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EFFECT OF SURFACE & SUBSURFACE STRUCTURE DUE TO UNDERGROUND TUNNELLING IN A MEGA CITY

MR. SUMIT GHANGUS[1], DR. TAUHIDUR RAHMAN[2]

1. M.Tech Scholar, National Institute of Technology, Silchar Department of Civil Engineering, NIT, Silchar, Assam, India
2. Prof. in Civil Engineering Department, National Institute of Technology, Silchar Department of Civil Engineering, NIT, Silchar, Assam, India

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Abstract: In the present study, the effect of surface structure due to the construction of underground tunnelling has been thoroughly examined. In our day to day life it is found that the ground surface space becoming a major factor of concern in every major cities in the world due to increase of population and vehicles. But the land or the pre-existing structures available in the major cities are fixed. With this in demand, the construction of underground Tunnels has become the only alternative way of providing passages to the people in a major city. Due to under tunnelling in metropolitan cities, it makes a problem of major concern regarding the safety of the presence of pre-existing structures. In the present paper, how to select the location of underground tunnel in a major cities along with the existing structures have been thoroughly studied. The effect of the surface structures located on an underground tunnel has been discussed in detail. In the present article, we have also addressed the issue of the effect of different type of soil through which underground tunnel has to be constructed. Based on the soil factor and the pre-existing structure in the cities, a safe line has been proposed below the ground line through which the underground tunnel may be proposed without hampering the surface structures.

Keywords: Underground Tunnels, pre-existing structures, safe line, soil factor, hampering the structures, major cities.

Corresponding Author: MR. SUMIT GHANGUS

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INTRODUCTION

In this paper, we are taking a building frame structure with pile foundation in weathering rock soil type. The focus of our studies is to check the soil-pile response in case if a tunnel is proposed to pass below this already existing particular building structure. Such a scenario is easy to find in this decade in every major city worldwide & most of the tunnels have to face the consequences like previously constructed tunnels, tiebacks & deep foundations like pile. We are using 3D FEM tool as it produces more accurate results instead of other analytical, empirical & 2D finite element methods. We used MIDAS GTSNX and MIDAS GEN in our studies for the soil & structural purposes. The tunnel is excavated below the structure in various construction stages and the response of the structure as well as the pile is recorded in each construction stages of the 28 meter long tunnel.

The Tunnel of diameter 7 meter is started behind from left end corner and finished at front of left front corner of building, i.e. below the left end face of the building. The piles are provided at bottom of each column, placed equidistantly through the frame. The settlement in soil at surface due to tunnelling is measured and its effects over the structure are recorded, which is further tried to reduce to minimal. The results were iterated and a safe line is proposed under which the building structure in kept out of the influence zone of the settlement curve formed by tunnel excavated below the structure. The building is 33 meter in height and the tunnelling in done in different 7 construction stages with each construction stage of 4 meter run. The lining support is provided with shell and the thickness of shell is kept 600mm uniformly throughout the tunnel.

2. Methodology

We are using the Numerical analysis for our studies over the structure response due to the tunnel excavation process under some specific depth in the soil mass. Even through empirical approach it is find that a parabolic curve shape is formed by settlement at surface due to tunnel excavation, same type of shape is tried to find but not in Greenfield condition but in presence of a existing structure.

2. 1. Building

The Building is analysed & checked for design using MIDAS GEN, here we generate the model of 11 storeys building with each storey 3 meter in height is constructed over the weathering rock surface. The building is designed using IS 456 code provisions; description of the column and beam sizes is defined below in Table-1. The building is residential building and the loads are considered accordingly, the building is square is shape with 5 columns each at a distance of 4 meter centre to centre.

Table. 1. Description of Building

Modelling	11 storeys building	Grade M30, floor height 11@3 m each
Loads	DL,LL,SIDL	DL=4 KN/m^2, LL= 2KN/m^2
Design	IS 456	All section pass
Results	ok	Beam 350X450, Column 600X600(in mm)

2. 2. Pile Foundation

The pile is designed for the critical load coming from the building in the MIDAS GTSNX and the same size of pile is provided under each column. The piles used are circular in shape and the pile cap of 1m thickness is provided under each column of the building. The pile of diameter 400mm is used with 8 meter in depth embedded in soil and 200mm in pile cap. The pile cap area is 1X1 sq. meter in size just at the bottom of each column, so the number of pile provided for building are 25 in number. We kept the pile constraint at their tip and give the interface properties for the soil and pile. The properties of pile are given below in Table-2.

