Study on Environment Problem and Its Prevention Caused by Underground Engineering in City

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***Abstract*—Our environment is coming in for the menace of negative influence caused by the large-scale exploitation of underground space in city, it is of great importance more and more to study such kind of problems. To achieve the exploitation of underground space in harmony with environment and optimize the underground-space-environment system. In this paper, we put forward the scientific meaning of exploitation of underground space in harmony with environment. Study the design method, scheme selection, subsidence forecast and damage evaluation exploringly that aim at decreasing the damage caused by underground space exploitation. At last, analysis and demonstrate the application take Qingdao sub-sea tunnel project as an example.**

***Index Terms*—underground excavation, in harmony with environment, subsidence forecast, timbering, construction distortion**

I. Introduction

Along with the acceleration of urbanization and the concentration of urban population and the high density of vehicle, the limited urban space become continuously excess load and the land for urban become seriously deficiency. The development and utilization of underground space is an inevitable trend. A widely accepted view had been put forward at present that the 19th century is the bridge time, the 20th century is tall buildings time, and the 21st century must will be the development and utilization of underground space one [1].

Although the development and utilization of underground space make great economic benefit and social benefit in relieving traffic pressure and resolving the urban space deficiency, it induce lots of negative effect on environment. Now days, most underground space exploitation focus on shallow layer and middle layer, besides, any kind of excavation will break the balance of stress, and newly stress distribution will be formed as well as overlying strata movement and deformation. As the influences such as movement, deformation, settlement and subside spread to ground surface, they will cause different degree of damage to the building, foundation, early structure, public underground pipe lines, underground facilities, road surface, roadbed and so on. Thereby, such damages result in a limitation to urban development and environmental protection [2]. In addition, underground excavation induces variety in level and quality of groundwater. Meanwhile, it brings about pollution source such as noise and exhaust gas.

People gradually realize the importance of underground excavation engineering in harmony with environment along with the growing concept of environmental protection. As it is known to us, underground excavation in harmony with environment is not only one of the topics of sustainable development strategy, but also the new subject to scientist. Therefore, it is of theoretical and practical importance to study the problems of urban underground excavation in harmony with environment. Thus, how to minimize the damage of urban underground excavation is what we concern especially in this paper.

II. Scientific Definition of Urban Underground Excavation in Harmony with Environment

The conception of external and internal environment must be taken seriously during urban underground excavation. The scope come under the influence of urban underground excavation is defined as "internal environment", "external environment" is the scope where is free of the influence. The environment mentioned in urban underground excavation refers to "external environment" mainly. It includes rock, soil mass, nearby constrictions, groundwater and living area nearby around with exploitation of underground space. The aim to study this problem is to find a harmonious way between underground excavation and the environment protection.

The scientific definition of exploitation of underground space in harmony with environment includes contents as follows:

Underground space coordinates with the aboveground one. It mainly means that we must planning, selecting site and designing in reason before the exploitation of urban underground space to ensure that we can avoid or reduce the conflict between the underground space and the constructions and pipes in process of exploitation. To the aim of reducing the harm of surrounding caused by the exploitation of underground space, we must consider the need of surrounding in the construction of underground space.

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Underground space coordinates with its surroundings. During the exploitation of urban underground space, we must take the request of the surroundings into account. A reasonable construction scheme is needed, in the process of excavation we must take effective methods to monitor, forecast, prediction and other measures to assistant the underground construction. Timely feedback is necessary to guide the next step of construction. Though the surrounding environment had a certain amount of disturbance by the construction, the impact can be restricted to a certain extent. So the relationship between the environment and surrounding is optimized [3].

The underground construction is in harmony with the surroundings after being put into use.

III. Studies on the Control of the Exploration on City Underground Space in Harmony with Environment

A. The Design of Underground Excavation in Harmony with Environment

It is of great importance that how to achieve coordination of underground excavation and the environment and how to take a rational measure to excavate.

