

Study on the Accident-causing of Foundation Pit Engineering

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Abstract. With the development of high-rise buildings and underground space, a large number of foundation pit projects have occurred. Frequent accidents of it cause great losses to the society, how to reduce the frequency of pit accidents has become one of the most urgent problems to be solved. Therefore, analysing the influencing factors of foundation pit engineering accidents and studying the causes of foundation pit accidents, which of great significance for improving the safety management level of foundation pit engineering and reducing the incidence of foundation pit accidents. Firstly, based on literature review and questionnaires, this paper selected construction management, survey, design, construction, supervision and monitoring as research factors, we used the AHP method and the Dematel method to analyze the weights of various influencing factors to screen indicators to determine the ultimate system of accidents caused by foundation pit accidents; Secondly, SPSS 21.0 software was used to test the reliability and validity of the recovered questionnaire data. AMOS 7.0 software was used to fit, evaluate, and explain the set model; Finally, this paper analysed the influencing factors of foundation pit engineering accidents, corresponding management countermeasures and suggestions were put forward.

1. Introduction

On June 20, 2017, a collapse accident occurred in the foundation pit of the heat receiving well in Fengdong New City, Xi'an, causing a big accident with 3 dead and 1 injured. With the continuous development and utilization of underground space caused by the increase of high-rise buildings, the scale of the foundation pit works and complexity are increasingly moving in the direction of "deep, big, near and tight". The construction of foundation pits is a high-risk construction project with the characteristics of large project volume, tight schedule, many construction projects, complex construction technology, many uncertain risk factors, and large impact on the social environment ^[1-2]. According to the research, more than 70% of the accidents are caused by poor management on site and unsafe behaviors of people ^[3]. The foreign scholar Petersen ^[4] (1971) put forward the compound causal theory model, pointing out the safety accidents caused by the defects and failures in management rules and regulations, management procedures, supervision effectiveness and staff training. Hyun Ho Choi ^[5] et al (2008) identified the risks of excavation work and believed that timely monitoring would reduce the probability of excavation accidents. Domestic scholars Zhao Tingsheng, Lu Xuewei and Fang Dongping ^[6-7] (2005) and others on the construction incentives, quality management and safety control conducted a survey, they believe that the frequency of accidents caused by indirect factors is higher than the frequency of accidents caused by direct factors. Li Lixin ^[8] et al. (2006) applied fuzzy comprehensive



evaluation method to evaluate the safety of excavation engineering, the main causes of excavation engineering accidents are summarized as follows: construction unit management problems, exploration problems, design problems and construction problems. Lan Shouqi^[9] (2009) summarized the causes of foundation pit accidents into three categories: nature, environment and construction, analyzed the failure mechanism of foundation pit engineering.

Scholars tend to research on construction technology, risk research and evaluation research. Most of the research focuses on the analysis of the causes of accidents during the construction of foundation pits and puts forward some suggestions such as safety inspection, safety management, safety supervision and legislation. However, little attention has been paid to the interaction between the causes of pit accidents. However, various factors and causes of pit excavation accidents are systematically analyzed. The structural equation modeling method is used to analyze the influencing factors and mutual relations of pit excavation accidents, and the corresponding management measures are put forward. It is very important to strengthen the safety management of foundation pit excavation, the incidence of accidents has important practical significance.

2. Case study

2.1. Accident factor extraction

Through the actual investigation of construction foundation pit engineering in Shaanxi and Beijing, combined with the literature reading, through the analytic hierarchy process(AHP) and the DEMATEL method to determine the weight of the foundation pit engineering and screen out the index with a relatively small weight. Finally, the set of influencing factors for engineering safety management of foundation pit containing 6 first-level factors and 30 second-level factors are determined. Due to the limited space, the specific screening process is omitted.

