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Behavior of Braced Deep Excavation in Soft Soils

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Behavior of Braced Deep Excavation in Soft Soils

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ABSTRACT

A successful case study of braced deep excavation in Hangzhou, 1994, is presented in this paper. A stiff braced retaining structure was adopted through theoretical analysis, the bottom soil of the pit was strengthened by cement mixed grouting to increase the stability of the retaining structure. The excavation was completed smoothly in short period of time, displacements surrounded the pit and stresses in braces were measured during the whole procedure of excavation and the measured results agreed well with the prediction by FEM. Some conclusions drawn from this successful case may be instructional to other similar engineerings.

KEYWORDS

deep excavation, braced retaining structure, FEM, cement mixed grouting, soil-cement mixed column

INTRODUCTION

Design and constructions of a deep excavation in soft soils within an urban setting is a very difficult task for geotechnical engineers (Zen Guoxi, 1988). In areas with deep deposits of soft soils, deep excavation often require expensive constructions, e.g. braced pile retaining structure.

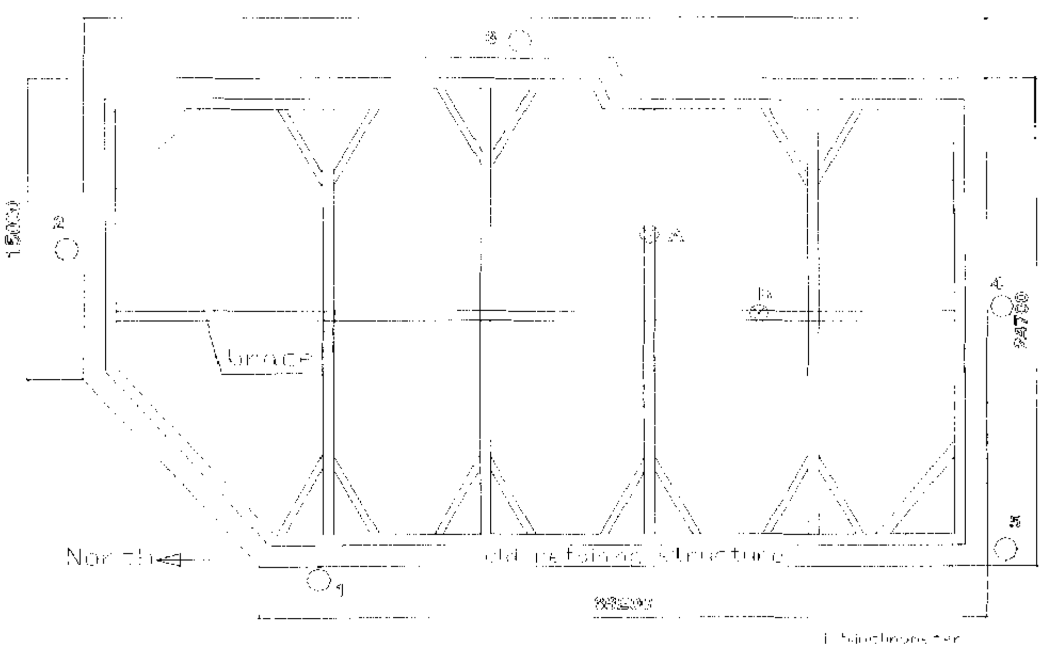

Fig.1 Plan of excavation area and location of Geotechnical instruments

A Successful case study of deep excavation in Hangzhou, 1994, is presented. Some principles of design, construction are reviewed. Measured results are analyzed by FEM in this paper. Some experiences gained from the construction performance could be used for reference to other engineerings.
The project consisted of construction a 10-story mixed-used high building overlying a two-level basement in Hangzhou. It was located northeast side of intersection of two main roads — Yanan Road and Qinchun Road (in the center of the city) and closed to a high building on its west side. The deep pit was about 7.4m in depth with the perimeter about 145m. The figure of the pit is shown in Fig.1.