1) The anti-damage urban design of underground structure

a. The anti-damage design of underground structure concerning geologic stress

The underground structure damage is due to the damage of stress environment directly. Because of the ground stress, especially the compressive, the rock mass is stable. In the process of excavating, rock should be disturbed not so much to keep stable. All these is the main idea of New Austrian Method that trying to obtain an effect from wall rock and alleviating the damage to wall rock to form a self-bearing system.

b. The anti-damage design of underground structure concerning stress redistribution

Owing to the stress redistribution, the wall rock will move towards the inner of the tunnel after excavating. If displacement evolves freely, the wall rock will be destroyed because of unstableness. In order to form a constraint to prevent the wall rock moving, supporting structure should be set up after excavation. Interaction of wall rock and supporting structure would exist until balance of resistance from the supporting structure and the action from wall rock. There would be a stable structure system which is named third stress state. Value of the supporting force can be received by equation (1) [4].

$$\left.\begin{aligned} p_i &= \frac{E_o}{r_c\left(\frac{t^2+1}{t^2-1}-\mu_o\right)}u \\ p_i &= Ku \\ K &= \frac{E_o}{r_c\left(\frac{t^2+1}{t^2-1}-\mu_o\right)} \\ t &= \frac{r_c}{r_s} \\ E_o &= \frac{E_h}{1-\mu_h^2} \\ \mu_o &= \frac{\mu_h}{1-\mu_h} \end{aligned}\right\} \quad (1)$$

Where, P_i is supporting force, u is displacement of the nodes to radius on the outside edge, K is the supporting stiffness which is determined by the supporting material and area, r_c, r_s and r are concrete covering layer's outside radius, inside radius and the distance to the center, E_h and μ_h are the Elastic modulus and Poisson ratio of concrete.

2) Study on anti-damage design of underground structure concerning ground environment damage

Settlement deformation, inclination deformation, curvature deformation, level displacement deformation and discontinuous deformation on the ground cannot avoided in the process of urban underground structure construction. The problems, such as Crack, settlement and inclination of around existing building, will be induced. A PC analysis system can solve the problems related to measured data processing and project forecasting and project evaluation system, which was opened out for ground deformation caused by excavation and relative experiment. According to different request, this system can realize the interface menu application, the interface menu input data, calculation, three dimension deformation, contour protract, fitting analyses of data based on the measured data.

3) The design measure of urban underground coordination excavation in harmony with environment

At present, design information is the most popular one of underground engineering design [5, 6], which flow chart is shown as Fig. 1. Its difference from other methods is that inspection system must be installed in the process of construction. Through message from inspection, the stableness and effect of supporting can be described indirectly, so that the new supporting parameter can be acquired to feed back to design and construction decision.

B. Evaluation of Influence of Excavation to Buildings Nearby

There has no standard to divide protection grade of the building in P. R. China now. The limits value usually was set by experts, which is dependent on their experiences [7, 8]. For example, Beijing underground construction regulated that each settlement value of ground cannot exceed 30mm. Shenzhen underground construction regulated that each settlement value of ground cannot exceed 40mm and inclination of ground cannot exceed 1/300. Based on the local project experience, according to the require of environment, Shanghai subway company suggested that control standard of the deformation can be divided to 4 grades in deep excavation engineering. In general, foundation pit engineering constructions in down town execute I or II protection grade standard, in the area next to subway should execute special protection standard. On the basis of analysis of concrete environment and the principle of safety and economy, corresponding standard should be chosen to instruct design in order to get optimization between underground excavation and environment.

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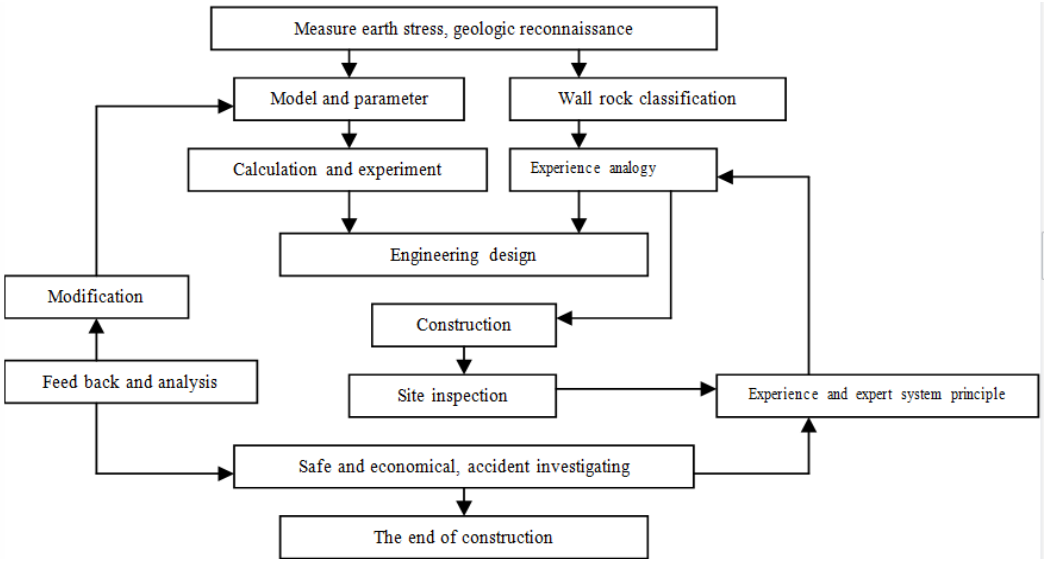

