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Effects of Tunneling On Existing Pile Foundation

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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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I. INTRODUCTION

The expansion of cities and urban areas is resulting in an increased demand for environmentally and economically sustainable transport and services infrastructure (e.g water, waste, etc). Underground construction and infrastructure that often require the excavation of tunnels represent an ideal solution to satisfy these needs. However, tunnel construction is increasingly taking place in close proximity to buried and surface structures. If protective measures are not adopted, tunnelling inevitably affects existing structures because of the induced ground movements and stress relief, with serious potential for damage. On the other hand, the use of protection measures, such as compensation grouting, increases the costs associated with the project. Therefore, to optimize the design of tunnel excavations (which involves assessing tunnelling-induced greenfield soil movements, the deformations induced on structures resulting from soil-structure interactions, and the risk of failure) engineers need to be able to accurately estimate the response of structures, foundations, and infrastructure to tunnelling.

This project used geotechnical centrifuge modelling as the main research tool. Geotechnical centrifuge modelling offers an efficient and cost-effective way to study tunnelling and soil-structure interaction (SSI) problems: it can provide high-quality data from experimental parametric studies, enabling isolation of simplified domains to gain understanding of individual.

1.2 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.

1.3 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).

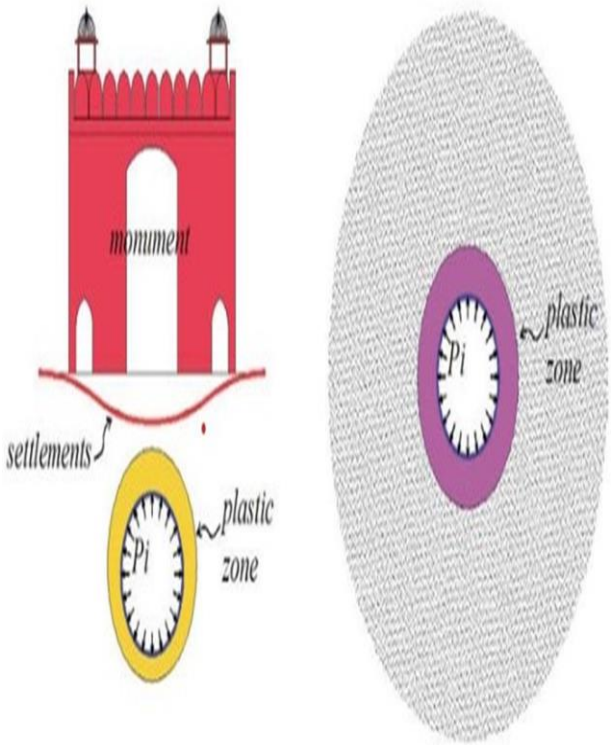

Fig. 1.1 Settlement on Surface Structure due to Shallow Tunneling

1.4 Tunnel stability

The problem of tunnel stability is particularly relevant at the tunnel heading where a portion of the soil is unsupported, if the temporary/permanent linings have not yet been placed, or only partially supported. To simplify a generally complex scenario depending on several technological and design aspects, engineers model the stability problem through the following parameters: the length of unsupported excavation (P), the cover to diameter ratio (C/D) or the depth to the tunnel axis (zt), surface surcharge pressure (σs), the unit weight of the overburden material (γ), the soil strength, water pressure, and tunnel support pressure achieved with compressed.

1.5 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.

II. LITERATURE REVIEW

1.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 analyzing and comparing results in both cases.

2. 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.

3. 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.

4. 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.

5. 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.

6. 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**.**

7 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.8. The article writes by Tsekeris and Geroliminis (2013**)** uses the "macroscopic fundamental diagram" (MFD) to analyze the relation between traffic and land use applied to a concentric city.

9. 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.

10. 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.

III. Theoretical Developement

3.1 **Finite Element Method (FEM):**

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.

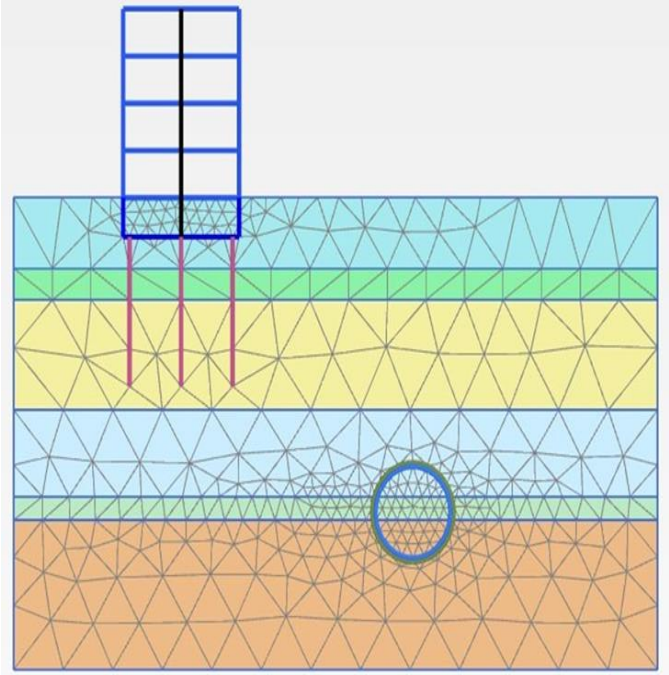

Fig 3.1 Finite Element Mesh created on Material model using PLAXIS 2D

3.2 PLAXIS 2D

It is a software which perform 2D investigation of deformity & stability in soils which is used for geotechnical designing and analyzing 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.

3.3 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.
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.

IV. Result & Conclusion

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

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

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

V. 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**.**

5.2 Future Scope of study:

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.

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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