SUBSOIL CONDITION

The soil condition for the project were determined from subsurface investigations. Table 1 shows the subsurface profile and relevant test results.

Table 1. Soil profile

Layers	e	w	ρ	C	ϕ
Fill			18.5	0	30
silty clay	0.90	31.5	19.8	31.8	20.1
mucky clay	1.30	48.3	19.2	13.1	9.8
clayey silt	1.40	30.2	17.1	13.5	25.8
silty clay	0.9	32.0	18.4	22.4	13.2

e: Void Ratio w: Water Content ρ: Unit Weight(KN/m^3)
C: Cohesive force(KPa) ϕ :Friction Angle

DESIGN AND NUMERICAL ANALYSIS

The profile showed the excavation was in soft clay layers. Eliminating soil deflection to protect the adjacent roads and buildings became the most important issue, so braced cast-in-place pile retaining structure was decided to employ. Preliminary analyses showed that one row of Φ800 @1000 cast-in-place piles with length of 16m might be satisfied. Reinforced-concrete braces were installed 2.1m below the top of the piles to reduce the effects surround the excavation. Two rows of ϕ 700 cement mixed column were added outside the piles to form waterproof screen. The bottom soil of the pit was strengthened by cement mixed grouting to increase the stability of the retaining structure. Existing high building was on the west side, and its retaining structure was still there and could make full use. One row of cement mixed column was added outside of the old retaining structure and two rows of cement mixed groutings were added between the two-rows of piles of old retaining structure for waterproof and supporting the braces to prevent too great deflection of existing building occur. Cross section of the pit and detailed plane of piles are shown in Fig.2 and Fig.3 respectively, Calculation based on the theory of sheet piles indicated that stability coefficient was about 1.94 and anti-slide coefficient was about 1.76. Other calculated results also met demands of design.

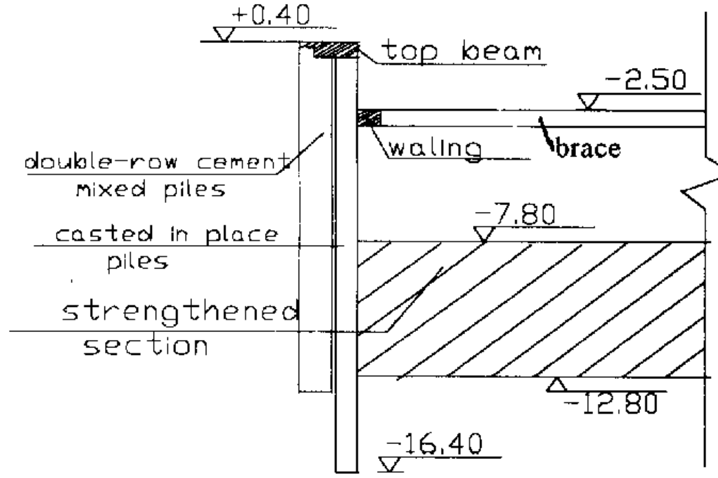

Fig.2 Cross-section of pit

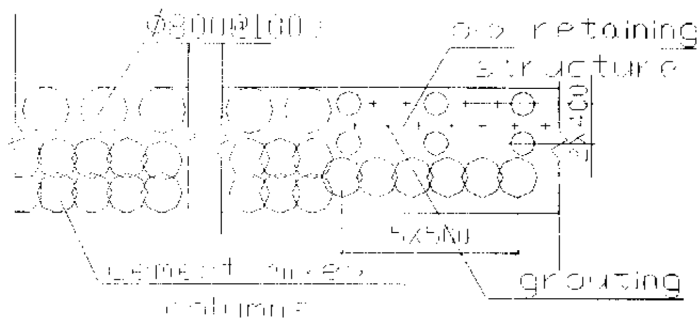

Fig.3 Detailed plane of piles of retaining structure

In order to explore the mechanics characters, plane strain FEM code was programmed. Pile, brace , waling and top beam were taken as beam element. The bottom soils strengthened were taken as elastic body in code. Stress-strain relation adopted Duncan-Chang model. (Chang and Duncan, 1970). The deflection and moment of piles at critical section are given by Fig.4 and Fig.5, respectively.
Figure 4 showed that the maximum deflection of pile occur nearly the bottom of the pit, was about 4.2cm. Since the stiffness of the brace is rather great, the deflection nearby the brace is negative to that of the deflection at the top of pile. For

buildings and roads surround the pit, such great deflection is acceptable.