Figure 1. Flow chart of the information-based design

C. *Preventing Measure of Environment Damage Caused by Underground Excavation*

Underground excavation engineering is developing on a large scale in China with development of the economy now. There will be a different disturbance and damage between different excavations. So according to special demands and limits of damage grades, we should take different measures to decrease the damage. And try to realize the harmony of underground excavation and environment protection.

1) The measure to supporting the wall rock

Once original stress departs from the balance state caused by underground excavation, the internal stress field will change. If stress in the new field is not exceed the capacity of rock, the rock mass will keep a self-balance state. Or else, around rock would be destroyed to affect the environment. If the damage to rock has occurred, the wall rock would be supported rationally so as to reduce effect to environment.

Referring to supporting, some parameters must be established such as supporting form, supporting time, supporting rigidity, supporting rationality and economical supporting. Supporting should be a measure to strengthen the rock stability. Therefore, choosing parameters should consider several aspects such as improving state of wall rock stress, mobilizing the self-bearing capacity, effect of interaction between rock and supporting. On the basis of these, the capacity and efficiency of supporting should be improved. For example, anchor is an effective measure because it can reinforce internal rock in favor of making full use of rock strength. When earth stress exceeds the capacity of supporting, it is a useful measure to select a kind of deformable supporting structure to adapt the earth stress.

When underground excavation projects were under an important area of a city, top covering rock mass is not allow collapsing or having a large deformation. On the foundation of making full use of rock self-bearing capacity and forming the interaction of wall rock and support, we must support the wall rock immediately to assure excavation safe and economical at the same time. Therefore, through rational support, decreasing the effects to environment from underground excavation is the best way to realize coordination between excavation and environment.

2) The measure to prevent ground buildings damaging from underground excavation

The members of building are not ideal elastic solid but Elastic-plastic solid, so the relationship between strain and stress is not fit to the Hooke's Law. After excavation settlement, movement and deformation will occur on the ground, then will spread to the around building, original stress state of building would be changed. Stress in the members of building will be redistributed. These would induce the concentration of stress and additional force, then building will break when its stress gets to ultimate capacity.

Taking the characteristics of ground movement, deformation and building, different excavation projects should take different measures to prevent the buildings from excavation damage. At present, there are several prevention measures as following.

a. Anti-deformation buildings

In order to assure the building safe, this method is to take some special structure measure to resist the additional stress caused by ground movement and deformation when the building was designed and constructed. For example, we can take some measures such as adopt a rational plane layout, special treatment of the foundation and wall, adding constructional column and ring beam, setting ground deformation cushion gully, etc.

b. Reinforcement technology of building

After underground excavation, it is an effective reinforcement measure that adding the anti-deformation structure system including flexibility and rigidity steps to the foundation and wall of building, then the additions would have an interaction with original building structures. The intention is to reduce the additional stress

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in the mainly supporting members of building and strengthening the capacity to bearing ground deformation.

c. The technology of buildings adjusting

In order to counteract the effect on buildings caused by ground inclination after excavation, two technologies, system of adjusting inclination and replaced ground base, can be adopted to leveling the building.

d. Technology of buildings movement

The movement of buildings is a technology including following contents. Firstly, the building is moved on a bracket which installed roller and orbit. Secondly, connection between building and foundation is cut off to make the building become removable. Thirdly, the building is moved to a scheduled place by draught device. Of course, if the building is a new one, the second step can be omitted. With the development of city construction in China, this technology will have a very widest market [9].

