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Analysis of factors influencing safety management for metro construction in China

Q.Z. Yu[a,b], L.Y. Ding[a,b], C. Zhou[a,b,*], H.B. Luo[a,b]

[a] School of Civil Engineering & Mechanics, Huazhong University of Science & Technology, Wuhan, China
[b] Institute of Construction Management, Huazhong University of Science & Technology, Wuhan, China

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ABSTRACT

With the rapid development of urbanization in China, the number and size of metro construction projects are increasing quickly. At the same time, and increasing number of accidents in metro construction make it a disturbing focus of social attention. In order to improve safety management in metro construction, an investigation of the participants' perspectives on safety factors in China metro construction has been conducted to identify the key safety factors, and their ranking consistency among the main participants, including clients, consultants, designers, contractors and supervisors. The result of factor analysis indicates that there are five key factors which influence the safety of metro construction including safety attitude, construction site safety, government supervision, market restrictions and task unpredictability. In addition, ANOVA and Spearman rank correlation coefficients were performed to test the consistency of the means rating and the ranking of safety factors. The results indicated that the main participants have significant disagreement about the importance of safety factors on more than half of the items. Suggestions and recommendations on practical countermeasures to improve metro construction safety management in China are proposed.

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1. Introduction

One of the major objectives and tasks for the 12th Five-Year Plan (2011–2015) period in China is to increase the urbanization level from the current 47.5% to 51.5%. In order to deal with urbanization pressure such as land consolidation, traffic congestion and environmental contamination, the massive speed and scale of metro (subway) construction and operations in Chinese metropolitan areas far exceed those anywhere else in the world. For example, with the rapid economic development in central China, metro network planning has been expanded from two urban lines to nine urban lines with 540 km and 309 stations in Wuhan, Hubei Province. However, urban underground construction is a high-risk task with complex characteristics such as huge investment, long-term project periods, numerous subprojects, and complex geological and hydrological conditions (Osama Ahmed and Salman, 2003; Seo and Hyun Ho, 2008). Additionally, large scale and intensive underground construction through dense urban areas increase sharply the safety risks on important structures and facilities such as gas pipelines, water supply systems and nearby drainage systems (Hyun-Ho et al., 2004). Also, as the history of urban underground construction in China is very short, many cities, building metro lines for the first time, do not have adequate technical and managerial experience. Therefore, key safety factors must be identified, investigated and resolved at the preconstruction phase to prevent metro construction accidents in China.

Safety factors influencing construction have been studied by many researchers. Due to differences in the construction industry and environment in different countries, there are some discrepancies in the results concerning safety factors (Fang et al., 2004; Wenzhe et al., 2007). Based on the questionnaire survey approach and factor analysis from different points of view, safety factors are divided into different categories. The studies are summarized and presented as follows: (1) identification of key factors from 100 accidents, including five categories: worker and work team, workplace, materials, equipment, and front line managers and supervisors. These five aspects contribute to forming a hierarchy of causal influences in construction accidents. It has also been proposed that front line managers and supervisors are the key individuals in accident prevention which implies that monitoring is important to construction safety (Haslam et al., 2005). (2) Influence of psychosocial factors on the health and safety of construction workers (Tarek et al., 2009). (3) 25 key risks were ascertained to understand the key risks on construction projects in China. Also, some strategies were developed to manage these risks. In addition, it was concluded that clients, designers and government bodies must assume the responsibility to manage their relevant risks and work

* Corresponding author at: School of Civil Engineering & Mechanics, Huazhong University of Science & Technology, Wuhan 430074, China. Tel.: +86 27 87557124.
E-mail address: charleschou@163.com (C. Zhou).

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cooperatively from the feasibility phase throughout the project. Only this comprehensive responsibility and cooperation will help to avoid potential risks over time. Meanwhile, contractors and subcontractors with solid construction and management experience should be utilized to minimize the risks and carry out safe, efficient and high-quality activities (Zou et al., 2007). (4) Two success attributes and one failure attribute affecting schedule performance were identified from 55 attributes using a two-stage factor analyses separately on construction projects in India (Iyer and Jha, 2006). (5) The impact of historical, economic, psychological, technical, procedural, organizational and environmental issues closely linked with the level of site safety is discussed. The top five important factors associated with site safety were identified as: management talks on safety, provision of safety booklets, provision of safety equipment, providing a safe environment, and appointing a permanent on-site safety representative (Sawacha et al., 1999).

