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PREDICTION OF STRUT FORCE FOR AN EXCAVATION OF METRO UNDER GROUND STATION CONSTRUCTION USING FLAC3D

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Abstract — *Deep excavations in city areas are increasing day by day. If the excavation is done close to heavily populated areas, it will be great challenge for the engineers to protect the buildings and to minimize the settlements. Retaining walls are used to support the excavation and to provide stability to the side walls. Strut beams are used to keep the retaining wall in position and to prevent the lateral deformation of the wall due to earth pressure. In this paper analysis of the strut beam force is done with FLAC3D software for an excavation near a major building. The strut forces developed were compared with the field monitored data and the results are found to be in good agreement.*

Keywords- *strut force; On site Visualisation and field monitoring; FLAC3D*

I. INTRODUCTION

A rigid and robust support system is required for the excavation work in order to avoid the failure of nearby structures and to minimise the excessive settlement. Vertical and Horizontal supports are usually provided for the excavation. Different types of retaining wall are used to vertically support the excavation work. Horizontal support is provided with the help of ground anchors and strut beams. Strut is a compression member to provide temporary support to in-situ retaining walls in deep excavations. It is mostly a steel beam of various sections or a pipe. Struts usually span the width of excavation. Their main function is to keep the vertical wall in position. Due to deformation of the wall compressive forces will be developed in the strut and if it exceeds the tolerable limit failure of the structure will happen. So it is necessary to monitor the strut forces so that precautionary measures can be taken if it goes beyond the trigger value. In addition to the above force, temperature variations will results in the development of thermal stresses which in turn results in the increase of strut force. The factor of safety selected during the design process usually compensates these changes. Design of strutted beam will be affected by factors like the stages of excavation, placement of supports, their stiffness and wall stiffness etc. Usually for large span width steel beams such as H sections and pipes are commonly used. The selection and placement should be such that minimum cutting requirements and least interference with construction activities are preferred. Horizontal and vertical spacing of struts are related to construction activities. Strain gauges are installed in the strut beam to monitor the strut force and sensors are installed which in turn connected to LEDS. If the strut force increase beyond the trigger value warning signals will be displayed as change in color of the LEDS. Fig.1&2 shows the support details and position of sensors installed; strain gauges are indicated with dark squares.

