, restricted only to just some special structures like tunnels, hydropower stations, mining, etc we are forced to use then urban areas due to lack surface space. Being said that we should also attract our attention that in a rising number of cases where a portion of public structures are likewise being built underground which is close to vicinity or near to the metro tunnels in urban areas for that reasons though it is effective and successful utilization of land and area ,this type of situation where existing structure is in the radius of influence of each other it poses a great threat for both the tunnel and surface structure. Hence, we can say that in urban/metropolitan areas or at any urban environment, it is very common to find tunnel having influence over an existing pile foundation and inevitably affecting or compromising the settlement of soil. Hence, this paper discusses the influence of newly built tunnel on the existing pile foundation using **FEM** (Finite Element Method), so the aim of this paper is to provide parametrical study to assess the extent of the settlement problem near piles. The numerical model which we have used to access the situation was modelled using **PLAXIS 2D** software. In which the plane strain model with 15 noded elements was defined therefore 2D plane strain approach was used to analyze the loading of pile rows & influence of tunnelling on the pile rows. There is a variation of position of tunnel corresponding to which the variation of the total displacement of pile is observed. Then these results are analyzed & as per which settlement criteria along with design guidelines are defined.

Keywords: tunnel; settlement; FEM; PLAXIS 2D; plane strain; pile rows

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LIST OF SYMBOLS

γ_{unsat}	**Unsaturated soil weight**
γ_{sat}	**Saturated soil weight**
ν	**Poisson ratio**
ψ	**Dilatancy angle**
e_{int}	**Initial void ratio**
e_{max}	**Maximum void ratio**
e_{min}	**Minimum void ratio**
u	**Displacement**
n	**Porosity**
G	**Shear modulus**
C_u	**Undrained Shear Strength**
c	**Cohesion**
Φ	**Friction Angle**
d	**Thickness**
E	**Youngs Modulus**
TBM	**Tunnel Boring Machine**
Q	**Shear Force**
K_0	**Earth Pressure Coefficient**
R_f	**Failure ratio**

CHAPTER 1: <u>INTRODUCTION</u>

1.1. Necessity of Construction Underground

For many years, our domain had been the outer layer of the ground. Demanded by the need & interest, we had generally attempted to build the structure on the outer surface of ground and looking for use of the leftover aspect in the remaining dimension or space either above the ground or below the ground. Being said that we would encounter great trouble, particularly in the process of going underground of course. But the space below the ground can give us the leniency to exercises activities required for building infrastructures which are required in the densely populated metropolitan urban communities i.e., metropolitan cities. Hence though the underground development works have forever been undeniably difficult but is the only choice to work with due to scarcity of land area. In any case, quick economic advancement in this century made us to take a dive into the depths of soil stratum deeper & deeper, motivated by various scenarios.

Now the major reasons for which legitimize utilization of the space underground are given as follows: -

a) **<u>Location & Area</u>: -**As of now, each metropolitan city is throwing away time and energy for finding or creating open spaces throughout the course of recent years. As a matter of fact, this absence of land over the surface isn't just the situation in metro urban communities yet in practically all urban areas all over the planet. It leaves us no choice except for to utilize the underground space in a more insightful and an efficient manner with a goal such that it takes the advantage of location which is being utilized.

b) **<u>Environmental Aspect:</u> -** In reality, an underground construction gives a some positive key points which are environmental friendly , in a way which is better than different structure/designs built on surface of the same area; these main issues are intriguing enough for us to pick the underground arrangement.The underground construction doesn't make actual physical barriers when crossing the land; the activity isn't impacted by atmospheric agents; ; less maintenance costs are required when compared with from surface structure;

the tunnel diminishes the length of the way offering the circumstances for energy related savings; (during the activity) the discharge of gas, noise, dust are gathered at the adits.

c) **Topographical Consideration: -** In uneven or hilly regions or metropolitan area the utilization of passages like tunnel improves or makes practical transport option like roads, railways, canals and so on. This is particularly evident with regards to the development of fast transportation lines, as low gradient and radius of curvature are required. Tunnels are a significant choice in river, waterways and harbour intersections, etc.

d) **Economic Consideration: -** The need for present day urban communities to foster proficient infrastructure keeps on delivering the choices for a deliberate use of the subsurface/underground space. In any case, the economic aspects of underground space usage are a critical parameter for the adoption of such sort of functions and framework over conventional surface arrangements. Moreover, a significant piece of the economic advantages of underground designs are inactive and are related with social and natural externalities, the standards of ecological financial aspects and presents case models where such advantages which are expressed in monetary related terms.

e) **Consideration for Isolation: - Soil** stratum is an fully opaque, infinitely spaced and provides us many benefits with regards to confinement/isolation. It can give security against outrageous extreme environment, seismic activity and other catastrophic natural events.

1.2 Shallow Tunnelling in Urban Environment

The main objective while planning to design a shallow tunnel in a metropolitan area is to limit the surface settlements induced by the tunnel. Thus, the face stability alongside the tunnel induced displacement are the critical variables to control the degree of the plastic zone formation and therefore to avoid the bothersome settlements on surface structure induced by the tunnel. To plan the tunnel design, the strategy for development to be taken on for the work's execution should be characterized. In the ongoing section, the standards for designing a Metro tunnel will be built with the help of **TBM** (Tunnel Boring Machine).

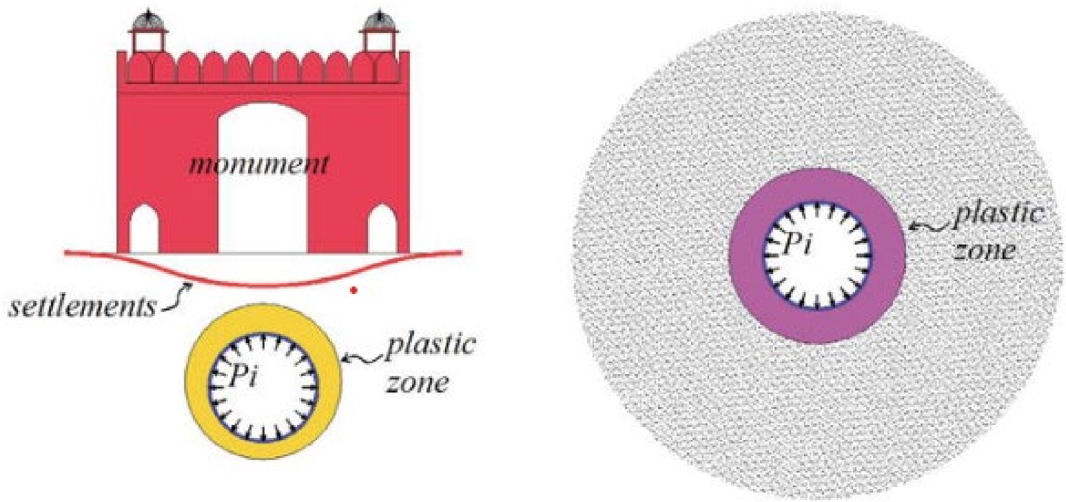


Fig. 1.1 **Settlement on Surface Structure due to Shallow Tunneling**

After the arrangement is fixed, the topographical and geotechnical conditions along the arrangement of any project are generally the primary information expected to further continue the design of tunnel. Information on the territorial geography of the area alongside geotechnical examination is obligatory to decide the ground properties for tunnelling process in which the TBM that gives immediate support across periphery and at front face simultaneously. The TBM both excavate and uphold both the tunnel periphery and the face simultaneously. Except for mechanical support machines, they all have the cutterhead chamber at the front, isolated by the remaining piece of the machine by a bulkhead, where a repression pressure is kept in control to effectively uphold the excavation and additionally balance the hydrostatic stress of the groundwater. The TBM is pushing ahead through pressure driven chambers that are pushing the all-around raised segmental lining.

1.3 Problem of Tunnel-Pile Interaction and Aim of the Project

Encountering an 'no-choice' situation, which requires a serious requirement of development of passage under extremely dense & thick metropolitan regions. Development & activity of the underground structure could cause harm on the surface structure as well as other structures underground. Consequently, the forecast of displacements of the surface structure induced by the passage of tunnel becomes an important issue in process of execution and design of tunnel. Hence there is a need of getting a better understanding of tunnelling induced settlement of the surface structure which will help us to reduce costs and furthermore also helps in resolving claims & disputes.

Fig. 1.2 **<u>Map of GAUTAM BUDDGA NAGAR (U.P.)/BOREHOLE Test Location</u>**

Aim of the study is to observe the effect of tunnel induced settlement on existing pile structure by varying the position of tunnel with respect to piles. To observe, tunnel pile interaction and tunnel induced settlement we will use **PLAXIS 2D** which will use **FEM** for calculation. The sub-soil condition/parameters are taken from **GAUTAM BUDDHA NAGAR District, (U.P.)** taken from a Geotechnical Investigation report created by **SAI GEOTECHNICAL ENGINEERS PVT. LTD**. This study concentrates on the use of the Mohr-Coulomb Drained Soil Model in the PLAXIS 2D which is a finite element software. The soil samples collected (from **BH-2**) are as follows: -

1. Light Brown Clayey Silt of Low Plasticity (ML-CL) (Depth of 0-4.5m)
2. Light Gray Silty Sand (SM) (Depth of 4.5-6.5m)
3. Light Gray Clayey Silt of Low Plasticity (ML-CL) (Depth of 6.5-13.5m)
4. Light Gray Clayey Silt of Low Plasticity (CL) (Depth of 13.5-19m)
5. Light gray Sandy Silt (ML) (Depth of 19-20.5m)
6. Light Gray Silty Sand (SM) (Depth of 20.5-30m).

CHAPTER 2: LITERATURE REVIEW

Schroeder, T. I. Addenbrooke, D. M. Potts & F. C. (2004)

This paper surveys the impact of loading of group of piles on an existing passage of tunnel utilizing FEM determined to work on the ongoing prohibitive guidelines. This approach is then used to access the reaction of a passage of tunnel to loading applied by the pile group found either on the two sides (case A) or on one side (case B) of the passage & then analysing and comparing results in both cases.