2.2. Study sample descriptive statistics

There are many links involved in the construction of the foundation pit, and there is a certain connection with the management abilities of the construction unit, the technical level of survey and design, the on-site management ability of construction and supervision, etc. The soil quality and geographical conditions all over the country also vary. To ensure the objectiveness and comprehensiveness of the research, 200 questionnaires were issued in 19 provinces including Beijing, Shaanxi, Hainan, Guangdong and Jiangxi, 165 questionnaires were returned, 20 invalid samples and 145 valid questionnaires, the effective recovery rate was 87.9%. Sample demographic information is as follows, the educational level is composed of: 68% undergraduate education, tertiary education accounted for 19%, other education accounted for 13%; working life is composed of: more than 10 years of service accounted for 52%, 5 to 10 years of service accounting for 33%; among the units involved in the investigation, 74% are construction and construction units, 10% are design units, 5% are survey units and 11% are supervisory and monitoring units. The positions include project managers, construction team leaders, security chiefs, security officers, designers, supervisors, and technical ministers. According to the demographic information of the sample, the sample structure of this survey is relatively reasonable. The distribution of the surveyed subjects in terms of qualifications, seniority and departments is more in line with the actual situation and has a certain degree of universality.

Table 1. Accident-causation of excavation

The first-level factor	The second-level factor
Construction unit management factors	Qualification examination and bidding procedures (KS1), Safety capital investment (KS2), Schedule reasonableness (KS3), Safety management measures (KS4)

Survey factors	Qualification (KC1), Survey data analysis and processing levels (KC2), Investigation of reasonable distribution of (KC3), Detailed geological survey of hydrological (KC4), Survey data and the reality of conformity (KC5)
Construction factors	Groundwater treatment level (SG1), the level of construction technology (SG2), A program to modify arbitrary (SG3), Information construction situation (SG4), Safety tests, Comprehensiveness of the content (SG5)
Design factors	Qualification units (SJ1), the reliability of the program (SJ2), Supporting structure design is reasonable (SJ3), Technology demonstration case (SJ4), Water and soil control measures (SJ5), Design changes timeliness of communication (SJ6)
supervision factors	Supervision unit qualification (JL1), Supervisors work attitude (JL2), the construction quality supervision (JL3)
Monitoring factors	Qualification monitoring units (JC1), Comprehensive monitoring program developed by rationality (JC2), the level of analysis in the monitoring of monitoring data (JC3), Timeliness of monitoring reports (JC4), Monitoring the content (JC5)

3. Cause factor analysis

3.1. Analysis method introduction and model construction

Structural Equation Modeling ^[10] (SEM) is called structural equation modeling, it is used to solve multivariate problems in research, and to analyze complex multivariate research data. It is an empirical analysis model, through the search for the internal structural relationship between variables, in order to verify the hypothesis of a structural relationship and model is reasonable, and if there are problems in the model, how to amend the suspicious. Using AMOS 7.0 software, the overall fitting level of the initial model and the sample data is firstly analyzed, the path analysis is conducted by structural equation modeling to test the causal hypothesis model between variables.

3.2. propose a hypothesis

According to the characteristics of all aspects of the foundation pit engineering construction, the following hypotheses are proposed between the six latent variables and the pit engineering accident:

H1: Construction links have a significant impact on the accident; H2: Survey links have a significant impact on the accident; H3: Design links have a significant impact on the accident; H4: Construction links have a significant impact on the accident; H5: Supervision links have a significant impact on the accident; H6: Monitoring links; H7: Significant impact of the survey on the design; H8: Design has a significant impact on the construction; H9: Supervision has a significant impact on the construction; H10: The construction unit has a significant impact on the construction; H11: Monitoring has a significant impact on the construction.

Based on the above hypothetical relationship, a hypothetical model of causal relationship between

foundation pit engineering accidents is constructed in this paper, as shown in Figure 1.

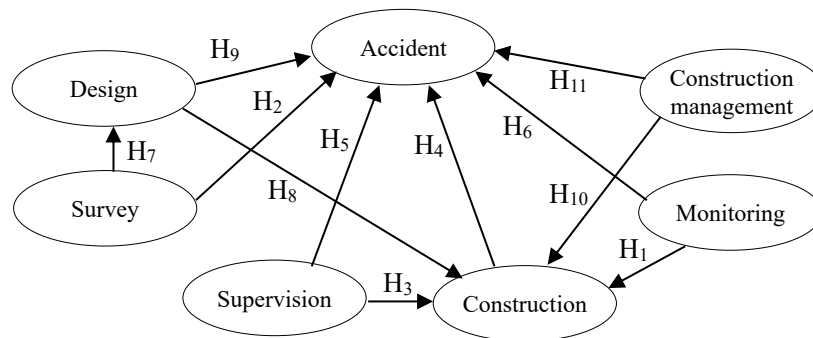


Figure 1. Hypothetical relationship model of excavation engineering accident causation