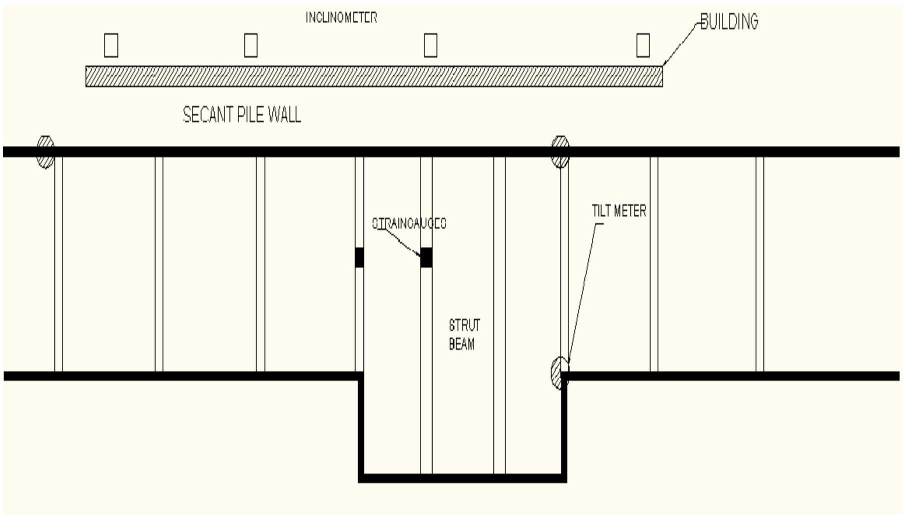

Fig1 Layout of the excavation and the position of the instruments in symbols

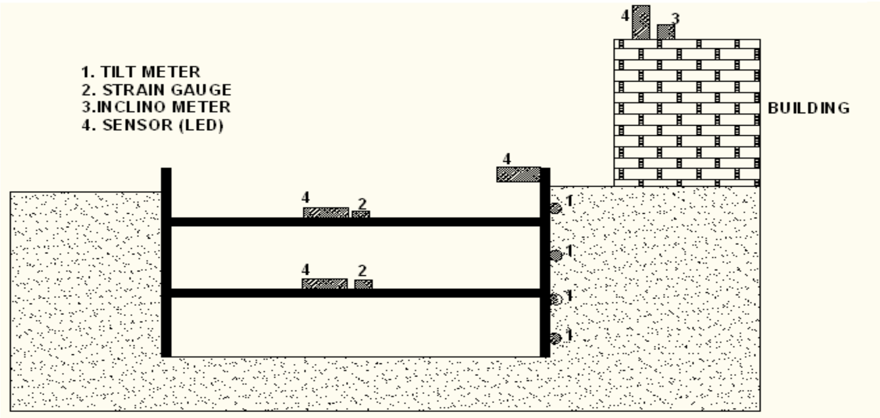

Fig 2 Details of the instrumentation and sensor location

II. PROJECT DETAILS

An excavation adjacent to a major building was carried out for the construction of a cut and cover tunnel as a part of the south north transit underground section 2 at the cricket stadium, Bangalore. The excavation extended below the foundation level of the building. The project route of a total length of 4km traversed well developed areas which imposed significant constraints on the construction work. To minimize the impact on buildings adjacent to excavation of the ground in close proximity to the site was a major concern. A robust support system for the excavation was adopted to control ground movement and to prevent damage to the existing structure. The support system for the excavation consists of secant piles, soldier piles, horizontal struts and ground anchors. The excavation was carried out in stages to minimize the ground deformation. The deflection of building was monitored to ensure that it is within the tolerable limit. Onsite visualisation study (OSV) will be conducted at the site by installing equipments like sensors and light emmitting converters (LECS) at the top of the HAL building and some other locations of impotance. The on site visualisation for the project is done by the japanese company JICA -Japan International Cooperation Agency. Lateral displacement of the secant pile wall was monitored using Inclinometers installed in the secant pile walls. Tilt meters are used to monitor the tilt in the buildings near to excavation. Strain gauges and sensors are installed at the midpoint of the strut beam to monitor the deformation in the strut beam used to keep the secant pile wall in position. Fig.3 shows the details of the support system at the site.

Fig.3 Excavation Site

III. NUMERICAL ANALYSIS

The Excavation near a major building is taken for the present study. To predict the ground performance during excavation and to optimize the design of ground support FLAC3D was employed to simulate the actual three dimensional natures of the problem, the construction sequence and the soil structure interaction. The excavation is supported during construction with the soldier pile walls and is horizontally supported with horizontal struts to keep the pile wall in position. Throughout the construction stages the analysis is done to evaluate the strut force developed. The analysis is done with single strut and two struts and the change in strut force is observed. The strut force developed with two struts is compared with the field data. The Medium consists of 8.6m depth soil layer below which is the rock stratum. The properties used for the rock and soil layer are shown in Table1.

The problem simulates a staged construction of a vertical excavation supported by secant piles of 800mm diameter and steel struts. The excavation is 30.5 m wide and the final depth is 8m. Figure 4 shows the finite difference model used for the analysis. The system of coordinate axes is defined such that the origin is beneath the center of the excavation with the *z*-axis pointing upward. The boundary is located approximately 10 times the excavation width away from the excavation, in order to minimize boundary effects. Drained condition is assumed throughout the analysis. The E value varies linearly with depth and the average value for each layer of excavation is calculated and assigned. Concrete properties are given to the zone near to the excavation to simulate the Soldier pile wall of width 800mm. The secant pile wall extends along the y direction for the entire length of the excavation. The properties of the secant pile wall are shown in Table 2.