Poulos & H. G. (2011)

In this paper correlations are made between the computed & measured lateral and axial reactions of pile bearing a viaduct span of bridge in Singapore. Computed data values were acquired from programs that utilization worked on analyses of boundary element for lateral and axial reaction of piles, assimilating it with input free-field ground displacement got from approximating closed form of solutions. Adjacent twin passages of tunnel were built close to the vicinity of pile and estimations of bending moment & axial force in any two of the pile which were implemented for the study were inspected.

Wang, Hongyu (2020)

Displacement of soil due to excavation of tunnel work might cause extreme stress on the piles supporting a structure close to its vicinity. The circumstance is especially extreme in case of short piles supporting a structure of low height or old structures with the toes of piles situated over the excavation of passage of tunnel. In this paper and centrifuge model tests was directed to investigate the axial response of a solitary short piles situated at different position from the center of tunnel with volume loss of soft clay in undrained condition. The experimental outcomes uncover that the pattern of transfer of load along the shaft of pile varies with the separation from the centerline of tunnel.

Sohaei, Houman, Aminaton Marto & Eshagh Namazi, (2018)

This paper examines the adequacy of micropiles to control displacement induced in soil due to excavation of tunnel and as well as displacement induced in the existing pile, situated at one time the diameter of the tunnel passage. In laboratory model tests had been directed in dry sand of fifty percent of Relative Density utilizing a row of micropiles of 3·7 mm dia., with two unique lengths (110 and 145 mm), in the middle of between the passage of tunnel with an overburden ratio of 3 and the current piles at four distinct points.

Mahmood, Khalid, Hyung-Sik Yang & Won-Beom Kim (2011)

The development of shallow passages of tunnel in densely populated metropolitan areas will influence the surface structure close to the vicinity of the tunnel passage due to which displacement of soil is observed. This paper reports the result of a parametrical analysis on displacement of the surface structure due to the influence of passage of tunnel. The mathematical model utilized in this appraisal was FLAC 2D. In this review, the settlement of pile results was accessed on by changing the parameters of rock, for example, modulus, tensile strength, angle of friction at a location where piles are located.

Fall, Massamba, Becaye Cissokho Ndiaye & Zhengguo Gao (2021)

Driving of pile is a dynamic as well as complex interaction of pile with soil, which causes settlement on ground surface. This paper focuses on the produced ground vibrations can possibly harm the close by structures and could prompt conceivable unsettling influence of structure inhabitants. The wellbeing of structures underground during the determined cycle of pile driving is of critical concern. In this paper, two distinct standards were taken on to appraise the security of passage of tunnel adjoining the determined pile driving site. The process of driving pile establishment is continuous process from the ground surface to final depth of pile & hence was executed utilizing Arbitrary Lagrangian Eulerian (ALE) mesh & element elimination techniques.

Marshall, Twana Haji & Alec M (2015)

This paper presents results got utilizing a computationally productive analytic methodology which intends to understand the impact of introducing a newly excavated tunnel and its effect on existing pile structure. The strategy utilizes a "Spherical Cavity Expansion" method in order to accesses the End Bearing of piles, & Cylindrical Cavity Contraction to measure reduction of pile end bearing resistance impacted from volume loss of tunnel. This study utilizes distributed works published in past and by this method also considers the impact of position of tunnel location on pile-tunnel interaction by examination of changed potential assumption of stiffness of soil & also considering impact of cavity contraction of tunnel which have its impact on the friction of pile shaft.

Lueprasert, Prateep (2017)

This paper suggests an evaluation technique for tunnel induced deformations, which is determined using the max. contraction & extension of tunnel diameter with their respective axes w.r.t horizontal and vertical direction respectively. This method can suitably easily trace the change in diameter of tunnel & global deformation of lining of tunnel. Utilizing a 3D elastoplastic mathematical examination led for the investigation of the impacts of the adjoining piles close to the vicinity of tunnel by varying the tip positions of piles concerning to tunnel & layer of soil, the method proposed could capture response of distorted tunnel as a misshaped which is nearly elliptical. The examination of investigation result helps us in the evaluation of pile-tunnel-soil association component behind the distortion of tunnel behavior due to adjacent pile load.

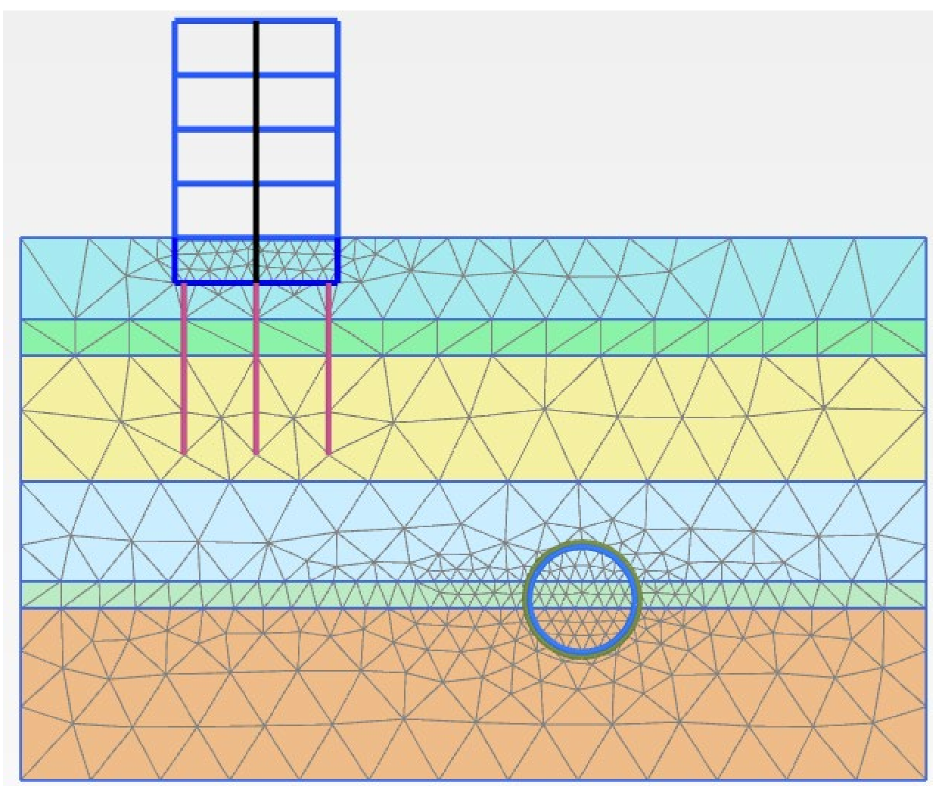
Meguid, Joe Mattar & Mohamed A. (2009)

This paper depicts the trial examination completed to inspect the impact of existing piles introduced in soil (cohesive in nature) which extends out to the bedrock on the peripheral stress creating a recently built tunnel upheld by a flexible lining. In laboratory a small-scale model was worked with, planned & executed in order to reproduce course of excavation of tunnel & lining establishment in nearby location of model of pile(preinstalled). The stress of lining was estimated for distance in between the tunnel lining and piles. Outcomes introduced in this paper showed that estimating lining reaction close to the pile foundation(existing) might be utilized to assess the degree of the association between encompassing pile & Lining.

CHAPTER 3: <u>METHODOLOGY</u>

3.1 Introduction:

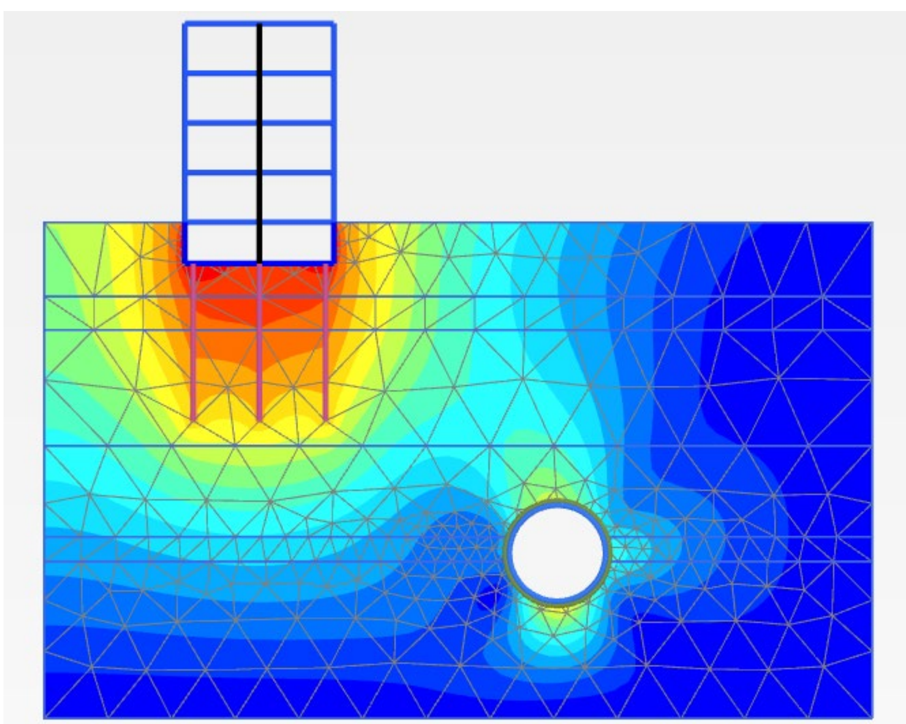
a.) <u>Finite Element Method (FEM):</u> - FEM is an mathematical procedure used to perform finite element analysis (FEA) of a material by defining it properties regarding to a particular phenomenon such as fluid flow or structural behaviour, heat flow, propagation of wave, growth of biological cells, etc. The important part is to utilize mathematical aspects in order to completely comprehend & evaluate any actual phenomena. Most of the processes, generally depicted utilizes partial differential equations (PDE). Nonetheless, for a computer to address these PDE, mathematical methods are created throughout the period of recent years and due to this fact, the most popular method in the current era is the FEM. When the equations of matrix have been laid out, the conditions are given to a solver for solving the system of equations. Depending on the problem type, iterative or immediate solvers are utilized for solving the FEM (Finite Element Method) by defining the boundaries. Before closing the discussion, a mathematical framework that is not suitable for some type of PDE equations is important to before utilizing the method. Such arrangements are also called as "IMPROPERLY POSED." Which means that the a small change in the domain boundaries can lead to enormous variation of results, or that the solution which will cease to exist in specific part of domain boundaries, which in any case are not reliable.