Due to the uniqueness of the Chinese construction industry and the status of safety management, risk-prone activities on construction sites should be examined. When looking at construction projects as a whole, 25 main factors affecting construction site safety were identified and summarized into five causes of accidents: poor safety awareness of top management, lack of worker training, poor safety awareness of project managers, reluctance to increase resources for safety management and reckless operations (Tam et al., 2004). In addition, safety risk factors from contractors and subcontractors were also considered, such as: lack of an emergency response plan which includes detailed response procedures, workers' unsafe operating of equipment and unsafe work practices, and contractors ignoring safety due to the time pressures of the project schedule (Yu et al., 2008). Also, 34 tunneling risk factors were identified and categorized into seven groups: (1) economics, politics and laws, (2) force majeure, (3) the physical construction site, (4) project personnel, (5) construction operations and techniques, (6) design, and (7) construction contract (Veerasak and Photios, 2009).

In summary, there is a good understanding of accident categories and the contributing factors in the whole construction industry. However, there is limited specific investigation into the safety factors in metro construction and the perspectives on these factors of different participants involved in metro construction. With this background, this research seeks to find the key safety factors in metro construction in China and to rank the importance of these factors by project participants. The consistency of factor ranking between participants is also evaluated.

2. Safety accidents in metro construction in China

According to incomplete statistics, from 2008 to the present, accidents that caused casualties have occurred more than 20 times in metro construction in China (Ding et al., 2012). The average insurance compensation rate for metro construction in the main cities of China is over 60% of the budget which indicates the huge economic loss caused by metro construction accidents in China.

The cases of safety accidents causing casualties and economic losses in urban underground construction are increasing. For example, on July 1, 2003, on the Shanghai Metro Line 4 construction project, a quicksand disaster occurred during the excavation of the tunnel cross passage connection between two shield tunnels. Freezing soil gradually melted because of an unexpected electric power termination, which leads to quicksand hazards. As the soil layer at this site was a fine sand layer with a 40 m confined hydraulic head, the quicksand formed in the confined aquifer and a large amount of soil flowed into the tunnels, resulting in the collapse of the tunnel for a length of about 210 m plus the inclination and collapse of 3 buildings over the tunnel. In addition, the government had to use army forces to deal with the damage to the Huangpu River embankment. Thanks to sounding an alarm in time, the workers on the construction site and the people inside the dangerous buildings evacuated safely, leaving a direct economic loss of only about 150 million Yuan.

The foundation collapse of the Xianghu Station of Hangzhou Subway Line 1 on the November 11, 2008 was the worst accident in subway construction history in China. During this construction project, a diaphragm wall, which supported a 17 m deep excavation adjacent to Fengqing Avenue, collapsed without warning, leading to Fengqing Avenue caving in 7 m. The accident site covered an area of the size of one football field. The accident resulted in the loss of 21 lives and 4 injuries, besides causing direct economic loss of about 49 million Yuan. The main reason was the overbrack of the soft clay in the foundation pit, together with the lag time of erecting the steel support system bottom construction. In addition to the severe defects in construction, the monitoring data for the foundation pit was erroneous due to the movement of the sensors. Therefore, there was no warning of impending disaster. Even worse, even though the deformation and crack in the diaphragm wall had already occurred, there were no repair measures, but only measure to catch up to the schedule.

The domino effect of the urban underground construction accidents can cause unexpected public crisis in urban areas. The EBP shield tunneling accident which occurred on February 5, 2007 in Nanjing Metro Line 2 construction project caused a large sinkhole and settlement to the road above the tunnel. Consequently, a 600 mm diameter water supply pipeline broke and enlarged the collapse site. This caused a 500 mm diameter gas pipeline to leak immediately, which resulted in a big explosion that damaged the Jinpeng office building 10 m north of the site. Finally, water, gas and electricity were suspended for two days which greatly inconvenienced the daily life of 5400 residents.

In order to improve safety management in metro construction, an investigation of the participants' perspectives on safety factors in China metro construction has been conducted to identify the key safety factors, and their ranking consistency among the main participants, including clients, consultants, designers, contractors and supervisors. Section 3 introduces the research method including questionnaire design and collection and data analysis method. Then, in Section 4, all the results are presented. Suggestions on practical countermeasures to improve metro construction safety management in China are discussed and concluded in Sections 5 and 6.

3. Research method

3.1. Questionnaire design

To investigate the perspectives of different participants empirically, a survey questionnaire approach was employed for data collection. This method made the survey more objective and reduced the cost of the research. First, a pilot study was conducted to screen a comprehensive list of safety issues to ensure validity, reliability, and significance of questionnaire items before the ground analysis. Then, item analysis was administered to test that each item could separate one participant from the others. The result indicated that each item was significant. The significant values of all items were under 0.05, and zero was excluded from the 95% confidence interval of the difference.

Cronbach's Alpha was used to test whether the items were consistent and reliable. The Cronbach's Alpha value for the questionnaire was 0.943, indicating high internal consistency (Lu and Shang, 2005).

Based on the questionnaire described above, the outcome of the exploratory interviews and the pilot study, a list containing

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