Table.2. Properties of Pile & Pile Cap

Pile and Pile Cap Material	M30 Grade concrete, Elastic material.
Size of pile and pile cap	Dia. 400mm , Height 8m & 1m thickness and area 1x1 sq. m
Stiffness Parameters	Kn= 10^8 KN/m^3,Kt= 10^6 KN/m^3, Tip spring stiffness =10^6 KN/m^3
Pile Constraint	Constraint in RZ direction.

2. 3. Soil

The soil type is weathering rock and the tunnel is excavated in a sequential manner through the soil mass at a depth of 35 meter deep from surface. Due to this excavation there will be the settlement curve observed at the surface level, which can be very deep or the negligible is size. It is directly related to the soil mass properties and also to the excavation methods. The more the soil is stiff more will be its self standing capacity & lesser it need the support system while on other side if soil is week then it need more accurate methods of its excavation and also the construction techniques. Here we are taking a soil type which is neither much stiff nor the week in strength. The properties of soil are given below in Table-3.

Table.3. Properties of Soil & Tunnel shell

1.	**Soil Properties**	
	Cohesion (C), Phi. (Ø)	200 KN/m^2, 33
	Unit wt. (ɣ), Poisson ratio(μ), Ko	20 KN/m^3, 0.35,1
	Young's Modulus of Elasticity (E)	150,000 KN/m^2
2.	Tunnel Shell	
	Material, Shell Thickness	Grade M30, 600 mm Uniform thickness.
	Tunnel Surcharge height	31.5 meter from head of tunnel.

2. 4. Combined Model

The models from the MIDAS GEN & GTS NX are now combined with each other and the building is now in GTS NX where one needs to create the soil mass and the foundation for the building structure. The pile foundation is created here in the model for the building mesh[(1)], the pile cap and the pile are generated with mesh sets. The interface properties for the pile and soil are defined also the tip spring stiffness will take in care. The mesh nodal connectivity must be ensuring for both the building and piles with soil mass. The tunnel should be at proper depth so that the building will not come under the influence zone of settlement at the surface. The tunnel is excavated from front face of building in seven construction stages, which is the cause of sudden settlement at the surface level. Due to this settlement the building will face the risk of damage or even the complete failure. So the response of building due to the settlement becomes very important issue to take care of to measure the health condition of the building. The figure 1 shows the Mesh set of Building, figure 2 shows Pile & Pile cap, figure 3 shows the tunnel & its lining.

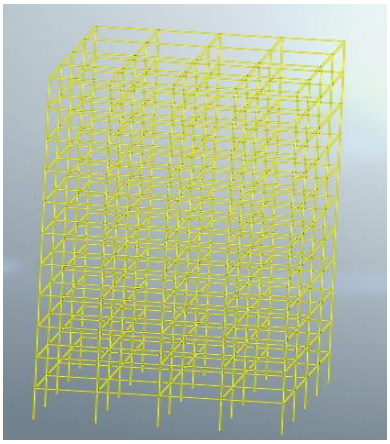


Fig.1. Building mesh set

Fig.2. Pile & Pile Cap

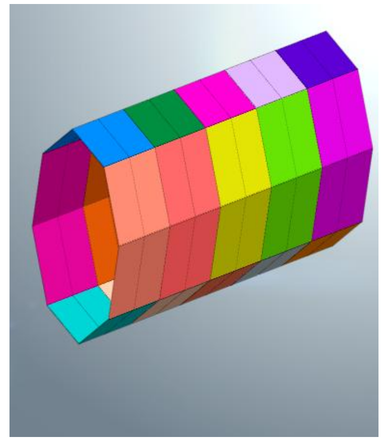


Fig.3. Tunnel shell

Where the Figure 4 shows a complete combined model of building, pile & tunnel in same soil mass as represented below in fig 4 (a), (b), (c).

