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Application of Risk-time Function to the -35.3m Scale Pit Deep Excavation of Baosteel Project

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ABSTRACT: In this paper the risk-time function is presented for qualitative and quantitative risk analysis based on the character of deep excavation in soft soil layers. Qualitative risk analysis shows that deep well dewatering failure and bottom boiling are the most important risk factors of scale pit deep excavation. Quantitative risk-time function analysis can estimate the risk at the time of peak value of excavation failure probability, and show that dewatering the second aquifer can reduce the total risk of bottom boiling failure greatly at low cost.

1 INTRODUCTION

The third hot rolling plant project (BH1880) of Baosteel project has a group of large and deep excavations located in the soft soil layers with two confined aquifers. The largest excavation is the main plant box basement of about 650m in length, 100m in width and 10m in depth, which is the largest one of all Baosteel project excavation. The deepest excavation is the scale pit of 35.3m in depth and 30.0m in diameter, which is the deepest finished excavation in Shanghai.

Because the scale pit is surrounded by the fast developing project, and the scale pits of other project had caused lots of risks and impacts, risk management for this scale pit is significant for the project. Risk management includes the works of collecting initial information for risk management, estimating risk, defining strategies for risk response plan, carrying out risk control and monitoring, reforming risk management. In this paper, based on the character of deep excavation in soft soil layers, the risk-time function is presented for qualitative and quantitative risk analysis.

2 RISK-TIME FUNCTION

2.1 Risk-time Function Model

In order to investigate the risk history of deep excavation, the risk-time function is presented in this paper,

$$r(t) = p(t)\,q(t) \tag{1}$$

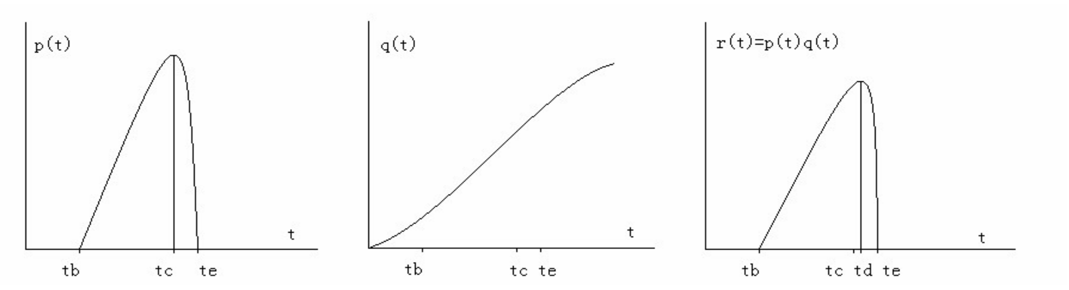

Figure 1 Risk-time function

Where $r(t)$, $p(t)$ and $q(t)$ are respectively risk-time function, excavation failure probability-time function and probable loss-time function.

2.2 Failure Probability-time Function Model

Based upon the character of failure probability of deep excavation in soft soil layers, the model of excavation failure probability-time function $p(t)$ is presented in this paper, with three essentialities:

- The probability of excavation failure increases gradually from zero at the beginning time (t_b) of excavation till bottom concrete cast.
- The probability of excavation failure reaches its maximum value at the time of bottom concrete cast (t_c).
- The probability of excavation failure decreases gradually from its maximum value at the time of bottom concrete cast (t_c) to zero at the end time (t_e) of excavation construction.

2.3 Probable Loss-time Function

Probable loss-time function describes the time-depended lost value induced by excavation failure. It can show the loss value of project or production within the influenced area of excavation failure. In most case of construction projects, it is an increasing function,

$$q(t) < q(t+\Delta t), \quad \Delta t > 0 \tag{2}$$

It means that with more and more infrastructures and production equipments being constructed in the influenced area, probable loss caused by excavation failure increases at the same time.

