Theoretical and practical problems on design of deep excavation in Shanghai

Les problèmes de la théorie et de la pratique sur le projet de construction de l'excavation profonde à Shanghai

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ABSTRACT: Based on the detailed analysis of experience and lesson for 20 typical cases of deep excavation engineering and the research results related in Shanghai, this paper focuses on the analysis of main problems about design, calculation programme, construction and field monitoring. some suggestions are also proposed.

RESUME: Ce thème prend l'experience et la lecon des détails d'analyses typiques dix-huit comme base, assimile l'experience pratique et le succés de la recherche scientifique de l'excavation profonde dans Shanghai, analyse les problèmes au sujet du projet de la construction et le monitoring sur place, et suggere aussi des propositions utiles.

1. INTRODUCTION

It has been recognized that the deep excavation is a risky engineering which involves multi-subjects--soil mechanics, foundation engineering, structure mechanics and field measurement. so, it may be said deep excavation is a system engineering. Its success or failure depends on many factors, such as engineering geology, design, construction and field monitoring, etc.

In recent years some engineering accidents had occurred, a great deal of money had lost due to excavation problems, on the other side a big successful project can save money more than several millions RBM. Therefore, there are many problems to be summarized and further studied, and it is just the major purpose in this paper.

2. DESIGN PROBLEMS

The correct design of deep excavation is both to assure the whole structure safety and to control the deformation of structure and surrounding soil mass for the safety of adjacent structures and under-pipeline during construction. Under this presupposition the design should be reasonable, economic, easy for construction and short period. To attain this goal it should make a concrete analysis of concrete problems, i.e. engineer should need the rich practical experience, high level design ability and creative spirit to deal with such a problem.

There are three main problems needed to be further studied, in the design of a deep excavation

2.1 *Retaining Wall*

2.1.1 Selection of types of retaining wall

The type of retaining wall is classified by the depth of excavation.

2.1.1.1 Deep excavation (between 6 m and 10 m)

If the depth of excavation over 6 m and there is a good surrounding environment, cement mixed piles as retaining wall should be stabilized. e.g. the depth of excavation shown 9.71m-11.71m in the project of Shanghai Next Age Mansion shown in Photo 1. On the other side, the cement mixed piles or the cement mixed piles inside with bored piles, with one level of bracing at the local place can be adopted too, e.g. the depth of excavation in the project of Shanghai Guo Mai Mansion is 9.8m shown in Photo 2.

The bored piles in diameter of 800-1000mm are widely used as retaining wall with one or two levels of bracing. The intermission between piles should be sealed by grouting, or root piles or cement mixed piles.

In Shanghai SMW(Soil Mixing Wall) method was used as retaining wall with baring, but seldom by using H-type steels.

2.1.1.2 Deep excavation(depth >10m)

Generally, the diaphragm wall with RC bracing is used as retaining wall, its thickness is between 800 and 1000mm. Now the deepest excavation is 19.65m in the project of Jin Mao Mansion, shown in Photo 3. However, steel structure bracings have to be used too.

It should be pointed out that the bored piles in diameter of 1000mm-1200mm can be used instead of diaphragm wall, for example, In the project of Shanghai International Shipping Mansion the depths of excavation and the depth of bored piles with the diameter of 1m as retaining wall are 16.9m and 26.0m ,respectively.

Sometimes, in the same excavation the diaphragm wall is used as retaining wall combined excavating with slop used in another side, if there is a desired surrounding condition.

Photo 1 Next Age Mansion
Dep. of exc.= 9.71~11.7 m, dep. of C.M.P. = 19m,
Breadth of wall = 8.7 ~ 9.7 m

Photo 2 Guo Mai Mansion
Dep of exc. = 9.8 m, cement mixed piles or inside with bored piles as wall

Photo 3 Jin Mao Mansion
Dep. of exc. =15.1~19.65m, dep. of diap. = 36m
thickness of diaphragm wall = 1m

Photo 4 Wan Du Mansion
Dep. of exc. =12.8m, dia. of circle bracing = 92m,
2 levels of R.C. bracing

Photo 5 San Jiao Di Square
Dep. of exc.= 12.5m, 3 levels of R.C. & steel pipe bracing

Photo 6 Yin Du Market
Dep. of exc. = 11.0m, radii of of arc = 31m & 26m

2.1.2 Earth pressure and water pressure

General speaking, the magnitude of earth pressure varies with the displacement of wall. It is summed the relationship between displacement and earth pressure can be considered as a hyperbolic type (Lu and Zhao,1996). Field measurements have shown that the active earth pressure can be calculated by Rankine's theory and the passive earth pressure is usually less than the measured one.

In design of wall one problem often to puzzle designer is how to calculate the lateral pressure. Principally, the wet unit weight of soil is used to calculate the earth pressure including water pressure for the clayey soils while for the sandy soils the earth pressure and water pressure should be calculated separately. However, in practice for safety sake the earth pressure and water pressure should be calculated separately to determine the lateral pressure although it is conservative for clayey soils.