Table1. Properties of the soil and rock

property	soil	Rock
Elastic modulus	5000+2500z kPa	5000+2500z kPa
cohesion	5e3	50e3
friction	25 degrees	66.9 degrees
density	1900	2500

Table2. Properties of the secant pile wall

Properties	value
Young's modulus	2.96e10
Poisson's ratio	0.3
c/s area(800mm dia pile)	0.5027
Moment of Inertia in xx axis	4.02e-2

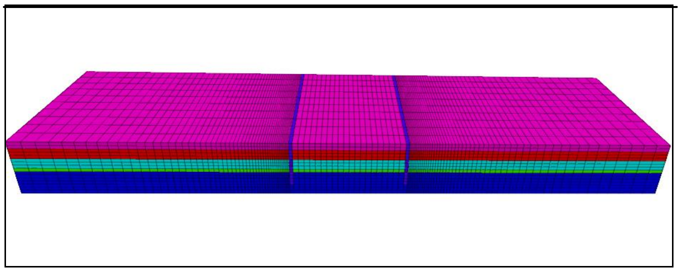

Fig 4.Geometry of the model with different properties assigned to different zones.

But for analysis the length of excavation considered is only 9.325m which is the center to center distance between the struts. The struts are placed at the mid length of excavation and are simulated with the beam structural elements option available in FLAC3D. The strut is used to keep the secant pile wall in position and is rigidly connected to the wall zones. The properties of the beam element used are shown in Table.3. Two struts were installed at a depth 1.85m and 5.35m from ground level respectively.

Mohr-coulomb elasto- plastic model is used for the analysis except for the concrete pile wall where elastic model is assigned. The null model is used to simulate the excavation. The analysis starts from the stage after the wall has been constructed prior to any excavation. The building load of 75kN/m^2 is applied as uniformly distributed load. Each stage is cycled for 3000 steps and the strut force developed is observed. The analysis is done in six stages as detailed in Table 4. Table 5 shows the assumed size of struts.

Table3. Properties of the strut

properties	Value
Young's modulus	2.1e11 Pa
Poisson's ratio	0.3
c/s area	0.0138 m^2
Moment of inertia	0.083

Table4: Excavation stages

stage	Remarks
1	Initial equilibrium, application of load 75kN/m^2 , vertical support system installed in the form of concrete wall.
2	Excavation is done to a depth of 2m
3	installation of the strut1 at 1.85m
4	Excavation is done to a depth of 5.5m
5	installation of the strut2 at 5.35m
6	Excavation is done to a depth of 8m

Table5: Assumed sizes of struts (BMRC report [2])

Prop no	section	Area M^2	Free length m	Spacing M	material	Prestressing force kN
1	2NPB 600x220 x122.4	0.0138	12.50	9.0	steel	144
2	2NPB 600x220 x122.4	0.0138	12.50	9.0	steel	143
3	200x2000 Blind strut	0.4000	1.60	1.35	conc	n/a
4	200x2000 Blind strut	0.4000	1.60	1.35	conc	n/a

Fig 5,6,7,8 and 9 shows the different stages of excavation done. Installation of strut is done after excavation of 2m and 5.5m as shown in Fig.6 and 8.