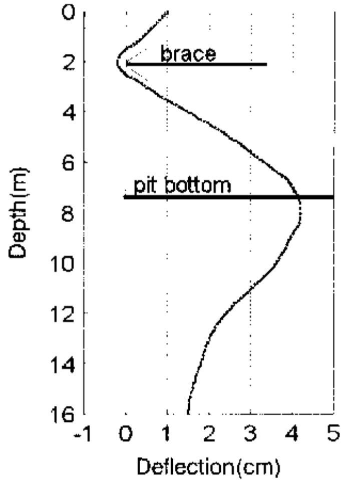

Fig.4 Deflections of pile

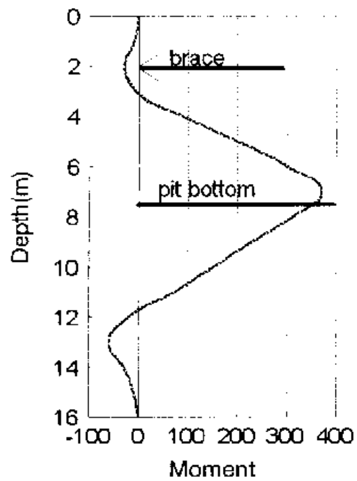

Fig.5 Moment of pile

Figure 5 presented moment of pile. From Fig.5, we can find that the maximum moment of pile, occurred nearly the bottom of the pit, was abut 380 $KN \cdot m$. Since the stiffness of the brace is rather great that the pile had two inflection-point. Negative moment was smaller than positive moment.

Some conclusions were drawn from the numerical results for comparative calculations, which can help engineers understand the mechanics of the retaining structure. These include that if the stiffness of the pile is increased, the deflection of pile can be control to some extent but the moment of pile increases; if the stiffness of the brace is increased, the deflection of upside of pile can be reduced , but the deflection of pile below the bottom is not affected much by that; too long length of the pile below the bottom of pit is not helpful to control the deflection and the moment of the pile, a little longer than the depth of excavation is advisable; the maximum deflection of pile will increase 40% and the maximum moment of pile will increase 25% if the bottom of the pit is not strengthened for this project.

MONITORING AND CONSTRUCTION

Since the bad soils characteristics and the large scale of the pit and static design method, in order to observe the stress and deflection changes of retaining structure during the excavation, a variety of geotechnical instruments were installed to monitor the movements of soil mass and stress in braces.

Five inclinometers with length of 20m were installed surround the pit for deflection monitoring and two strainometers, for stress monitoring. The location of them is shown in Fig.1. Monitoring can remedy the limitations of static design. By geotechnical instruments adopted in monitoring, messages about the deflection and stress during the excavation can be obtained and feedback to field to instruct the construction procedure. Soils in the south section of the pit were excavated first, then the excavation was proceeded from south to north. The excavation began on Nov. 26, 1994 and completed on Dec. 09, 1994. Concrete cushion and slab were construct in area excavated during the course of excavation, and the slab was completely constructed on Dec.25, 1994. Fig.6 and Fig.7 presented the deflection of piles measured by No.2 and No.3 inclinometer respectively. Table 2 presented the stress in braces measured by strainometer A and B respectively.