<u>Fig 3.1 Finite Element Mesh created on Material model using PLAXIS 2D</u>

b.) <u>PLAXIS 2D:</u> - It is a software which perform 2D investigation of deformity & stability in soils which is used for geotechnical designing and analysing rock mechanics by using FEM (Finite Element Method). Organizations & companies in Civil & Geotechnical Designing firms rely on PLAXIS for this enormous task. From embankments, mining, tunnelling, excavation, and reservoir, geotechnical engineer depends on the software (PLAXIS 2D) as they go for finite element analysis application. The predefined underlying structural component & stacking type in an CAD like environment, for quick & proficient creation of model permitting the user additional chance for intercepting of outcome by integrating the FEM and limit equilibrium analysis capacities of PLAXIS applications for the analysis and design of soil, rock, and related structures is performed. The properties of PLAXIS 2D software is defined as follows: -

- It can model diverse geotechnical problems.
- Makes FE (Finite Element) models rapidly and effectively.
- Simulates different types of rock and soil results.
- Accomplish reliably precise outcomes.
- Capacities for analysing the impacts of vibrations in the soil, for example, traffic loads and earthquakes.
- Can simulate complex hydrological, variation of water levels (time dependent) and capable of simulating flow function on boundaries of soil model.
- Can access and evaluate Dynamic Modelling, Groundwater Flow Analysis and Thermal Modelling. Evaluate the impact of transient flow of heat on the hydraulic and mechanical behaviour of soil.



<u>Fig 3.2 Soil Model Prepared using PLAXIS 2D Software</u>

3.2 Structural Elements & Soil Layer:

Present model of the problem comprises of an tunnel & existing building which have one underground floor of height of 2.5m and four stories above surface having height of 3m each, the length of piles are 9.5m & as far as tunnel is concerned it has a radius of 2.9m is excavated below the structure. The model has been modelled by the utilization of soil layers & structural components like beam, plate, anchor and embedded beam rows in PLAXIS 2D. The detail of the components are as following: -

1. **Soil Layers: -** Soil stratigraphy is defined in soil mode utilizing the borehole feature of PLAXIS 2D. Borehole is a particular specific location in the model of soil, at which data of the soil layers and the water table position is given. With the help of multiple boreholes variation in the soil layers could be defined. Pore pressures & Groundwater assume a major part in the behaviour of soil, this requires water conditions to be properly defined. The water conditions can be defined using boreholes.

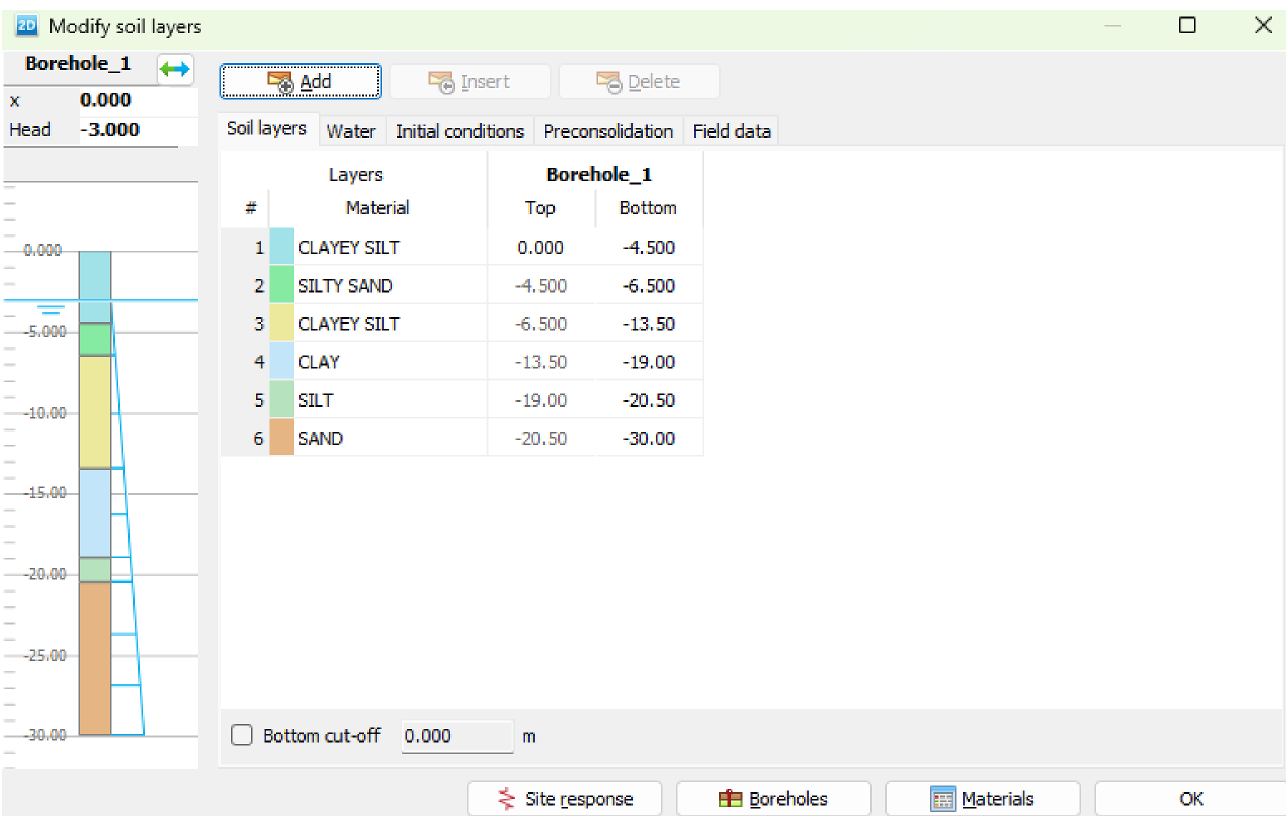


Fig 3.3 Soil Stratigraphy Modelled using PLAXIS 2D

2. **Embedded Beam Rows: -** An embedded beam row acts as a pile which is made up of components of beam which could be placed at any direction in the soil below the ground level & which creates an interface with the soil through the mean of predefined interaction element. The association might include resistance along the skin with end bearing resistance. The friction along the skin and the end bearing determined is relative.

3. **Node-Node Anchor:** - The node-node anchor is an component that is connected to the structure at one side & is fixed at the opposite side of structure. Node to Node anchors could also be utilized for modelling pile in a simple manner, for example without considering interaction between soil and pile. On the other hand, fixed end anchors could be utilized for simulating anchor to supporting retaining walls. In our case we have used node to node anchor to model column in the building structure.

4. **Beams: -** In PLAXIS 2D beams are underlying structural elements used for modelling thin 1-D structure with an significant rigidity of flexure (Bending Stiffness) & axial stiffness, defining of a beam (structural element) is similar to generating a geometry line in PLAXIS 2D.

5. **Plate: -** Plate is an structural elements used for modelling slender 2-D structure in the model with an significant rigidity of flexure. The modelling of a plate is like modelling of a geometry line or beam on PLAXIS 2D.

6. **Interfaces: -** Interface is a joint element which must be added to plates geogrids or type of structure to consider an appropriate modelling of structure-soil interaction. Interface might also be utilized to modelling, for instance the slender zone of intense shearing on the material at the contact between the plate & the encompassing soil. Interface can be made close on geogrid or plate component or between two volume of soils. Though the software can differentiate between soil and structure, but interface helps the software to differentiate between soil and structure easily and defining soil-structure interaction.

3.3 Procedure applied for Analysis and Simulation of Project:

Each model has a unique position defined for the tunnel with respect to piles the following flowchart explains the procedure adopted for each simulation. The **CONTRACTION** & **GROUTING** phases are used to define the movement of **TBM** (Tunnel Boring Machine) in the soil stratum below the existing structure. The **CONTRACTION** & **GROUTING** phases are used to define the movement of **TBM** (Tunnel Boring Machine) in the soil stratum below the existing structure axial contraction was 0.5% and grout pressure of -300KN/m² was taken.