In order to increase the stability of excavation to stabilize the passive zone is necessary, but the determination of range of stabilization and value of parameter depends on the designer experience, thus, the result may be either overestimated or underestimated.

In Shanghai in design of wall the ration of embedded depth of wall to the depth of excavation is controlled to be 0.8 to 1.0 and the value of calculated displacement of wall is usually limited to 3cm or it may be a little more with the permission of surrounding environment.

2.2 Bracing system

2.2.1 Bracing structure

Recently, with the development of computer and computation technology new bracing system appear constantly. Besides common well shape type and well shape with corner-bracing type, there are many other bracing types.

The principle used to select bracing system is to make full use of mechanical function of circle, ellipse, parabola and arch element. In practice to select one type or composite form according to the concrete condition of construction site and the latter is more suitable.

The typical examples are shown in Photos 3-6. It should be mentioned that the excavation depth of 19.65m in Jin Mao Mansion is the deepest, while the diameter of 92m for circle bracing in Wan Du Mansion is the biggest one in China.

2.2.2 Bracing axial force

There are many factors influencing on bracing axial force, such as change of temperature, shrinkage of concrete, surrounding earth pressure, heave or settlement of soldier pile, construction, and measurement equipment etc. e.g. the influence of temperature is 15-25% of axial force; the shrinkage stress of reinforced concrete even comes up to $10MN/m^2$(Zhao et al.1996).So, the axial force measured in the field is often considerably different from calculated value, some values in the field are 20-100% greater than calculated ones while some are only 60-75% of calculated. therefore, for safety sake the factor of safety is usually taken as 2 at least for the reinforced concrete bracing.

2.2.3 Soldier piles

Soldier piles are mainly applied to bear the self-weight of bracing structure and relevant construction load. When the possibly eccentric action of load and bracing stability caused by settlement or heave of soldier piles are taken into account, soldier piles should have enough strength rigidity and embedded depth.

2.3 *Relationship between the part and the whole*

Although the most important factor of design is to assure the whole safety, design of the part can not be neglected. Serious accidents happened in some projects because of the unreasonable design of joints.

3. CALCULATION PROGRAM PROBLEMS

Now the SUPER SAP-5 or SAP-90 based on elastic theory is the most common program to calculate the internal force and displacement of wall and bracing system. Naturally, the calculated results are always greatly different from the values measured in situ, e.g., the measured values of horizontal displacement are often 2-3 times more than the calculated ones, individually even up to 4 times. For safety sake the calculated value of horizontal displacement of wall should be controlled within 3cm, that is, the measured value will be about 10 cm. In fact ,during construction the displacement of wall relates to many factors, such as the rigidity of wall and bracing, earth pressure, excavating sequence, excavating speed, exposed time of soil mass, and so on. These factors are difficult to be considered completely, the discrepancy between measured and calculated values is unavoidable. Consequently, the more reasonable method and step should be the combination of three methods as follows:

Firstly, the calculated value of horizontal displacement of wall using the program mentioned above multiplied with an experienced coefficient, such as 2 or 3. This value is considered in preliminary design stage.

Secondly, a more reasonable elastoplastic program is used to calculate the horizontal displacement of wall.

Then, there are two values using elastic and elastoplastic programs, respectively, the expected value will be within the range of the two controlled values.

Thirdly, during construction a kind of back analysis method in accordance with the measured values can be used to trace the forecast, modify the calculated parameters and judge the correctness of elastic or elastoplastic program in order to make the decision in next stage.

It is worthy to be mentioned that the lasting period of creep of soil during excavation is about three months(Zhao et al.1996) and that the influenced range and displacement magnitude surrounding environment due to excavation can be forecasted.

4. CONSTRUCTION PROBLEMS

Generally, the causes of construction accident are summarized as follows;

a. Construction quality problem,
b. Excess excavation problem,
c. Management problem and
d. Luck psychology.

Moreover, the above causes are often criss-cross in same project, therefore, construction engineer must pay attention to the following main points.

1) Construction regulation and standard must be strictly obeyed.

2) It is very important that dewatering before excavation can provide a good construction condition in pit and improve the stability of excavation, dewatering system must keep on normal condition, otherwise construction would meet troubles.

3) Excess excavation is the first "enemy:" in construction. There are many lessons in construction sites, so, excess excavation must be strictly prohibited.

4) Effectively preventive measures should be taken to meet the emergency which may occur at any time during construction.

5) When adjacent building is also under construction, the influence on each other should be considered in design as well as during construction.

6) Information construction should be an important part of construction, the measured data in the field has to be seriously analyzed in time.

7) Two different types of wall in the same pit should be dealt carefully with to the excavated problems.