3.3. Model verification and correction

In this paper, SPSS21.0 software was used to test the reliability and validity. The test results show that the *Cronbach's α* of construction management, survey, construction, design, supervision, monitoring and other indicators are 0.780, 0.729, 0.705, 0.825, 0.764, 0.786, 0.861, both greater than 0.6, meanwhile the *CITC* values of all the indexes are in line with the standards, indicating that their reliability is acceptable. Meanwhile, the results of *KMO* measurement and Bartlett's sphere test showed that the *KMO* values of each index were 0.691, 0.671, 0.672, 0.824, 0.679, 0.767 respectively, and the significant probability of χ^2 statistics of Bartlett's sphere test was less than 0.01, indicating that the data is relevant, suitable for factor analysis^[11].

The overall model fitness is used to evaluate the fit of the model to the data. According to the structural equation model fitting literature^[12] and the actual situation analysis, this paper mainly uses the fitting index as shown in Table 2 to test the model and data fitting degree.

Based on this, this paper uses AMOS 7.0 analysis software to test the fitting of the initial model, and the statistical value of χ^2/df of the initial model is 2.477. From Table 2 above, it can be seen that the reference standard is met; the *CFI* value is 0.834, the *NFI* value is 0.750, the *IFI* value is 0.836, and the approximate error root mean square (*RMSEA*) is 0.078, indicating compliance with the reference standard. All hypotheses were tested by the model's intrinsic structural fit. Table 3 shows the path regression coefficients and test indices in the model.

Table 2. Evaluation Criterion of Fitting Degree of Structural Equation Model

χ^2/df	RMSEA	NFI	IFI	CFI
<3	0.05 < RMSEA < 0.08	>0.8	>0.8	>0.8

Table 3. Parameter estimation path of initial model

Path relationship between latent variables	Unstandardized estimation	Standardization estimates	Standard error	Threshold	P value
Survey ← accident	0.209	0.534	0.054	3.883	***
Construction management ← accident	0.172	0.451	0.056	3.051	0.002
Design ← accident	0.123	0.433	0.043	2.880	0.004
Monitoring ← accident	0.187	0.667	0.059	3.183	0.001
Supervision ← accident	0.195	0.555	0.063	3.122	0.002
Construction ← accident	0.189	0.695	0.053	2.224	***
Construction ← Design	0.331	0.513	0.067	4.964	***
Construction ← Construction management	0.365	0.356	0.085	4.287	***
Construction ← Supervision	0.159	0.228	0.055	1.441	0.060
Construction ← Monitoring	-0.017	-0.030	0.043	0.475	0.691
Design ← Survey	0.268	0.667	0.079	3.393	***

The results show that the absolute value of the *C.R.* The absolute value of *C.R.* for monitoring

the impact on the construction of this path parameter is 0.475, all less than the reference value of 1.96, and both are $p > 0.05$, indicating that the significance test has not passed and should be deleted. The *C.R.* absolute values of the remaining path parameters are all greater than 1.96, and $p < 0.05$, indicating that the significant test should be retained. After many fittings and corrections, the final model fitting index was obtained. The comparison with the initial model's fitting index is shown in Table 4.

Table 4. Initial model and modified model fitting index comparison

Index Name	χ^2/df	RMSEA	NFI	IFI	CFI
Initial statistics	2.447	0.078	0.750	0.836	0.834
Correction Statistics	2.079	0.066	0.816	0.878	0.869
Evaluation results	match	acceptable	acceptable	acceptable	acceptable

After correction, the path relationship between the latent variables in the structural model and the coefficient values of the error term results in the following: the absolute value of the path parameter critical value between the latent variables is a minimum of 2.244 and a maximum of 4.946, much larger than the reference standard 1.96, the standard error of 0.054~0.079, the smaller the value, all through the significance test. The complete revision validation model is represented by a simplified path map, as shown in Figure 2.