2.4 Influenced Area of Excavation Failure

For an excavation of depth h, excavation failure would cause probable loss of the excavation and infrastructure or production equipment within the ring area of width μh. Probable loss includes direct and indirect loss. Indirect loss includes reconstruction loss and production loss.

2.5 Measures of Risk

In this paper, two methods are suggested to measure risk.

(1) Maximum risk value

Find the maximum value of risk-time function $r(t) = p(t)\, q(t)$,

$$\| r(t) \|_{\max} = \max(p(t)\, q(t)) \tag{3}$$

(2) Integration of risk-time function

Integrate the risk-time function of excavation $r(t) = p(t)\, q(t)$ from the beginning time (t_b) to the end time (t_e), Time integration can show the degree of risk in the whole excavation time.

$$\| r(t) \|_{\text{int}} = \int_{tb}^{te} p(t)\, q(t)\, dt \tag{4}$$

For risk-time function $r(t) = p(t)\, q(t)$, it is difficult to obtain the failure probability-time function $p(t)$ and probable loss-time function $q(t)$ in the whole excavation stage. However, it is possible to obtain the peak value of $p(t)$ and the corresponding value of $q(t)$. Therefore, maximum risk value $\| r(t) \|_{\max}$ is more practicable for measuring the excavation risk.

2.6 Risk-time Control

Let's study two excavation plans, which have the similar failure probability-time function shape and peak value, except that plan I begins Δt earlier than plan II,

$$p_I(t) = p_{II}(t+\Delta t) \tag{5}$$

If other parts of the project remain the same, and the probable lost-time function $q(t)$ remain the same, then the risk-time functions of the two plans are respectively

$$r_I(t) = p_I(t)\, q(t) \text{ and } r_{II}(t+\Delta t) = p_{II}(t+\Delta t)\, q(t+\Delta t) = p_I(t)\, q(t+\Delta t) \tag{6}$$

For increasing probable loss-time function,

$$r_{II}(t+\Delta t) - r_I(t) = p_I(t)\,(q(t+\Delta t) - q(t)) \geq 0 \tag{7}$$

Therefore

$$\| r_I(t) \|_{\max} < \| r_{II}(t) \|_{\max} \tag{8}$$

Because

$$\| r_I(t) \|_{\text{int}} = \int_{tb}^{te} p_I(t)\, q(t)\, dt \text{ and } \| r_{II}(t) \|_{\text{int}} = \int_{tb}^{te} p_I(t)\, q(t+\Delta t)\, dt \tag{9}$$

Hence

$$\| r_I(t) \|_{\text{int}} < \| r_{II}(t) \|_{\text{int}} \tag{10}$$

So, plan *I* which begins Δt earlier than plan *II* has smaller risk.