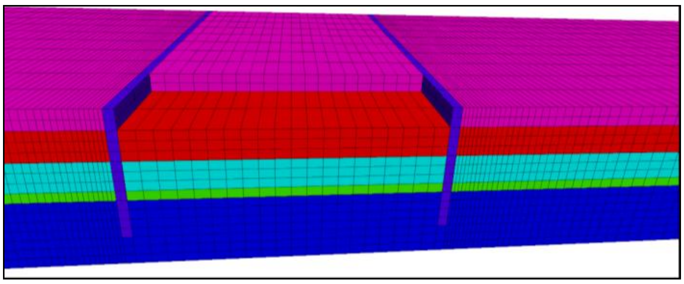

Fig 5. Model after 2m excavation

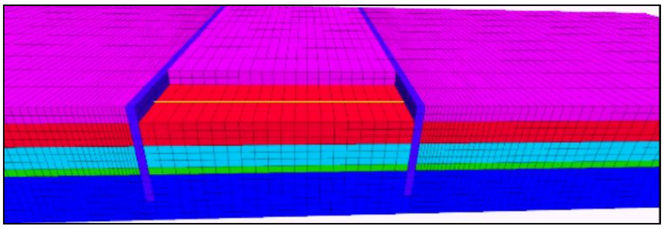

Fig 6. Model after the installation of strut1

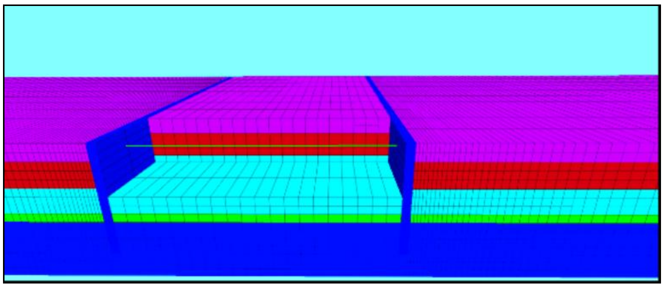

Fig 7: Model after the excavation of 5.5m

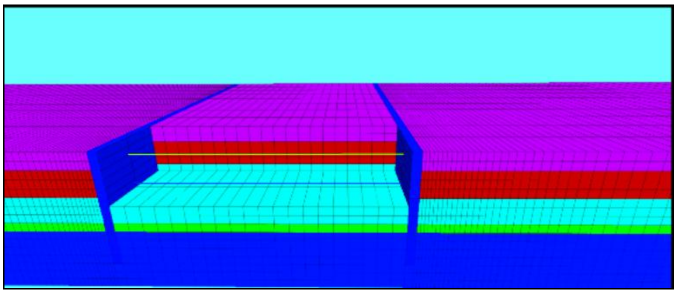

Fig 8: Installation of second strut at 5.35m

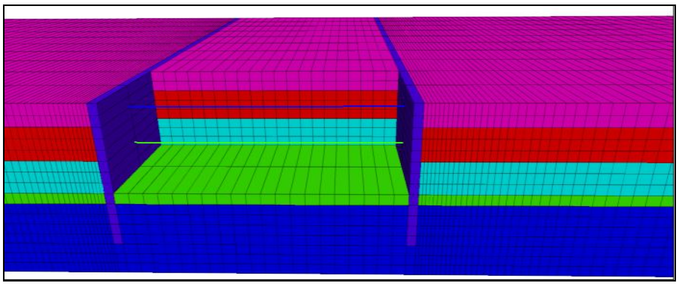

Fig 9: After 8m excavation

IV. RESULTS

Strut beams are used to keep the retaining wall in position. While the wall deforms some compressive stresses will be developed in the beam and is monitored. The first strut is installed at a depth of 1.85m and the second strut at a depth of 5.35m after an exacavtion of 2m and 5.5m from the ground surface. Fig.10 shows the variations of strut force.Daily fluctuation of axial force is observed. Readings were taken from 25.7.2011 to 21.01.2012 at different times daily. This variation is mainly due to the changes in temperature that occur during the particular day of observation. But the sensors are designed in such a way that the strain due to the temperature effects should automatically cancel [4]. The field measurement shows a value of 784.8kN.