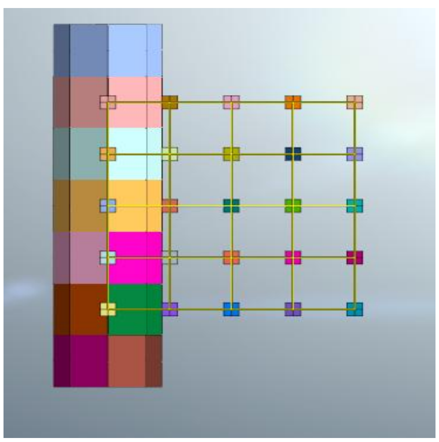


Fig.4 (a) Plan of building & tunnel

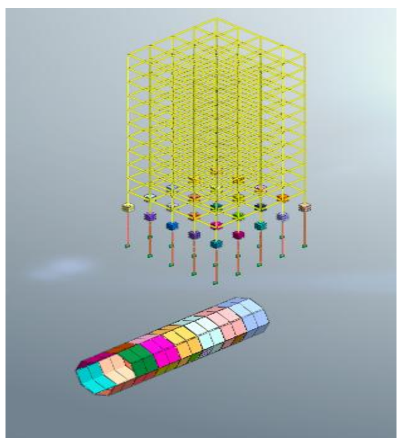


Fig.4 (b) Isometric view

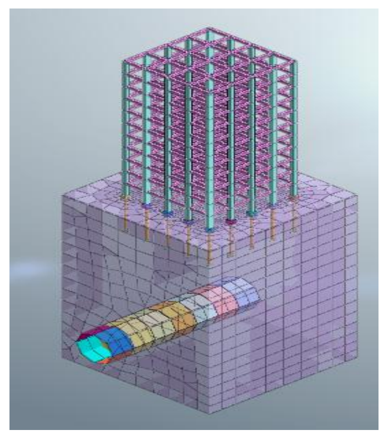


Fig.4 (c) Building cum tunnel model

3. Analysis

The model is provided with creating the boundary conditions for ground support. Also the beam elements of building are assigned the loads in form of line beam load for each element individually. The reason to provide these loads is that when model is imported to the GTS NX it only import the self weight of the predesigned building and rest other loads we need to assign here, which are the superimposed dead loads and live loads. Now the construction stages are need to be define with the normal ground condition and with the presence of pile foundation and building. This can be analysed in different construction stages, where after this excavation of tunnel can be started at the specified depth. The tunnel is 28 meters long and hence we are excavating it to seven different construction stages each 4 meter in length. The first stage of excavation is to remove the soil and also to provide the support in form of shell. We have already defined the thickness of shell for this particular soil type at this depth of tunnel. Similarly for the other six construction stages process will be repeated over and again. The construction of tunnel will end at the last stage by providing the shell element support for excavated part.

In our analysis the building response in normal condition and in all seven construction stages of tunnel excavation through soil is recorded. The first stage deals only with ground and building for the time when no excavation is done before, here the situation is as normal for the existing structure without any interference from outer source. Where in the next stage is with the excavation below the structure through the ground, which will affect the ground strength and cause the settlement at ground level. This settlement in ground will hamper the structure, to certain level it might affect very less but it might cause the structural failure which is a critical situation. So avoid such situation the building response due to excavation of complete tunnel is noted and checked that how it is varying with different excavation depth in soil mass.

4. Results

The results from the analysis are obtained for each node but here in our studies we will take the result only for the nine points or the nodes just below the columns. The points consider are enable to represent the situation of building, as all four corners of building and points existing at their mid are considered also the point just below the centre column of building is considered to obtain the real response of building. Our structure is lying at a height of 31.5 meter top of tunnel head in much hard soil strata which helps to avoid any type of sudden settlement due to excavation which we take is care. As the tunnel is passing below the left face of building so there is more chance of settlement, which in case if exceeds much can tilt the structure which is not a good sign.

We tried to keep the structure much away from influence zone of excavation even after the completion of the work. The results are represented here for the initial stage in Figure.5. in which the structure is existing over the normal ground conditions.