IV. Applications

Kiaochow bay Submarine tunnel is the south tunnel of the south tunnel and the north bridge of Qingdao, which is the important tie of Qingdao and Huangdao Island. Kiaochow bay Submarine tunnel connection engineering of Qingdao area starts in Kiaochow bay bay-mouth Submarine tunnel terminal of Qingdao area, northwards is in form of up and down separation double tunnel along with Sichuan road and Yunnan road, is out of ground in north of Dongping road junction and links to Viaduct, joins in the top of Shanxi road junction and links to the third term Expressway engineering. Fig.2 is the second section of Submarine tunnel connection engineering of Qingdao area. The example mainly study on Yunnan road main-line ZK1+160-ZK1+460 section (the length is about 300m, the net width is 13.5m). The relation between this tunnel section and building under construction of peripheral areas shows as Fig.3.

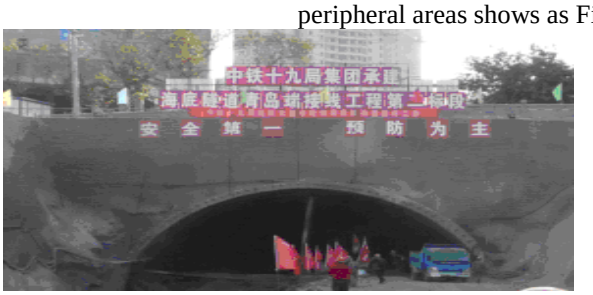

Figure 2. Tunnel entrance

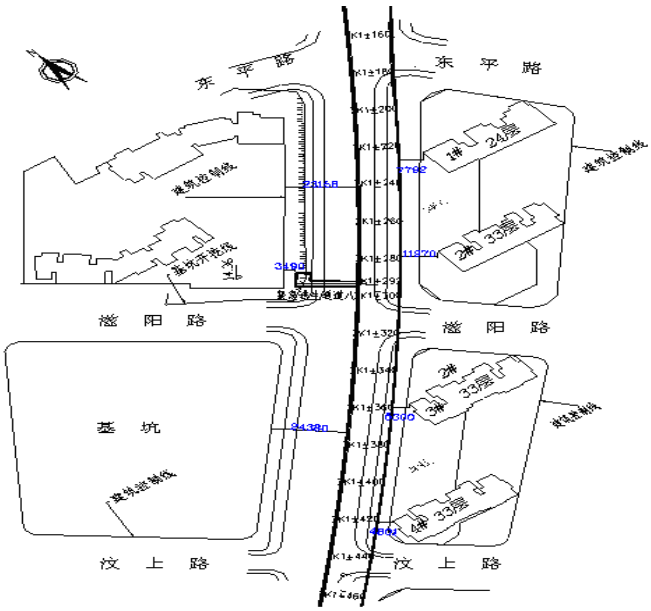

Figure 3. Position relationship between tunnel excavation section and surface buildings

Wall rock grade is Ⅱ-Ⅵ, surrounding rock grade is very low in partial section, according to the result of drilling ,tunnel connecting line excavated top boundary mostly imbed weak weathered rock, light weathered rock, filling type Structure develops in partial section, cuts coarse grain granite used as rock foundation that destroys integrity of rock mass, at the same time, due to affection of structure, surrounding rock weathering become harder and harder, manifests as granular form structural rock, surrounding rock grade decreases, integrity degree decreases. May cause fall-block and landslide etc on the process of excavation, especially in structural belt which pore permeability is relatively strong, surrounding rock landslide, leakage cause tunnel's normal and safe construction serious hidden trouble.

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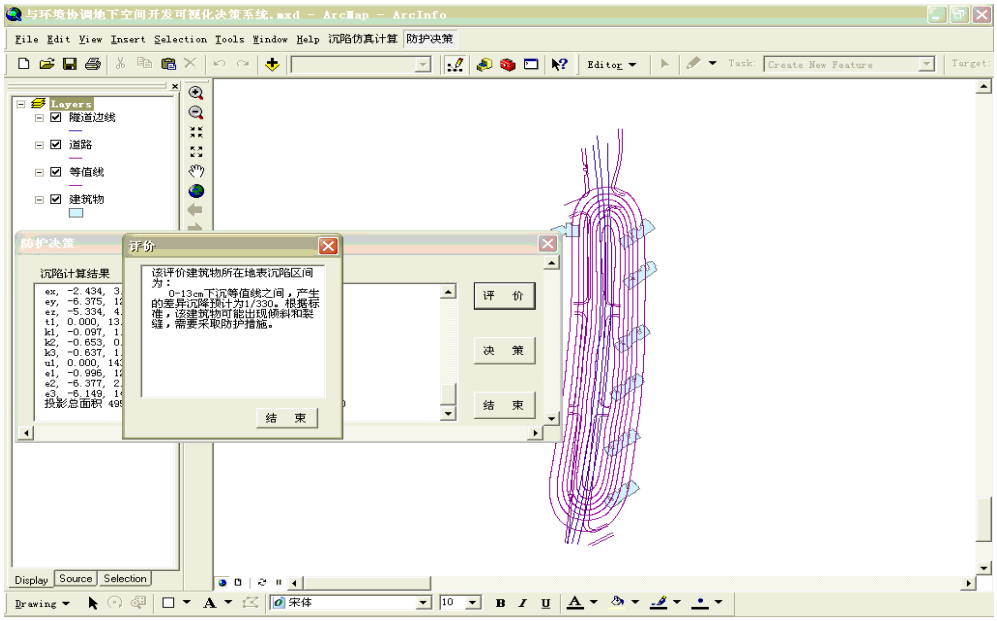