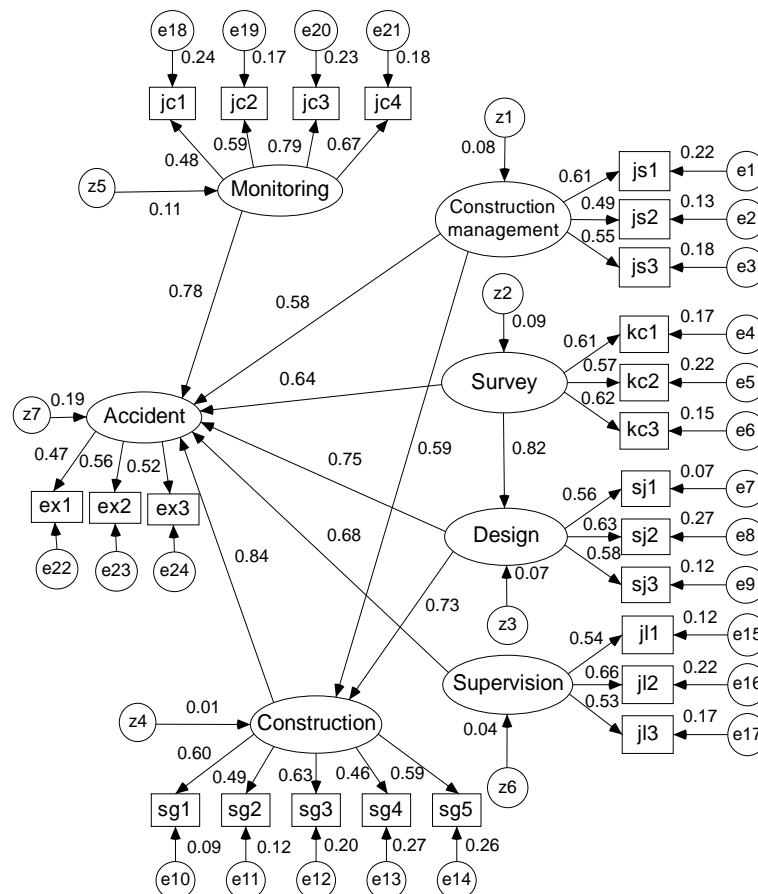


Figure 2. Revised path of relationship between excavation engineering accident and link

4. Analysis and Suggestions

It can be seen from the revised route diagram that the management of the construction unit has a significant impact on the accident after the model is amended. Meanwhile, the investigation, design, construction, supervision and monitoring have a significant impact on the accident, and the investigation has a significant impact on the design, the design links have a significant impact on the construction links, the nine hypothetical paths all passed the significance test. The results and suggestions are

explained as follows.

The on-site construction management level and the effectiveness and comprehensiveness of monitoring have the greatest impact on the foundation pit accidents, the assumed path coefficients are 0.84 and 0.78, the next two links that affect the larger design and supervision, the path coefficient of the figure were 0.75 and 0.68. For the above data we can make the following suggestions: (1) Standardize the pit construction process. According to the construction plan, improve the quality of construction, attention to information construction. The construction process can easily lead to personal injury and property damage, so we must strengthen the management of the construction process. (2) Strengthen the monitoring during construction of the foundation pit and implement dynamic monitoring. Dynamic monitoring can enable various information on the scene to be fed back to related units in time to adjust design and construction plans. (3) Reasonable and standardized design can reduce the occurrence rate of foundation pit accidents, provide appropriate supervision personnel, and conduct standard supervision, which can reduce the occurrence rate of foundation pit engineering accidents.

Relative to other factors, The survey link also has a certain impact on the occurrence of the foundation pit accident, with a path coefficient of 0.64. At the same time, the survey link has a greater impact on the design process, with a path coefficient of 0.72, indicating that detailed and accurate survey data can be provided to improve the foundation pit. The reliability of the design plan. Therefore, in the early stage of the foundation pit project, the survey and design link will grasp the site situation in the construction process, modify and improve the design according to the actual situation, and strictly conduct on-site inspections.

The results also show that the decision-making management and design aspects of the construction unit have some impact on the construction link, the path coefficient of 0.59 and 0.73, indicating that the construction unit in the bidding, the need for strict qualification review and strengthen the management of the construction unit and supervision, and require the design unit to provide detailed and reasonable design of foundation pit in order to provide support for safe construction, thus reducing the incidence of pit accidents.

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