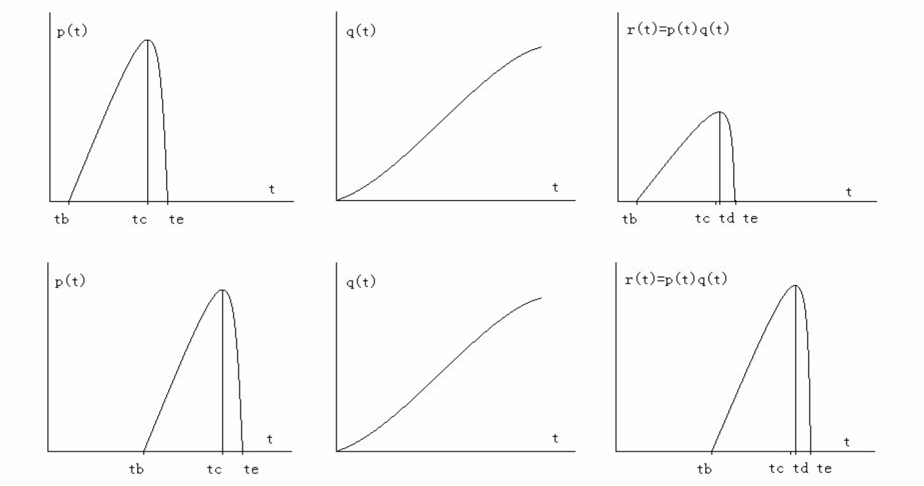

Figure 2 Two excavation plans with different beginning time

3 INITIAL INFORMATION FOR RISK MANAGEMENT

3.1 Geology Conditions

Baosteel is located near the south bank of Yangtze river, in the north suburban of Shanghai. Around the scale pit, the soil layers from ② to ⑤ consist of estuary deposits Q_4, which are of low degree of consolidation, low strength and large compressibility. The soil layers from ⑦ to ⑨ consist of marine deposit Q_3, which are of relative high strength and low compressibility.

Table 1. Parameters of the soil layers

Soil layer	layer name	T (m)	γ_0 (kN/m^3)	ϕ_{uk} (°)	C_{uk} (kPa)	ϕ_k (°)	C_k (kPa)	K_0	E (Mpa)
①$_1$	backfill soil	1.55	18.4					0.50	-
②$_3$	clayey silt	1.5	18.5			22.0	11.0	0.45	5.0
③$_2$	clayey silt	5.9	18.5			24.0	8.0	0.40	6.0
③$_3$	mucky clayey silt	2.1	17.4	1.0	23.0	14.0	11.0	0.60	3.0
④	mucky clay	11.5	17.0	1.0	23.0	12.0	11.0	0.70	5.0
⑤$_1$	silty clay	9.5	17.9	2.0	38.0	18.0	17.0	0.55	9.0
⑤$_2$	silty clay	9.4	18.1	2.0	50.0	20.0	17.0	0.50	18.0

⑦$_1$	sandy silty	15.6	18.5	-	-	25.0	7.0	0.35	31.0
⑦$_2$	silty sand	11.7	18.7	-	-	26.0	7.0	0.32	32.0
⑧$_1$	silty clay	5.3	18.1	6.7	41.4	20.0	19.0	0.5	34.0
⑨$_1$	silty sand	4.1	19.4			30.0	3.0	0.32	64.0

Diaphragm wall is built of 53.0m in depth, with sandy silt ⑦$_1$ as bottom bearing layer. Below the scale pit, there are two confined aquifer layers. The first one consists of sandy silt ⑦$_1$ and silty sand ⑦$_2$, with the top level of -40~-42m, and the water pressure head altitude of -4.3m. The second one consists of silty sand ⑨$_1$ and medium sand ⑨$_2$, with the water pressure head level of -3.9m. The two confined aquifers are separated by silty clay ⑧$_{1,}$ and partly connected by geological survey deep well.

In table1, we denote T the thickness of soil layer, γ_0 the gravity density, Φ_{uk} and C_{uk} the strength results of undrained and unconsolidated triaxial shear test, Φ_k and C_k the strength results of quick shear test, K_0 the lateral pressure coefficient, and E s the pressure modulus.

3.2 Similar scale pit and dewatering information

Practice cases of scale pit excavation and deep well dewatering confined aquifer in Shanghai soft soil layers are collected. The problems and difficulty encountered are studied.

Table 2. Main factors of Baosteel project scale pits over -30m deep

Hot rolling project	BH2050	BH1580	YH1780	BH	BH1880
construction age	1987	1995	2002	2003	2006
excavation depth	32.2	34.7m	32m	31.6m	35~36m
diaphragm depth	50.7m	53m	53m	51.1m	53m
diaphragm thickness	1.2m	1.2m	1.0m	1.0m	1.0m
diaphragm inner diameter	27.54m	29.43m	27.70m	22.60m	29.60m
thickness of lining	1.0m	1.0m	0.8m	0.8m	0.8m
reverse construction	1	1	5	5	5

3.3 Construction Program of Scale Pit

By studying collected information, the construction program of the scale pit is planed.