The figure represents the settlement of building during the initial stage in which no excavation is done in soil mass. So there is no external influence to the soil and structure stability. The displacement obtained is lying at mean value of 4 mm for each column this shows that the structure is easily situated without any harm. In next figure we come to know about the response of structure due to excavation and how each construction stage will affect the structure stability.

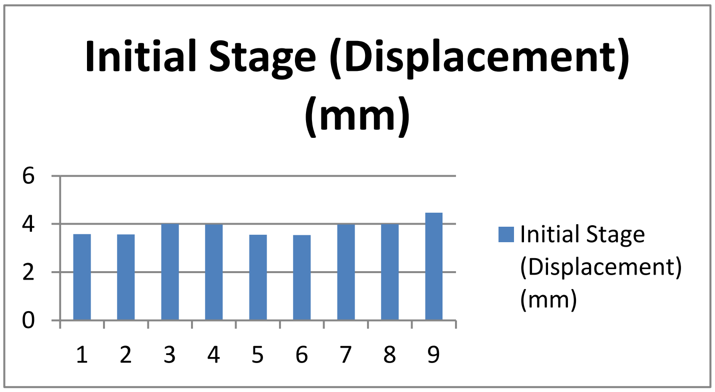
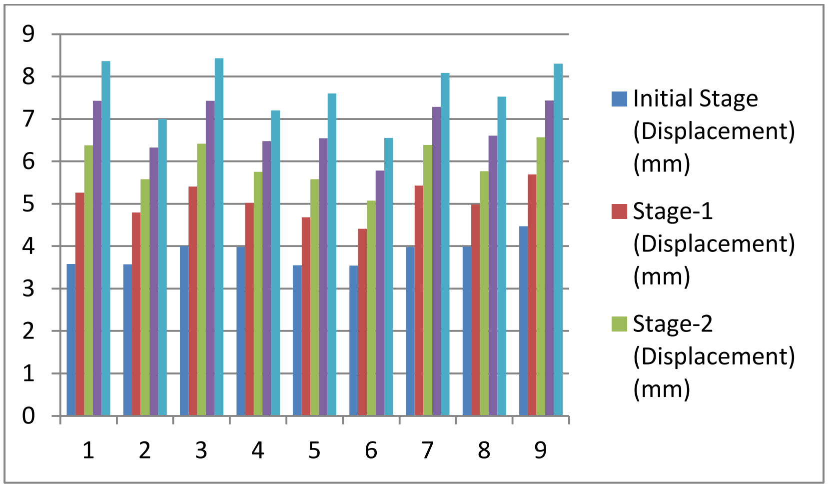


Fig.5. Displacement at nine points in initial stage

The next figure shows the response of nodes below column for the first four construction stages which are studied individually and reported as one in given graph. From this graph the displacement variation for each node with each excavation stage can be recorded. Also by observation from results we can find the critical situation (if any) and take the suitable steps for securing the structure health.

The results for the next four stages are represented in figure.6. below.