5 FIELD MONITORING PROBLEMS

Field monitoring is not only an important mean to examine and develop design theory, but also an essential measure to guide correct construction in time to avoid accident. So, it has become a kind of informative technology in the deep excavation engineering.

Table 1 Mearsured data of horizontal displacement of continuous pillar in 10 projects

No	Pit Area A, m² / Wall thicks. t, mm	Pit depth D,m / Wall embed. H,m	Bracing type / Level number	Wall top dis. S1,mm / Wall body dis. S2,mm	S1/D ‰ / S2/D ‰	S1/H ‰ / S2/H ‰
1	6100	3.4/15.8	RC	20	1.4	0.8
	800	26.0	3	83	6.3	3.2
2	3700	11.0	Steel pipe	25	2.3	1.1
	800	22.3/24.3	3	88	8.0	3.9
3	8340	10.3	Steel pipe	130	12.6	5.5
	600	23.5	3			
4	7400	12.0	RC	5.0	0.4	0.2
	800	23.5/25.0	3	108	9.0	4.7
5	5435	11.4	RC	6.5	0.5	0.3
	800	21.6	3	16.9	1.5	0.8
6	7500	16.0/18.0	H-type	124	7.7	4.1
	1000	30.0	3	113	7.0	3.8
7	4600	12.5	RC & Steel pipe	19	1.5	0.9
	800	25.5	3	120	9.0	4.5
8	22000	11.6/12.6	RC			
	800	24.0	2	106	8.8	4.4
9	5000	13.0/17.0	Steel pipe			
	800	23.0	3	40.3	3.1	1.7
10	23000	19.65	RC	33	1.7	0.9
	1000	36.00	4	50	2.5	1.4

5.1 Alarming problems

5.1.1 Critical data

Some data of field measurement and referred criterion on alarm are given in Table 1.

5.1.2 Alarming criterion

This is a serious technical problem as well as a comprehensive examination to monitor. In fact, it is very difficult to present an united criterion.. Here, some cases are given for reference.

Case 1, 7~8m in depth of excavation, cement mixing piles without bracing, working piles being constructed in adjacent project, The velocity of displacement measured by clinometer was 1.1cm/day for 12 days in succession, unfortunately, the monitor and construction unit did not pay attention to this sign of collapse, piling was still going on at the same speed, later, the velocity of displacement was up to 6-7cm/day in two days before destruction of wall.

Case 2, 8.1m~10.7m in depth of excavation, cement mixing piles without bracing. Informative construction was adopted during the whole construction, several times of alarms were given to construction unit :at the first time the horizontal displacement on the top of wall caused by excavation was 13 cm ;at the second time the horizontal displacement cause by excavation and piling in the adjacent project was over 19cm; at the last time the horizontal displacement on the top of wall increased more than 10cm/day within 3 days, i.e. the velocity was 4.2 cm/day because the rainwater could permeate into the wall due to rainy days and the pre-remained soil body in the passive zone was not enough. However, the construction unit paid attention seriously to the data and took the corresponding effective measures each time, so, this collapse danger had turned into safety.

Case 3, 13.5m in depth of excavation, triangle shape in plane, diaphragm wall with 3 levels of bracing, the horizontal displacements of middle points of three sides at 9-10m depth measured by clinometers were over 4 cm when the excavation was going on the top of second level of bracing. Moreover, the displacements were developing at the velocity of 0.8mm/day within 20 days in succession, the displacements of surrounding pipelines were all over 3 cm. The project is located at the important place of communication. In this condition monitor resolutely gave an alarm in time . Later , the fact had shown that this alarm was correct to avoid the possible accident.

5.2 *Suggestions*

Alarm to gas pipe is most important in the lifeline, according to the standard in Shaghai the settlement of alarm to gas pipe is 1cm. In practice the settlement in many projects is usually over 2cm or 3cm, even up to 10cm,in that case ,some measures should be taken to avoid possible accident, therefore, the standard value of alarm to gas pipe in Shanghai should be modified, 2cm is more reasonable.

5.2.2 Alarm to wall

The field data has indicated that the ratio of horizontal displacement to depth of excavation is between 0.5% and 1%. If this ratio is grater than 1%, it means the possible accident may occur; on the other hand, if the velocity of horizontal displacement of wall is up to 1cm per day, attention should be paid to this developing process. If this velocity occurs for three days in succession, the emergency measures should be taken immediately, otherwise the accident will be happened. In analysis of alarm it should be emphasized that the settlement or horizontal displacement and velocity should be taken into consideration, i.e. comprehensive analysis is required.

6. CONCLUSIONS

1. Engineer should pay serious attention to the deep excavation because of risky engineering.
2. The common points of success of these examples mentioned above are the design and construction based on science, creation, information construction and complete measures including emergency measures.
3. To attend the high level of design and construction, a practical earth pressure theory, excellent bracing system, accumulation of experience and lesson are needed.
4. The field monitoring should be an important part of construction to assure the success of project.

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