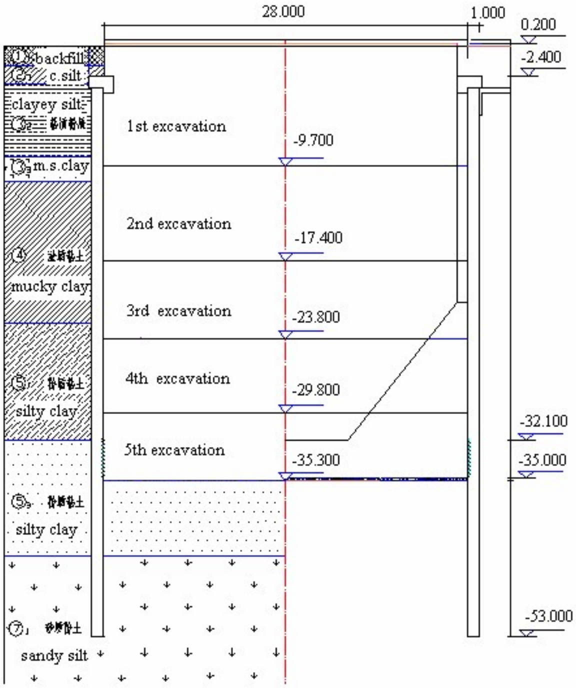

Figure 3 Scale pit elevation section

First a diaphragm wall of 53.0m in depth, 1.0m in thickness and 30.0m in outer diameter is built. Then excavate within the diaphragm wall for four times at the level of -9.7m, -17.4m, -23.8m, and -29.8m. and at each level the inner concrete linings of 0.8m in thickness are built. Finally excavate to the bottom level of -35.3m and reinforced concrete bottom plate and inner structures are built.

4 ESTIMATION OF RISK

4.1 Identification of Risk Factors

By investigating, discussing, and experts consulting, main risk factors are discovered as following:

- Risk of diaphragm wall trench difficulty
- Risk of diaphragm wall joint leakage
- Risk of deep well dewatering failure
- Risk of bottom boiling induced by confined water
- Risk of structure damage of diaphragm wall and inner lining
- Risk of soil damage and bottom heave

4.2 Qualitative Risk Analysis

Results of qualitative risk analysis are presented in table 3.

Table 3. Results of qualitative risk analysis

risk factor	reason	impact	possibility	risk degree
Diaphragm wall trench difficulty	trench collapse, digging difficulty	ground surface collapse, scheme delay, partly filled soil in diaphragm wall joint	B	C
diaphragm wall joint leakage	underground water leakage	ground surface collapse, excavation difficulty, person and machine risk	B	B
deep well dewatering failure	electricity supply break	large area ground surface collapse, damage of other finished buildings, displacement of installed production equipment, person and machine risk, project and production delay	A	A
	water from deep well become worse		A	A
	pump damaged		A	A
bottom boiling induced by confined water	confined aquifers damaged and boiling		A	A
structure damage of diaphragm wall and inner lining	Soil layer , size error of diaphragm wall	ground surface collapse, damage of other finished buildings, person and machine risk, project and production delay	B	B
soil damage and bottom heave	weak strength of soil, less depth of diaphragm wall	ground surface collapse, damage of other finished buildings, person and machine risk, project and production delay	B	B

4.3 Influenced Area and Probable Loss of Bottom Boiling

Qualitative risk analysis shows that deep well dewatering failure and bottom boiling are the most important risk factors. Influenced area of excavation bottom boiling can be obtained as two ring regions. The first one is the ring region outside scale pit with the width equal to the depth of diaphragm wall. In this area, excavation failure would cause large area ground surface collapse, damage of finished buildings. The second one is the ring region outside the first one and with the width equal to the depth of diaphragm wall. In this area, excavation failure would cause displacement of installed production equipment, and delay of project and production