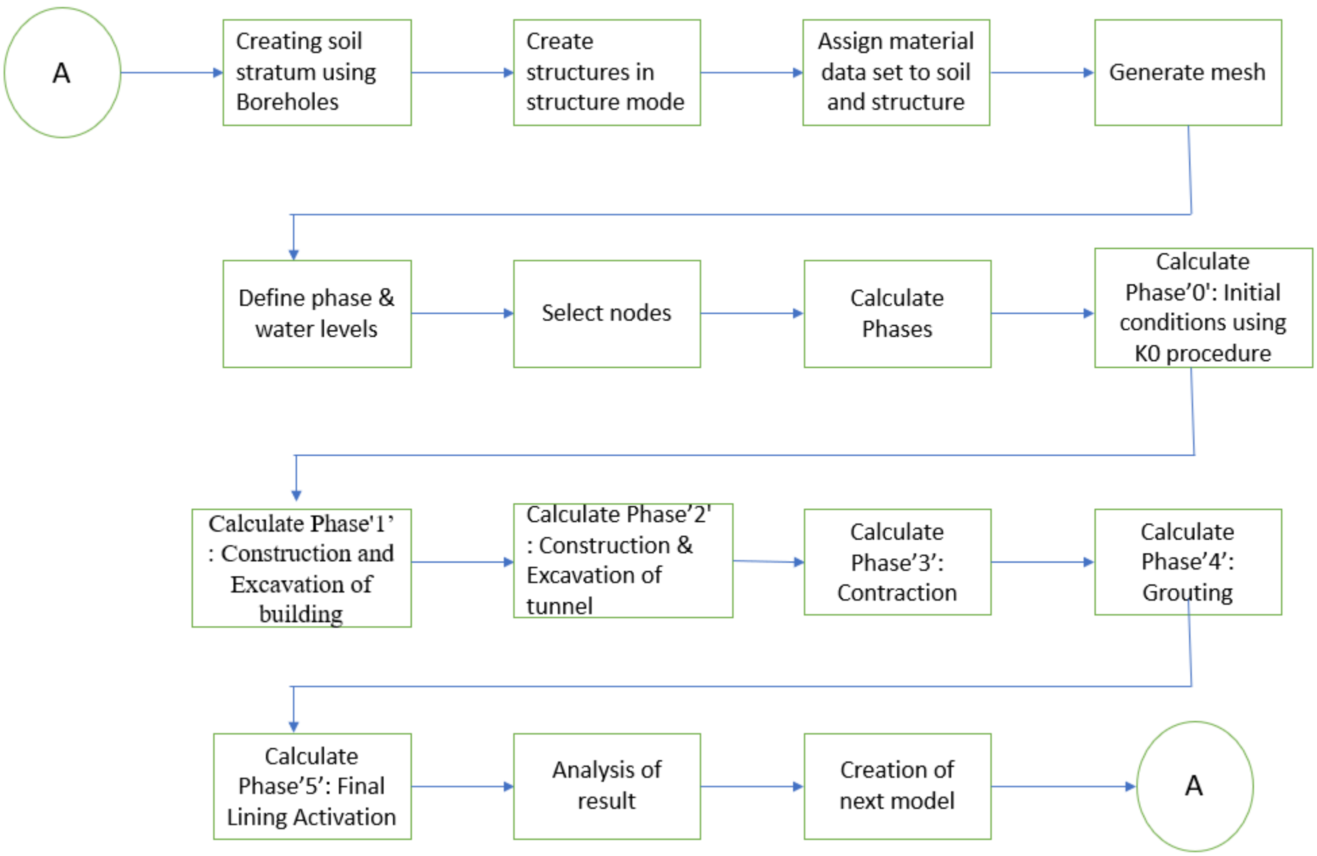


Fig. 3.4 Flowchart Explaining Procedure for Analysis and Simulation of Project

3.4 Details of Current Model

The sub-soil condition/parameters are taken from **GAUTAM BUDDHA NAGAR DISTRICT, U.P.** taken from a geotechnical investigation report created by **SAI GEOTECHNICAL ENGINEERS PVT. LTD**. This study concentrates on the use of the Mohr-Coulomb Drained Soil Model modelled in the PLAXIS 2D software. The soil samples collected (from **BH-2**) are as follows: -

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The model comprises of a tunnel and existing building which have one underground floors of height of 2.5m and four stories above surface having height of 3m each, the length of piles are 9.5m & as far as tunnel is concerned it has a radius 2.9m is excavated below the structure.

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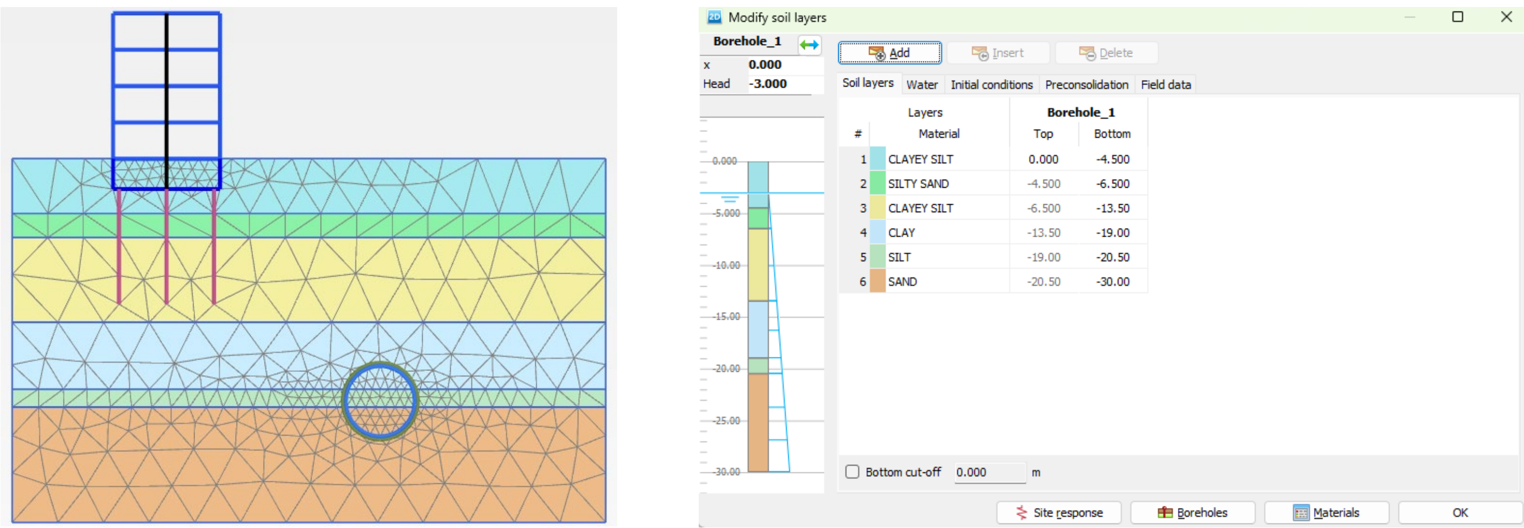


Fig. 3.5 Soil Stratigraphy Defined for the Model

TYPE OF SOIL	Depth (m)	γ_{unsat} (kN/m³)	γ_{sat} (kN/m³)	$e_{initial}$	e_{min}	e_{max}	ν	E (kN/m²)
1. Light Brown Clayey Silt of Low Plasticity (ML-CL)	0-4.5	17.07	19.22	.5	0	999	.3	8500
2. Light Gray Silty Sand (SM)	4.5-6.5	17	19.2	.5	0	999	.3	8400

3. Light Gray Clayey Silt of Low Plasticity (ML-CL)	6.5-13.5	18.83	19.24	.721	0	999	.3	7200
4. Light Gray Clayey Silt of Low Plasticity (CL)	13.5-19	19.62	20.05	.599	0	999	.3	8400
5. Light gray Sandy Silt (ML)	19-20.5	19.6	19.87	.599	0	999	.3	10200
6. Light Gray Silty Sand (SM)	20.5-30	19.6	19.9	.599	0	999	.3	11400

TABLE-1 MATERIALS-SOIL AND INTERFACE

IDENTIFICATION	**NODE TO NODE ANCHORS-COLUMNS**
Material type	Elastic
EA (kN)	2.5×10^{6}
$L_{spacing}$	2.0 m

TABLE-2 MATERIAL-COLUMN/NODE TO NODE ANCHOR

IDENTIFICATION	**UNITS**	**BUILDING**	**BASEMENT**	**TUNNEL LINING**
MATERIAL TYPE	-	ELASTIC	ELASTIC	ELASTIC
EA_1	kN/m	9.0×10^{6}	12.0×10^{6}	14.70×10^{6}
EA_2	kN/m	9.0×10^{6}	12.0×10^{6}	14.70×10^{6}
EI	kNm^2/m	67.50×10^{3}	160.0×10^{3}	143.0×10^{3}
d	m	0.3	0.4	0.314
w	KN/m/m	8	20	8.4

ν	-	0	0	0.15

TABLE 3 MATERIALS– PLATES

IDENTIFICATION	UNITS	EMBEDDED BEAM ROWS/PILES
E	kN/m^2	29.58×10^6
γ	kN/m^3	23
Beam Type	_	Predefined
Predefined Beam Type	_	Massive Circular Beam
Diameter	m	1.00
A	m^2	0.7854
I	m^4	0.04909
$L_{spacing}$	m	3.00
Axial Skin Resistance	kN/m	Layer Dependent
Base Resistance	kN	600

TABLE 4 MATERIALS-EMBEDDED BEAM ROWS

3.5 Model Design

The models have been divided into three categories which depends on central position of the tunnel with respect to piles (i.e. from the nearest pile) which are as follows: -

a) Variation of tunnel in Y-Axis with respect to piles keeping X=8m (from Nearest Pile to centre of tunnel).
b) Variation of tunnel in X-Axis with respect to piles keeping Y=10m (from Nearest Pile to centre of tunnel).

c) Variation of tunnel in Y-Axis with respect to piles keeping X=14m (from Nearest Pile to centre of tunnel).