Figure 4. Result of subsidence simulation calculation

In order to know the situation of surface subsidence in the whole affected range of tunnel excavation, we apply subsidence simulation calculation software, compile the procedure of surface moving and deformation and establish the automatic list and mapping system to generate subsidence isolines, the surface subsidence panorama is expected to influence scope of whole excavation in Fig. 4. It can be obtained from the calculation, the maximum value of surface subsidence occurred in the X=0, that is, the tunnel center, its value is 16.61cm, the surface tilt shows in three regions, one is on the tunnel center line, the other two are in the tunnel on both sides of the center line, the max value is 0.46cm/m, the surface curvature for the maximum is 0.05cm^{-1}. The level displacement of surface for the maximum is 7.8cm, the level deformation of surface for the maximum occurred in the tunnel center around, the value is 0.66cm/m, the width of the surface subsidence is about 80m. Surface movement and deformation is very small beyond the 80m.

The damage degree of buildings affected by the underground excavation depends mainly on its surface where the value of the deformation and its ability to resist deformation. According to the provisions of the response under different settlement difference of buildings, the settlement difference of the general framework of the reinforced concrete structure reach 1/500, then cracks appeared, in the right building the largest settlement difference reach 1/300, in order to guarantee the normal use of the building, need to take some reinforcement measures to reduce the damage caused by surface deformation to the buildings. Construction measures include: comply with the first forecast, advanced pipe, strong support, weak explosion, closed quickly, frequentative measurements. In the principle of construction, to the weak surrounding rock increase arch section long pipe roof, small pipe and so on advanced support measures. When excavating with CD (Center Diaphragm) method or double sides heading method to excavate to the bad surrounding rock section, shorten footage in time spray concrete to reduce the exposure time of surrounding rock, take the two impending pore straight holes cutting technology to reduce the disturbance of bedding rock plane of weakness caused by explosion, after every step excavation need to carry out the initial support in time, to ensure the supporting structure having sufficient strength, geological prediction of having water inrush, burst mud occurs , using whole section advanced curtain to stop Water and grout. For the relatively great deformation of the surrounding rock, take lengthening bolts, encrypted steel frame etc measures to control the deformation and appropriately increase the reservation settlement. Environmental protection measures include as follow.

a. For the tunnel around high-rise section, take high-rise building foundation reinforced treatment after underground excavation.

b. In the process of foundation reinforcement construction, according to the difference of all foundation, take different methods of reinforcement.

c. Grouting reinforcement.

d. Bolts and mesh reinforcement.

e. Examination and repair to the waterproof layer.

f. Concrete pouring.

V. Conclusions

According to the damage of underground excavation to the surrounding environment in traditional conditions, this paper combined with the idea of environmental protection, putting forward the scientific definition of urban underground excavation in harmony with environment. Find a way to solve the problem between the urban underground excavation in harmony with environment with the different stages of the development and design of the urban space exploration. So we should take measures actively and timely, resolving the

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environment problems of the urban underground space projects and creating a harmonious living environment.

CONFLICT OF INTEREST

The authors declare no conflict of interest for the paper.

AUTHOR CONTRIBUTIONS

All the authors made significant contributions to the work. Guangming Yu, Guangtai Zhang and Yongjun Qin conceived this study; Liangfu Xie and Xiankun Zeng wrote the paper; Guangming Yu reviewed the manuscript for scientific contents.

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