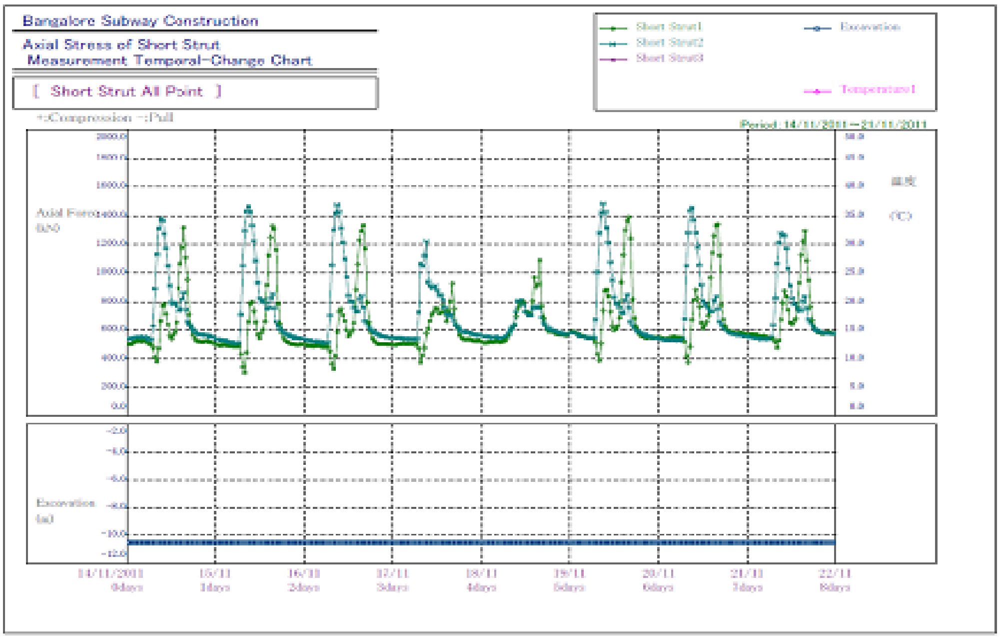

Fig.10 The variation of strut force (BMRC report[2])

Fig 11 shows the variation strut force with excavation. It shows that the strut force increases with the the depth of excavation. There is not much difference in the strut force if the analysis done with single or two struts at different levels. Strut force at each stage of exacavation is shown in table 5. The strut force developed in the analysis is slightly greater than the field value.

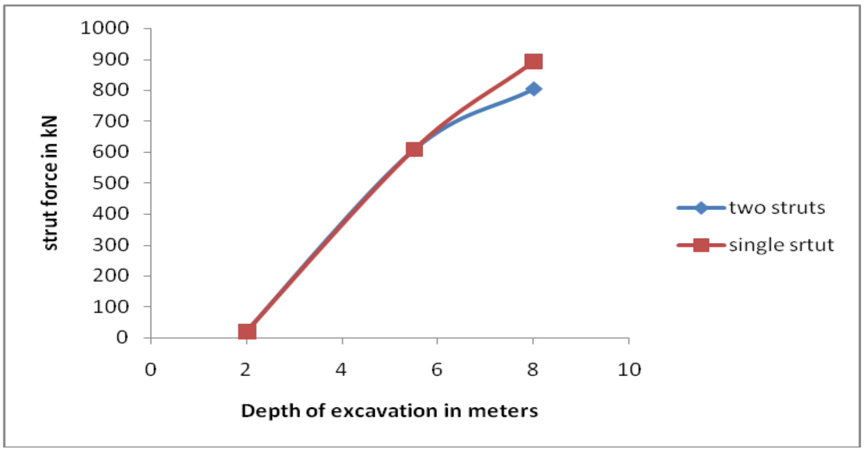

Fig 11: Variataion strut force with depth of excavation

Table5: strut force at each stage of excavation

(strut at 1.85m and 5.35m)

Excavation depth in meters	Strut force in kN	Field Value
2	18.08	
5.5	608	
8	805	784.8

If the analysis is done with asingle strut at 1.85m the force developed is shown in table 6. With single strut the strut force developed is more than that with struts at 1.85m and 5.35m.

Table6: strut force at each stage of excavation

Excavation depth in meters	Strut force in kN
2	18.08
5.5	608
8	893

V. CONCLUSION

The results show that there is increase in strut force as the depth of excavation increases. The force developed in the strut beam with single strut and with two struts at different levels shows that the there is little variation in the strut forces. This indicates that the lateral supporting system is strong enough to withstand the forces. The field data is matching with the numerical results. Slight variation in field data from the numerical results is because of the difficulty in simulating the exact field condition. This shows that Flac3D is good enough to catch the behavior of strutted excavation. In field the measured strut forces shows variations for a particular day, mainly due to the variations in temperature. Strain gauges are designed in such a way as to accommodate the variations in temperature.

VI. REFERENCES

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