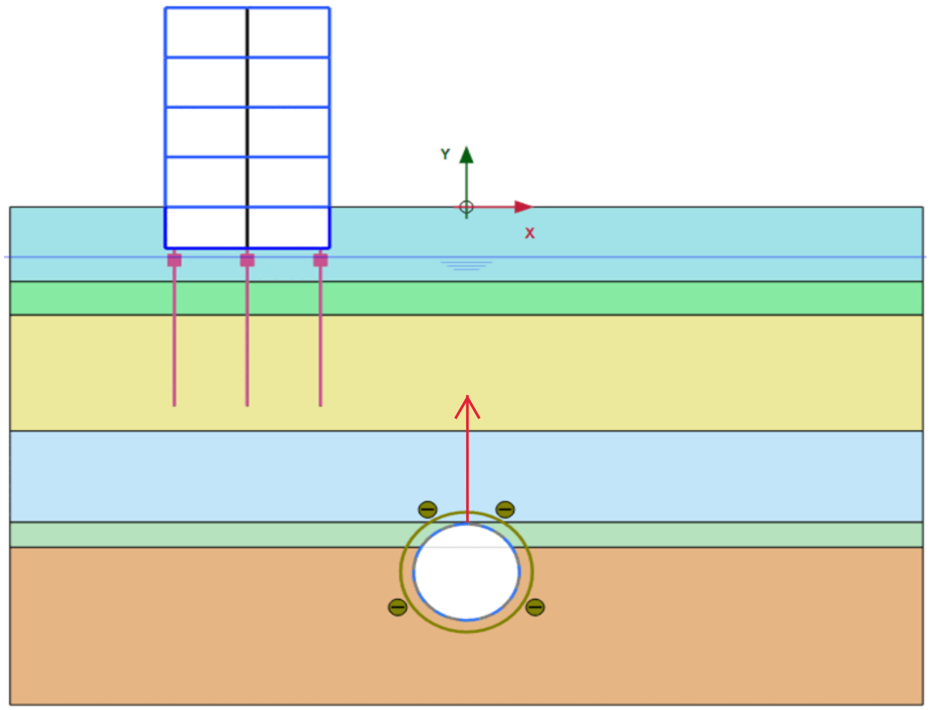


Fig. 3.6 Variation of tunnel in Y-Axis with respect to piles keeping X=8m

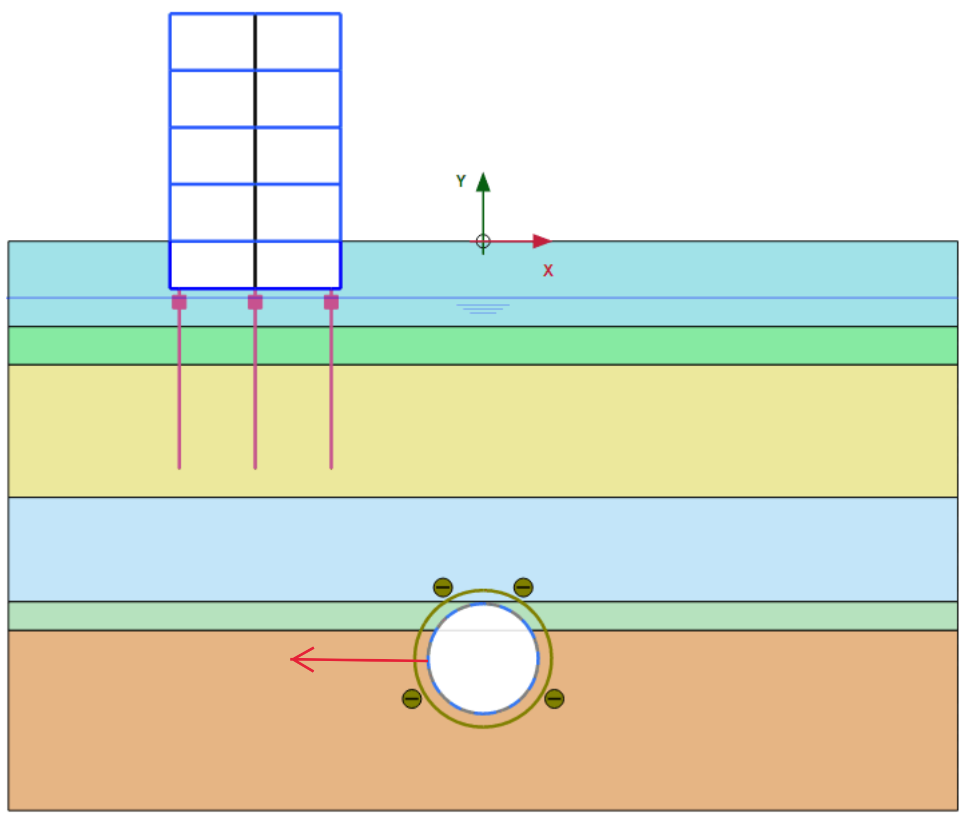


Fig. 3.7 Variation of tunnel in X-Axis with respect to piles keeping Y=10m

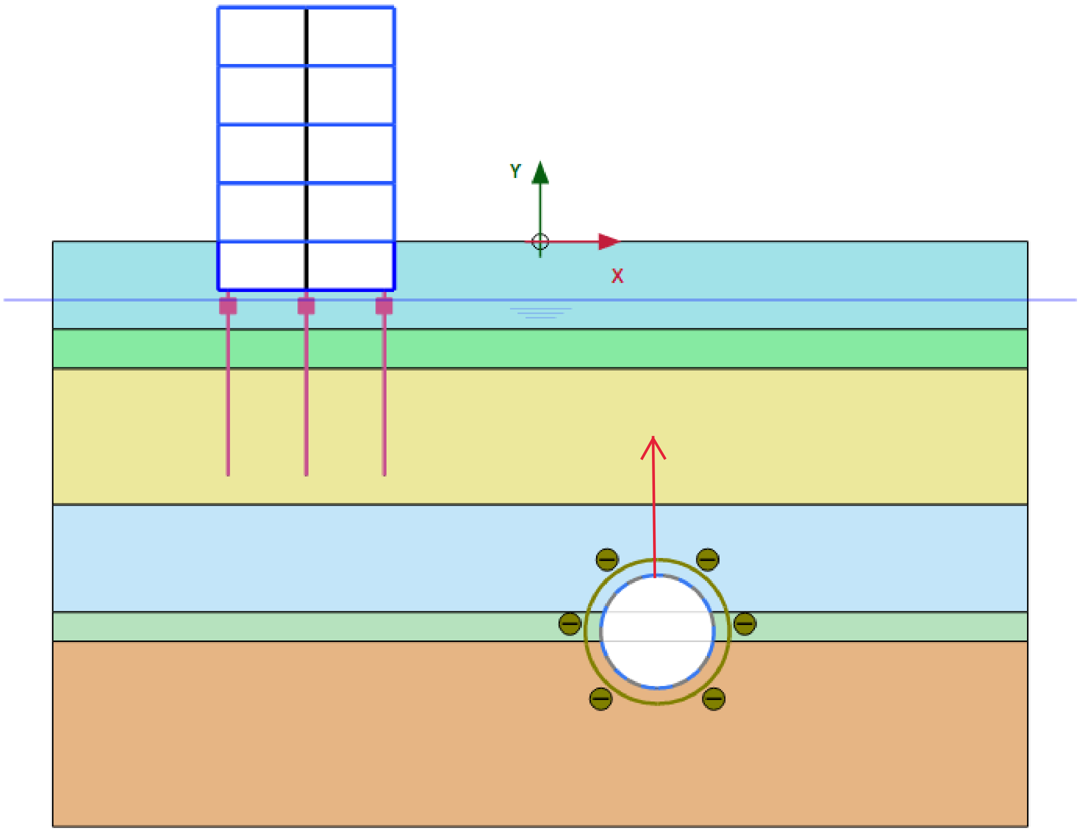


Fig. 3.8 Variation of tunnel in Y-Axis with respect to piles keeping X=14m

S. No	From Center of Tunnel to Nearest Pile X(m)	From Center of Tunnel-Ground Surface Y (m)
1.	8	-22
2.	8	-20
3.	8	-18
4.	8	-16

5.	8	-14
6.	8	-12
7.	8	-10

TABLE 5 a.) Variation of tunnel in Y-Axis with respect to piles keeping X=8m

S. No	**From Center of Tunnel to Borehole X(m)**	**Vertical Distance Between Centre of Tunnel to Nearest Pile Y (m)**
1	0	-10
2	-2	-10
3	-4	-10
4	-6	-10
5	-8	-10
6	-10	-10
7	-12	-10
8	-14	-10

TABLE 5 b.) Variation of tunnel in X-Axis with respect to piles keeping Y=10m

S No.	From Center of Tunnel to Nearest Pile X(m)	From Center of Tunnel-Ground Surface Y (m)
1	14	-22
2	14	-20
3	14	-18
4	14	-16
5	14	-14
6	14	-12

TABLE 5 c.) Variation of tunnel in Y-Axis with respect to piles keeping X=14m

CHAPTER 4: RESULTS AND DISSCUSSION

The cases for which model were prepared are as follows: -

a.) Variation of tunnel in Y-Axis with respect to piles keeping X=8m
b.) Variation of tunnel in X-Axis with respect to piles keeping Y=10m
c.) Variation of tunnel in Y-Axis with respect to piles keeping X=14m

4.1 Variation of total settlement of pile with variation tunnel in Y-Axis at X=8m (Nearest Pile)

S. No	**X-Axis (m) Nearest Pile**	**Y-Axis (m)**	**Total Settlement of Structure without Tunnel (m)**	**Total Settlement of Structure with Tunnel (m)**	**Total Settlement of Structure with Tunnel before Grouting (m)**	**Total Settlement of Piles with Tunnel**
1	-8	-22	0.06132	0.07047	0.06130	0.06816
2	-8	-20	0.06132	0.06527	0.06055	0.06221
3	-8	-18	0.06132	0.06043	0.06030	0.05806
4	-8	-16	0.06132	0.05606	0.05606	0.05373
5	-8	-14	0.06132	0.05756	0.06045	0.05506
6	-8	-12	0.06132	.1448	0.06074	.05328