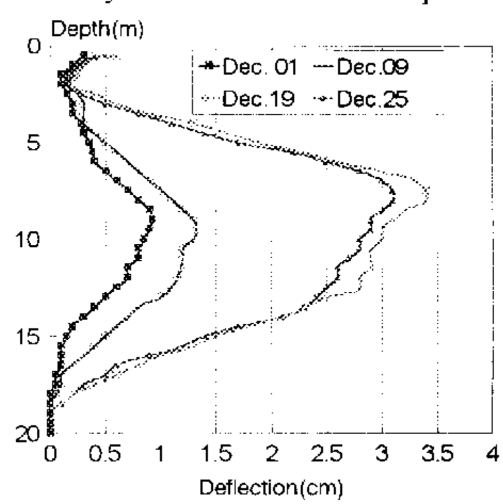

Fig.6 Deflection of soil around the pit(measured by No.2 inclinometer)

It can be seen from two Fig.s that the maximum deflection of soil occurs near the bottom of the pit and is less than 3.5cm and deflection of soils on the top of the pit is no less than 0.5cm since function of brace. Deflection changes from

Dec.01 to Dec. 19 show that the deflection increase with the depth of excavation increase. With construction of concrete cushion and slab after the excavation, the deflection decreased a little. Deflection of soils measured by No.2 is a little bigger than that measured by No.3 inclinometer, since No.2 inclinometer is more far to brace than No.3 inclinometer (see Fig.1). Measured results agree with the FEM prediction as to the deflection pattern, the little difference between the prediction and the monitoring may be caused by the inaccuracy of soil parameters determination and some other factors.

From Table.2, we can see that the stress in brace increase fast as excavation progressed and increase slowly after the excavation is completed, which indicates that the brace play an important role especially during the course of excavation.

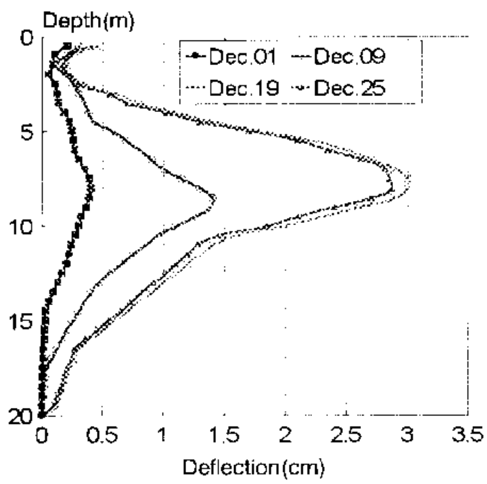

Fig.7 Deflection of soil around the pit(measured by No.3 inclinometer)

Table 2. Stress in brace (recorded by strainometer)

procedure / stress (KN)	excavate to EL.-5.40	excavate to EL.-7.80	cushion constructed	slab constructed
strainometer A	400	1150	1450	1500
strainometer B	500	1280	1590	1650

CONCLUSIONS

The following conclusions can be drawn from the analysis above:

1. Braced-pile retaining structure can function effectively to limit lateral deflection of soils around the pit. It is advised to adopt this type of retaining structure for the pit excavation in cities to minimize the deflection around pit.
2. FEM calculation show that the deflection of pile can be controlled to some extent if the stiffness of the pile is increased, but the moment of pile increase; if the stiffness of the brace is increased, the deflection of upside of pile can be reduced , but the deflection of pile below the bottom is not affected by that deeply; interact to control deflection; too long length of the pile below is not helpful to control the deflection and the moment of the pile, little longer than the depth of excavation is suitable; and deflection and moment of pile can be reduced much if the bottom of the pit is strengthened.
3. It is essential to implement an observational approach using appropriate geotechnical instrument for deep pit excavation in center of city. It can provides insight that is not available during the design phase, remedy the limitation of static design, therefore prevent unpredictable accidents occurring.

REFERENCES

Chang, C. Y. and Duncan, J. M. [1970]. " Analysis of soil movement around a deep excavation." , Journal of Soil Mech and Found. Div. ASCE, No.96(5).

Zen guoxi. et al. [1988]. " Study of behavior of excavation in soft clay." , Chinese Journal of Geotechnical Engineering., No.10(3).