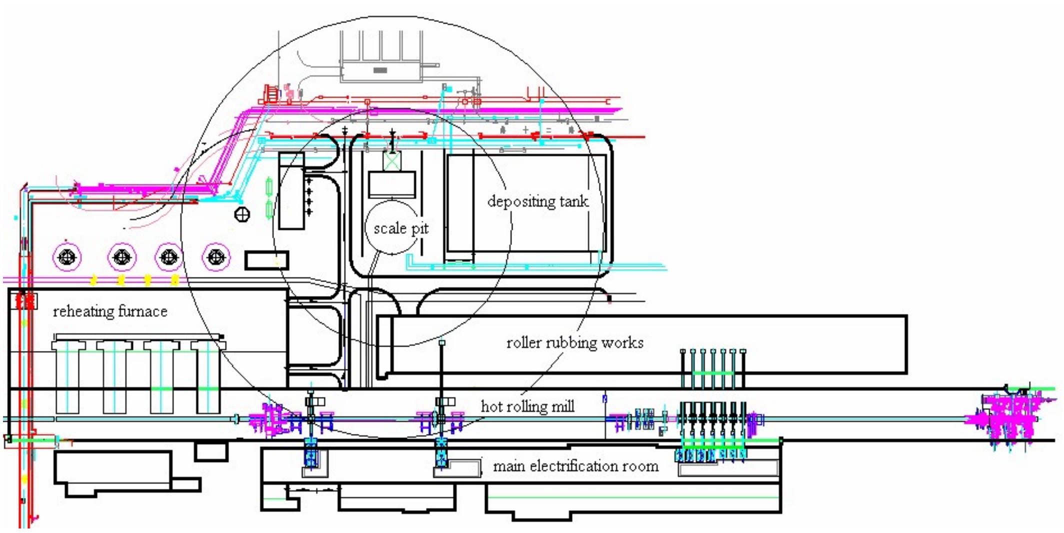

Figure 4 Influenced area of excavation failure

Probable direct loss-time function of scale pit excavation failure can be obtained as shown in figure 5. Indirect loss-time is difficult to estimate in the whole excavation time. However, it is possible to estimate the indirect loss at the time of peak value of $p(t)$. The reconstruction loss is over 5000×104 yuan, and the production loss is over 150000×104 yuan.

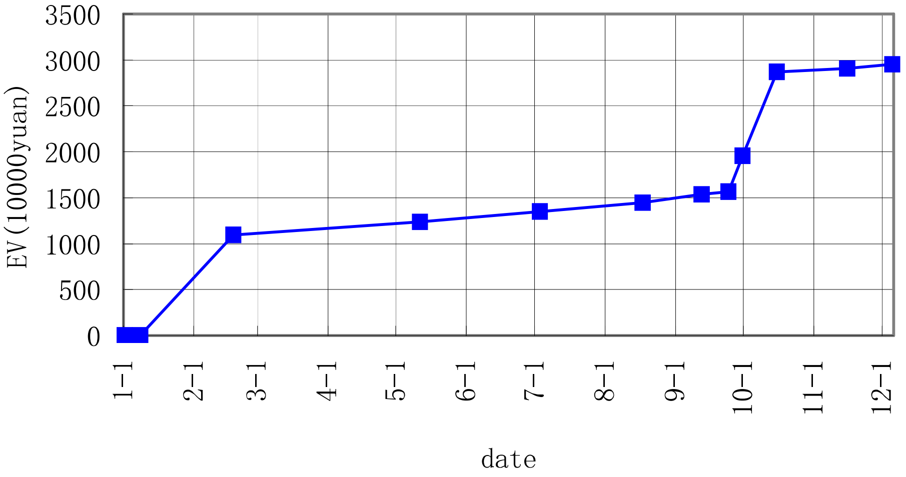

Figure 5 Influenced area of excavation failure

Table 4. Probable loss at the time of risk peak

type of loss	direct loss	reconstruction loss	production loss
loss（10^4yuan）	1540	>5000	>150000

4.4 *Quantitative Risk Analysis of Bottom Boiling*

Below the scale pit, there are two confined aquifer layers. For the first aquifer of sandy silt ⑦$_1$ and silty sand ⑦$_2$, the water pressure head altitude is reduced to -36m by deep well dewatering. Originally, the second aquifer of silty sand ⑨$_1$ and medium sand ⑨$_2$, are not considered requiring dewatering. However, as detail geology survey results show that at some place the thickness of silty clay ⑧$_1$ is not enough to resist the water pressure of the second aquifer. Therefore, its water pressure head is reduced from the level of -3.9m to -5.4m.