7	-8	-10	0.06132	FAILS	_	FAILS

TABLE 6 MAXIMUM TOTAL DISPLACMENT OF PILES WITH VARIATION OF TUNNEL

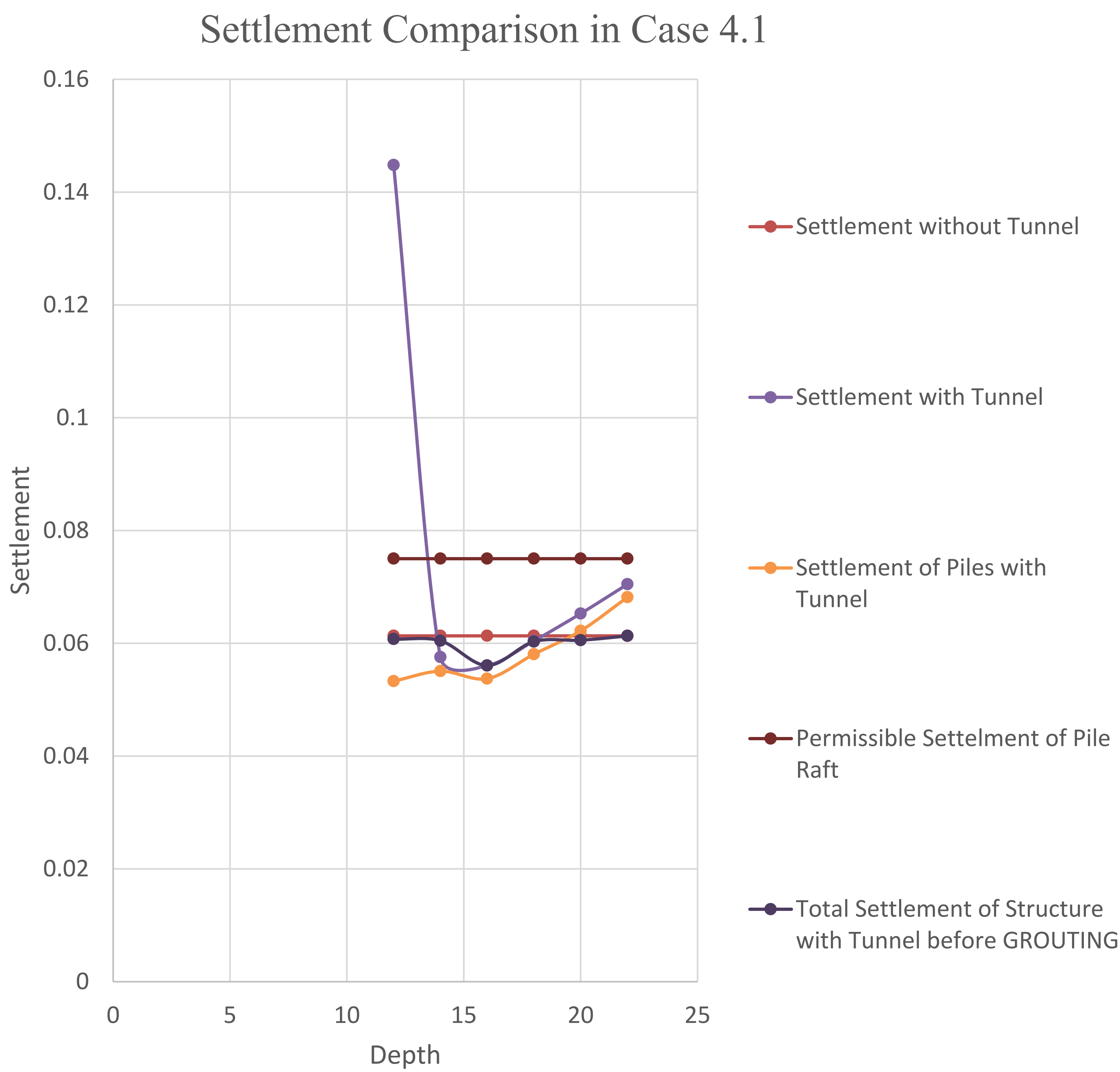


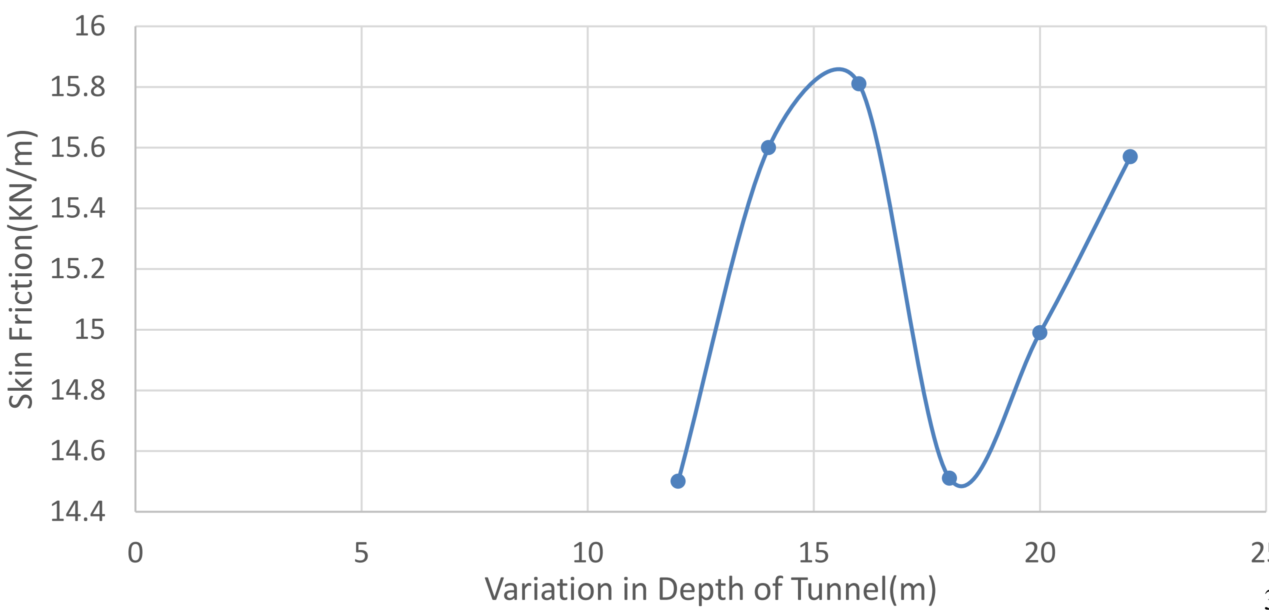
Fig. 4.1 Total Settlement of pile with Variation of Tunnel in Case 4.1

From the graph we can observe that settlement of the piles is exceeding the permissible limit after grouting phase in which it crosses the permissible limit only when the tunnel is at 12 m depth & except the grouting phase the settlement of pile is controlled in every other case.

4.2 Variation of total skin friction of pile with variation tunnel in Y-Axis at X=8m (Nearest Pile)

S No.	X-Axis (m) Nearest Pile	Y-Axis (m)	Skin Friction KN/m (Max. Value)
1	-8	-22	15.57
2	-8	-20	14.99
3	-8	-18	14.51
4	-8	-16	15.81
5	-8	-14	15.60
6	-8	-12	14.50

TABLE 7 SKIN FRICTION VARIATION OF PILES WITH VARIATION OF TUNNEL IN 4.2



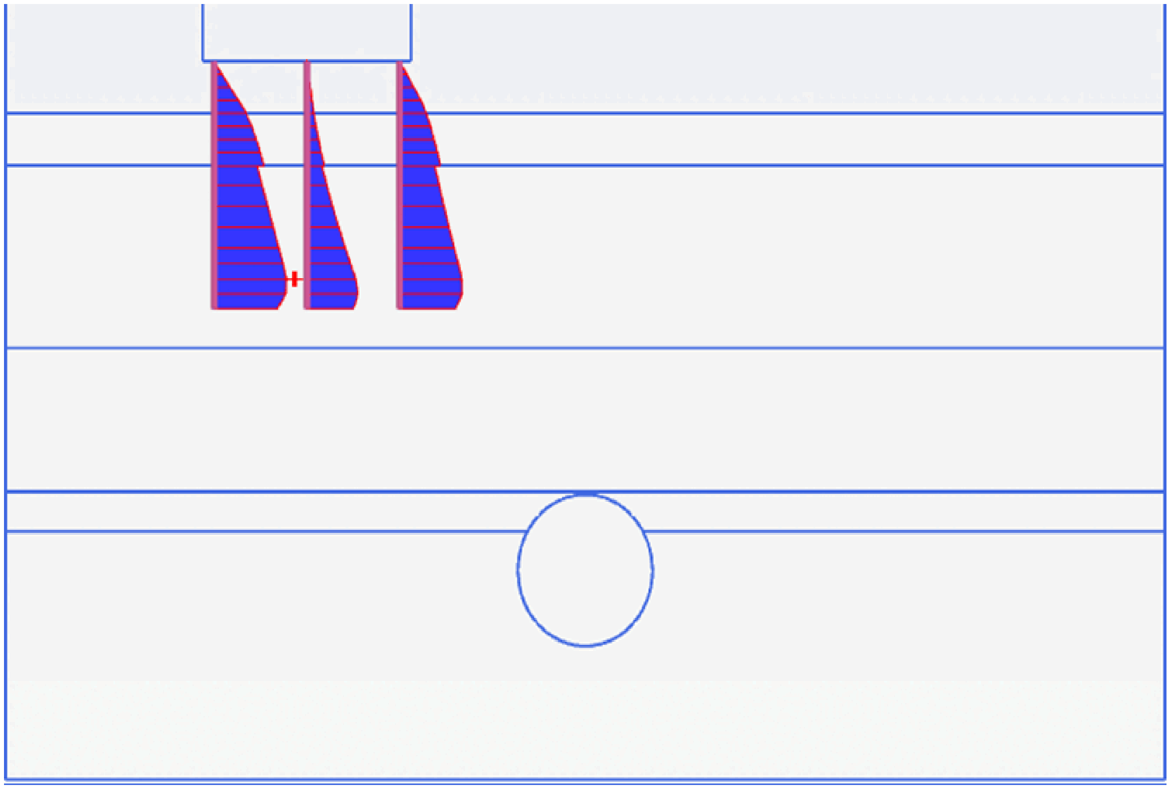


Fig. 4.2 Total variation Skin Friction of pile with Variation of Tunnel in Case 4.2

Fig. 4.3 Skin Friction Variation in Case 4.2

4.3 Variation of total settelment of pile with variation tunnel in Y-Axis at X=14m (Nearest Pile)

S No.	X-Axis (m) Nearest Pile	Y-Axis (m)	Total Settlement of Structure without Tunnel (m)	Total Settlement of Structure with Tunnel before GROUTING (m)	Total Settlement of Structure with Tunnel (m)	Total Settlement of Pile with Tunnel(m)
1	14	22	0.06132	0.06037	0.06431	0.05968
2	14	20	0.06132	0.06144	0.06175	0.05897
3	14	18	0.06132	0.06027	0.05874	0.05949

4	14	16	0.06132	0.06187	0.05952	0.05668
5	14	14	0.06132	0.06043	0.05726	0.05616
6	14	12	0.06132	0.06243	0.06191	0.05896