No	Node
1	26
2	27
3	30
4	31
5	34
6	35
7	41
8	42
9	44

Fig.6. Displacement at each node from initial to 4th stage

Similarly for the next stages the response is given in figure.7

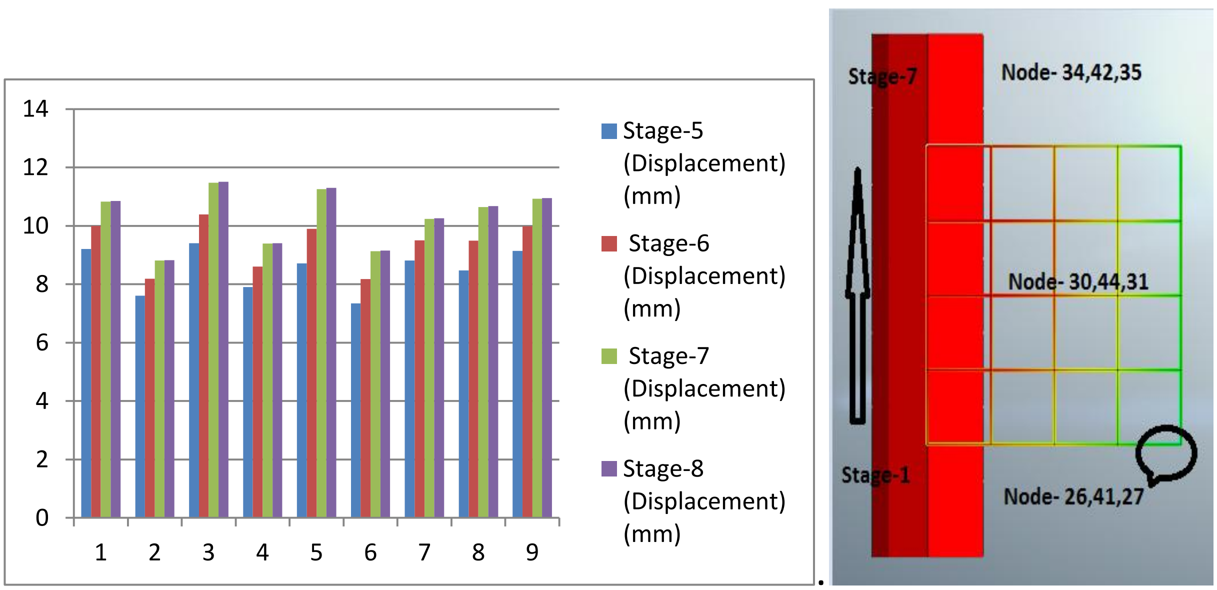


Fig.7. Displacement at nodes from stage 5th-8th

The above figure 6 shows the maximum displacement at first, third and ninth point which is in average of 8.2 mm settlement while rest others are below this value, similar case will happen for the figure 7 which shows that the third, fifth and ninth point are at maximum where all others including first are lesser than average of 11.2 mm settlement. This shows that there is variation of settlement occurrence with each construction stage and same can be observed for the other points also. The maximum settlement values for the nodes are observed and that is done for other nodes also which are touching these values.

So we take three nodes in Figure.8 and check the displacement variation in these column nodes from the initial to the final stage of tunnel excavation completion.

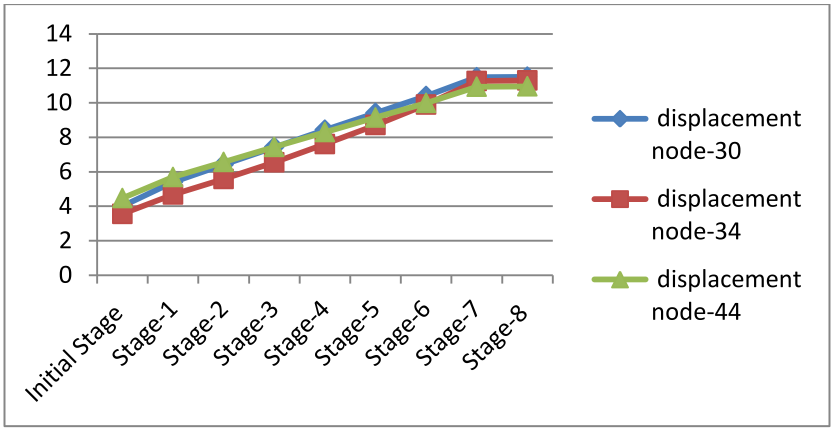


Fig.8. Variation of displacement from Initial to final stage for critical cases

The above figure shows that the maximum settlement touches the 12mm, which mean that from the initial stage where the settlement was 3.8mm, 4mm & 4.2mm for the nodes 30,34 & 44 now it reaches to average to 11.6mm. This shows that the average settlement 7.51 mm will increase due to tunnel excavation.

These are the reduced values which we taken to show the effect of tunnel excavation over a structure, where if we repeat the process and analyse the settlement at column tip which is kept over the pile cap for the tunnel depth less than 31.5 meter from ground level the settlement values for the same soil model will change suddenly. Hence this is the safe line for tunnel excavation by taking care of existing building over the tunnel.

4. CONCLUSION

We concluded that the settlement of building can be regulated with the depth of tunnel line, in mega cities the safe line for tunnel depth can be find as accurate because if tunnel is done at depth more than required it increases it cost and same if at low depth it can easily hamper the existing structures. In our case the settlement is in allowable limit of less than 25mm, which will affect the structure but not allow it to complete failure.

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