Table 5. Gravity density of soil layers（kN/m3）

soil layer	sample	max	min	average	standard deviation	variance factor
⑤3	298	18.8	17.5	18.1	0.23	0.01271
⑦1	705	20.4	17.8	18.5	0.27	0.01459
⑦2	114	19.4	17.8	18.7	0.32	0.01711
⑧1	146	19	17.6	18.2	0.31	0.01703

Table 6. Thickness of soil layers (m)

soil layer	sample	max	min	average	standard deviation	variance factor
⑤3	4	8.9	5.22	7.0675	1.681535	0.23792
⑦1	4	17.2	12.5	14.825	2.027108	0.13674
⑦2	4	11.7	11.4	11.55	0.173205	0.015
⑧1	4	4	1.8	2.95	0.9	0.30508

Assuming gravity density and thickness meeting normal distribution, the peak failure probability of bottom boiling on the condition of dewatering the second aquifer or not dewatering the second aquifer can be estimated. Then substitute in $r(t) = p(t)\ q(t)$, risk value can be obtain.

Table 7. Risk value of excavation without dewatering the second aquifer

bottom level (m)	reliability index	failure probability	direct loss risk（10000y）	reconstruction loss risk（10000y）	production loss risk（10000y）	total risk（10000y）
-30.0	3.392942	0.000350	0.539	1.75	52.50	54.789
-30.3	3.003966	0.001345	2.071	6.725	201.75	210.546
-30.0*	3.520476	0.000215	0.331	1.075	32.25	33.656

Table 8. Risk value of excavation dewatering the second aquifer

bottom level (m)	reliability index	failure probability	direct loss risk（10000y）	reconstruction loss risk（10000y）	production loss risk（10000y）	total risk（10000y）
-30.0	4.447044	0.0000043	0.0066	0.0215	0.645	0.673
-30.3	4.058068	0.0000245	0.0377	0.1225	3.675	3.835
-30.0*	4.574578	0.0000025	0.0039	0.0125	0.375	0.391

* Pit bottom covered with concrete cushion of 0.3m in thickness

Dewatering the second aquifer which costs 80×10^4 yuan., reduces the total risk of bottom boiling failure from 210.546×10^4 yuan to 3.835×10^4 yuan.

5 RISK MANAGEMENT STRATEGIES AND RISK CONTROL

For the risk factors such as diaphragm wall trench difficulty, diaphragm wall joint leakage, deep well dewatering failure, bottom boiling induced by confined water, structure damage of diaphragm wall and inner lining, soil damage and bottom heave, risk mitigate is chosen as risk management strategy.

Risk monitoring and control are strictly carried out by dynamical feedback of site inspection and monitor of settlement, displacement, soil and structure stress, water pressure level. As the deep well group dewater the two confined aquifers pressure successfully and the bottom concrete base is quickly constructed, the whole project is well protected from the most important risk factors of deep well dewatering failure and scale pit bottom boiling.

6 CONCLUSIONS

Main conclusions can be obtained as following:

-Based on the character of deep excavation in soft soil layers, the risk-time function is presented for qualitative and quantitative risk analysis.

-Scale pit deep excavation risk management includes the works of collecting initial information for risk management, estimating risk, defining strategies for risk response plan, carrying out risk control and monitoring, reforming risk management.

-Qualitative risk analysis shows that deep well dewatering failure and bottom boiling are the most important risk factors of scale pit deep excavation.

-Quantitative risk-time function analysis can estimate the risk at the time of peak value of excavation failure probability, and show that dewatering the second aquifer can reduce the total risk of bottom boiling failure greatly at low cost.

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