TABLE 8 MAXIMUM TOTAL DISPLACMENT OF PILES WITH VARIATION OF TUNNEL IN 4.3

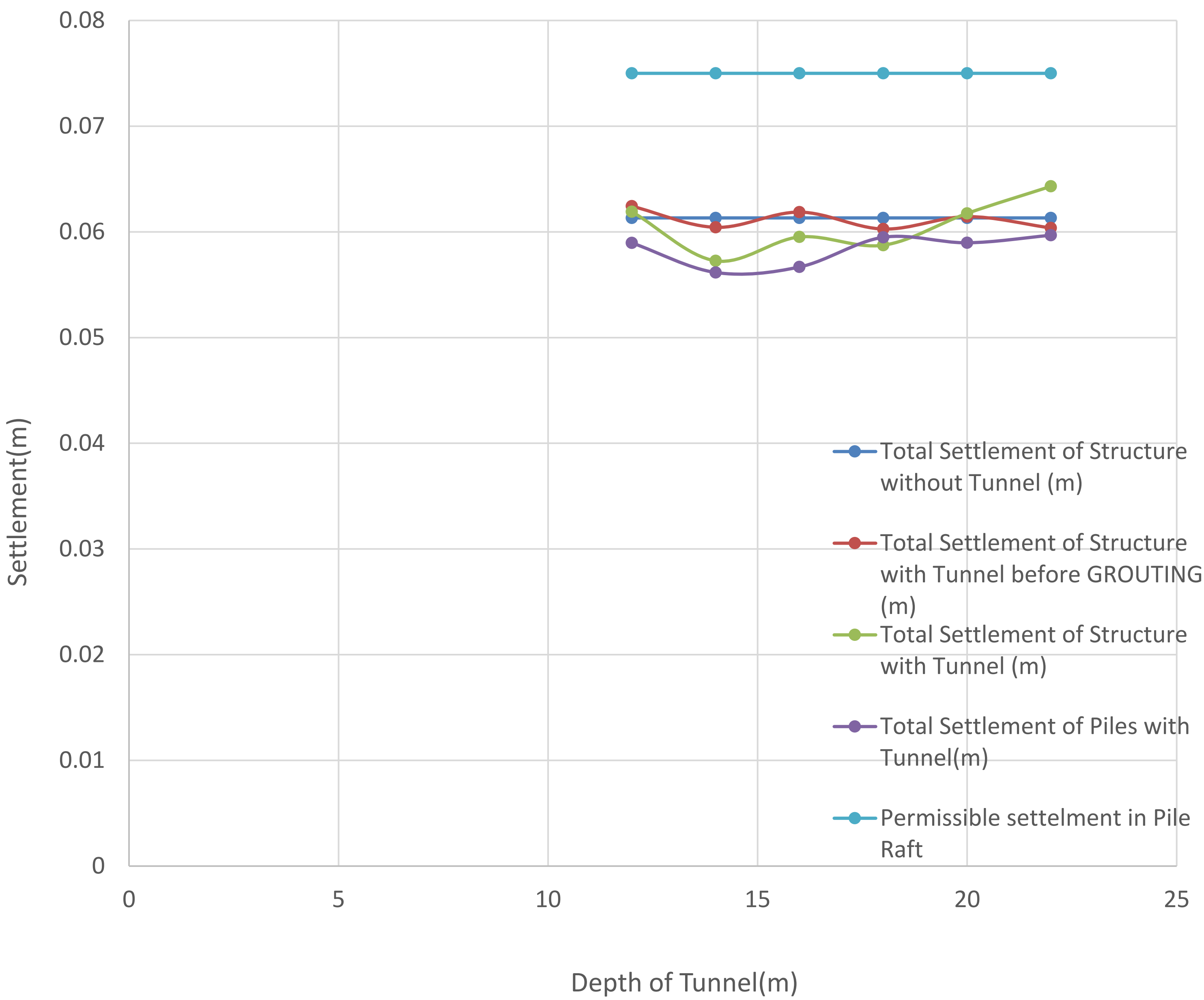


Fig. 4.4 Total Settlement of pile with Variation of Tunnel in Case 4.3

From the graph we can observe that settlement of the piles is not exceeding the permissible limit even in grouting phase not only in any case any value crosses the permissible limit but the value in each sufficiently less than the permissible value which means as tunnel distance increases with respect to piles the tunnel induced settlement also decreases.

4.4 Variation of total skin friction of pile with variation tunnel in Y-Axis at X=14m (Nearest Pile)

S No.	X-Axis (m) Nearest Pile	Y-Axis (m)	Skin Friction KN/m (Max. Value)
1	14	22	14.23
2	14	20	14.40
3	14	18	14.55
4	14	16	14.55
5	14	14	14.23
6	14	12	14.36

TABLE 9 SKIN FRICTION VARIATION OF PILES WITH VARIATION OF TUNNEL IN 4.4

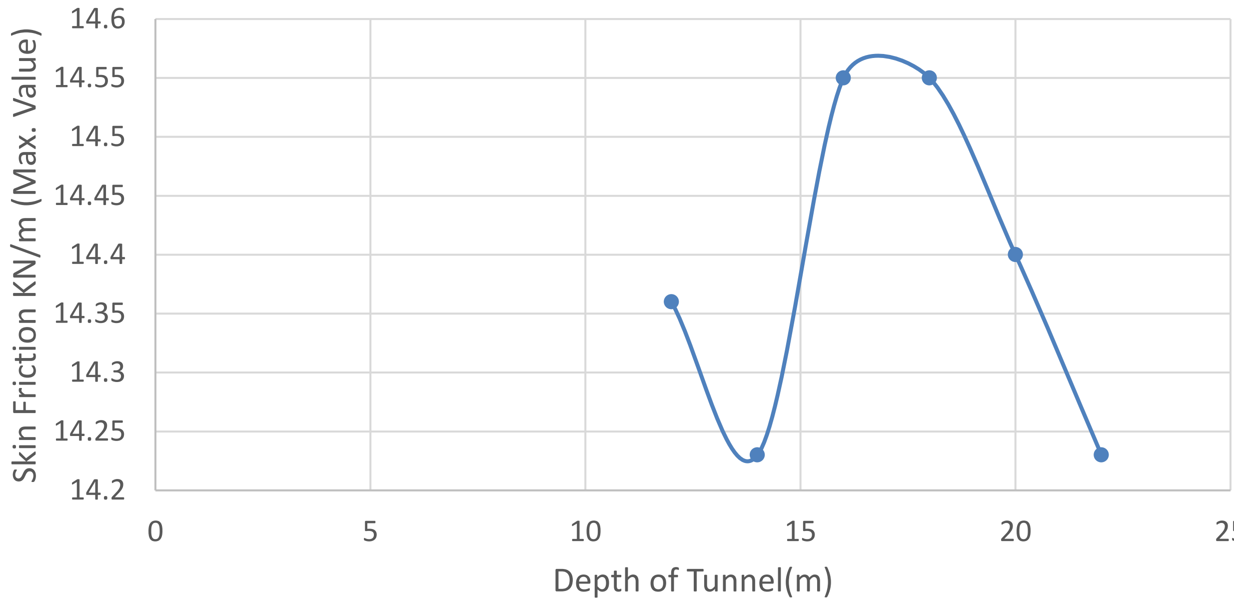


Fig. 4.5 Total variation Skin Friction of pile with Variation of Tunnel in Case 4.4

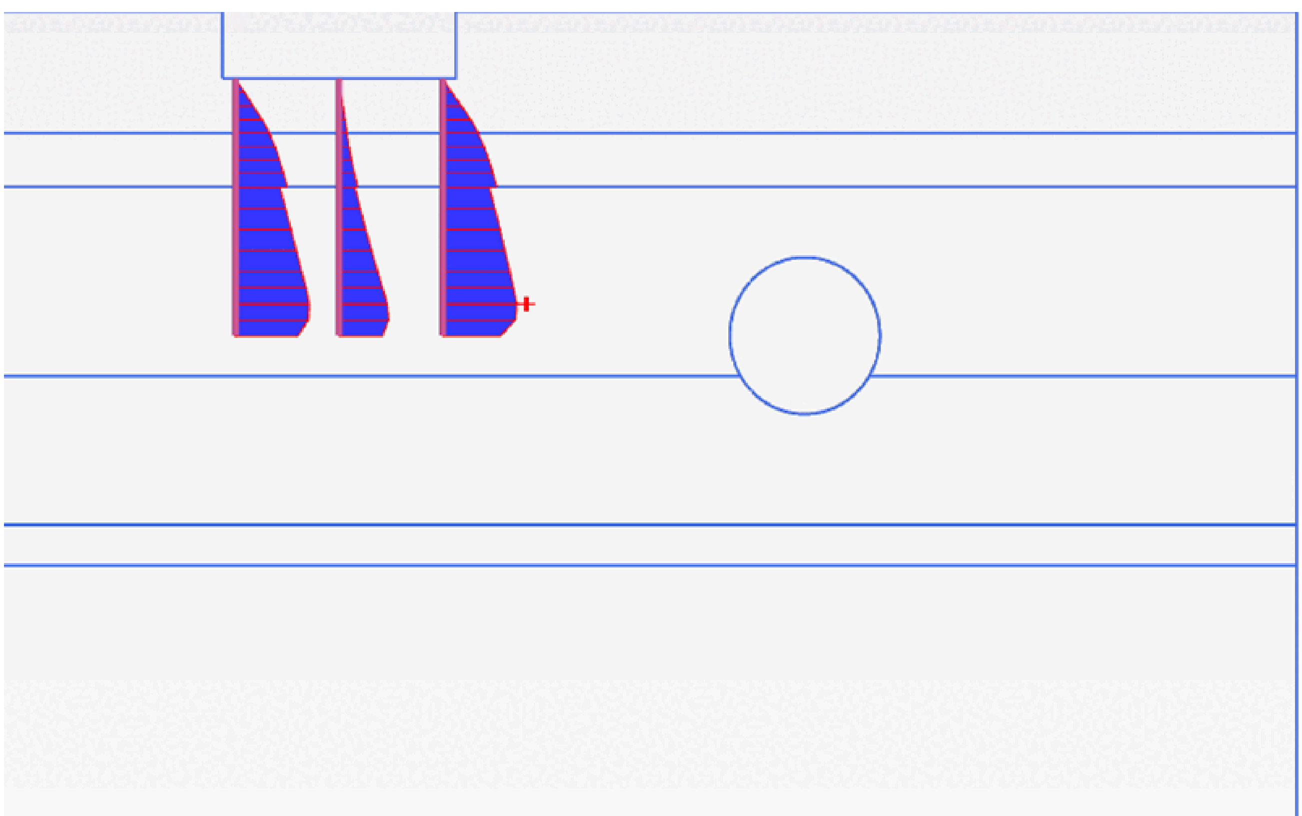


Fig. 4.6 Skin Friction Variation in Case 4.4

4.5 Variation of total settelment of pile with variation tunnel in X-Axis at Y=10m (Nearest Pile):

S. No	X-Axis(m)	Y-Axis(m) Nearest Pile	Total Settlement of Structure without Tunnel (m)	Total Settlement of Structure with Tunnel before GROUTING (m)	Total Settlement of Structure with Tunnel (m)	Total Settlement of Piles (m)
1	0	-10	0.06132	0.06130	0.07047	0.06816
2	-2	-10	0.06132	0.06114	0.07400	0.07125
3	-4	-10	0.06132	0.06100	0.07823	0.07466
4	-6	-10	0.06132	0.06086	0.08249	0.07795
5	-8	-10	0.06132	0.06074	0.08640	0.80510
6	-10	-10	0.06132	0.06063	0.08953	0.08434
7	-12	-10	0.06132	0.06054	0.09157	0.08784
8	-14	-10	0.06132	0.06047	0.09456	0.09000

TABLE 10 MAXIMUM TOTAL DISPLACMENT OF PILES WITH VARIATION OF TUNNEL IN 4.5

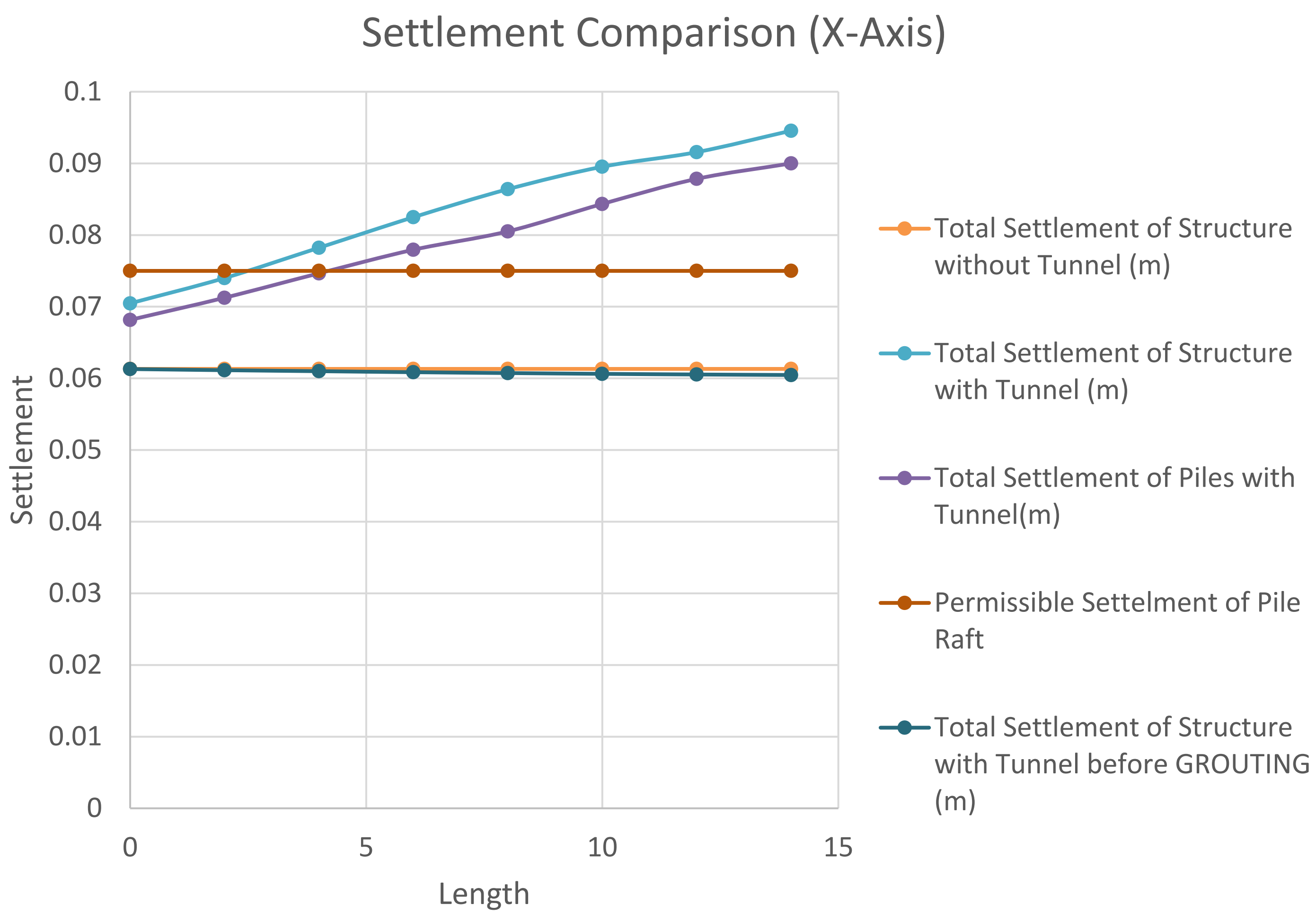


Fig. 4.7 Total Settlement of pile with Variation of Tunnel in Case 4.5

4. 6 Variation of total skin friction of pile with variation tunnel in X-Axis at Y=10m (Nearest Pile)

S No.	X-Axis(m)	Y-Axis (m) Nearest Pile	Skin Friction KN/m (Max. Value)
1	0	-10	15.57
2	-2	-10	15.98
3	-4	-10	16.35

4	-6	-10	16.55
5	-8	-10	14.27
6	-10	-10	14.29
7	-12	-10	14.54
8	-14	-10	15.07

TABLE 11 SKIN FRICTION VARIATION OF PILES WITH VARIATION OF TUNNEL IN 4.6

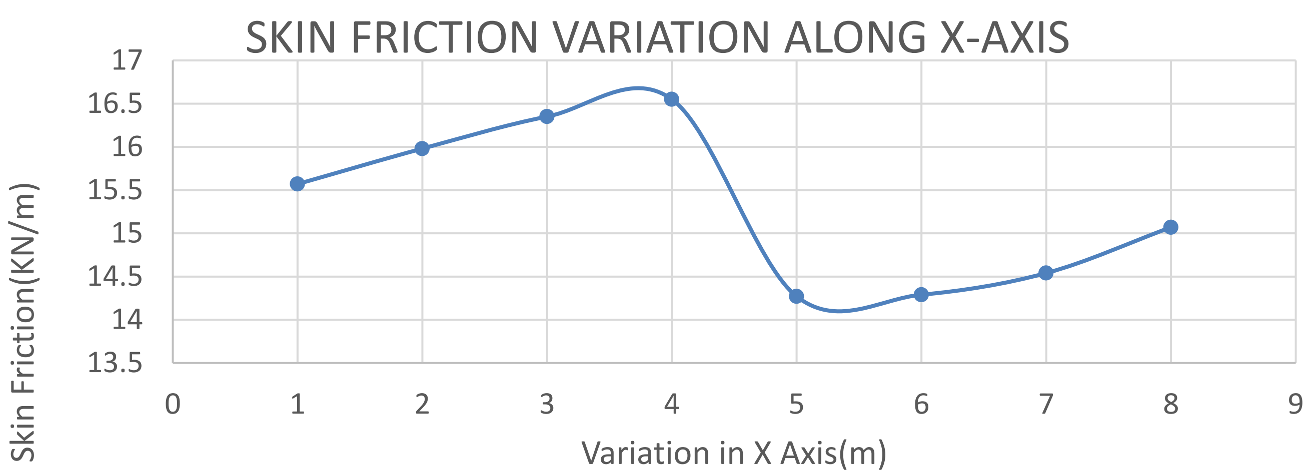


Fig. 4.8 Total variation Skin Friction of pile with Variation of Tunnel in Case 4.6

CHAPTER 5: FUTURE SCOPE OF STUDY & CONCLUSIONS

5. 1 Conclusions:

In many situations, in order to cope the heavy loads of multi-storied building the arrangement of pile foundation becomes vital. Yet, in near future, this pile foundation at sufficient depth might get impacted by recently constructed tunnel passing nearby, so to foresee impact of such passage of newly built tunnel on pile foundation becomes important. The project deals mainly with the analysis of such pile foundation affected under influence of the passage of tunnel on the existing structure by utilizing of FEM (Finite Element Method) with the help of PLAXIS 2D software. After an in-depth analysis of results the following points could be concluded/drawn out: -

a) The piles foundation of the building structure is impacted by the passage of tunnel only when the passage of tunnel is very close to the vicinity of the pile foundation and the impact of passage of tunnel becomes irrelevant whenever the tunnel is situated far away from the building structure.
b) The skin friction of the piles is also impacted by the passage of tunnel below the building structure or near to the pile the variation of skin friction in each case is neither linear nor uniform, but the variation of skin friction observed can be approximated to a sinusoidal behaviour thought magnitude wise it very less when compared so skin friction does not get much variation when compared to settlement.
c) When the passage of tunnel is allowed below the existing structure then the settlement of piles crosses permissible in various position of where the passage of tunnel is allowed from which we can conclude if the passage of tunnel is just below the existing structure failure due settlement for both structure and tunnel might happen. The crossing of permissible limit is only after the grouting before that the settlement are below the permissible limit.

5.2 Future Scope of study:

This work could be extended by taking some extra considerations to get better results which are as follows: -

a) The analysis of effect of tunnel passage on existing piles was completed without the consideration of dynamic forces & vibration caused by the passage of tunnel on existing piles. Considering these dynamic portions in account the model could be made more practical to obtain great outcomes.
b) The Project was made using PLAXIS 2D so trajectory of tunnel is not taken into account the sequencing phase of tunnel is not that accurate & the increment of axial contraction is also not taken into account in order take all these condition into account PLAXIS 3D software must be used for achieving accurate results.

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