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SEWERAGE PIPE-JACKING CONSTRUCTION: SEWERAGE SYSTEMS IN TAICHUNG

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Abstract. *Constructing sewerage systems is a critical index for cities that affects national image and competitiveness. Risk factors encountered during the construction of sewerage systems influence the construction success. Through a literature review, we investigated the geological distribution of Taichung, conducting a case analysis on the city sewerage projects. A questionnaire survey on the risk factors affecting sewerage system construction was administered to experts, and a hierarchy analysis was conducted to examine the risk factor weighting. Finally, an analysis was performed to determine the most appropriate solutions, including using suitable cutter heads on tunnel boring machines, applying cone crushers for slurry shield tunnel boring machines, and selecting the size of the screw conveyor of earth pressure balance tunnel boring machines according to the gravel particle size. These results can be a reference for future sewerage projects in Taichung to facilitate timely and successful completion.*
Keywords: Sewerage, Risk factor, Pipe-jacking machine, Countermeasure

1. **Introduction.** As one of the most important overhead capitals of urban economics and social development, the sustainable development of urban infrastructure is becoming a key issue of prosperous society growing [1]. In order to protect the environment, specific water contamination requires the recycling process prior to its discharge into the public sewerage network [2]. The sewerage system is a vital component of all wastewater disposal structures. Sewerage systems are indispensable public facilities in cities [3]. Teklehaimanot et al. have investigated the effects of population growth on the performance of the targeted wastewater treatment plants. The impact of population growth was assessed in terms of plant design, operational capacity and other treatment process constraints [4]. Construction of the sewerage system in Taichung began in 1965 and has continued according to the Third Implementation Plan for Sewerage Systems in Taichung, approved by the central government. By the end of December 2013, an estimated 100,000 households (14.2%) in Taichung had gained access to the sewerage system. The Taichung City Government plans to expand access to the sewerage system annually by an average of 2.5% households until a total of 250,000 households have access by 2014-2017.

The geology of Taichung is characterized by solid gravel layers, a majority of which are below the groundwater table, hindering construction [5]. Additionally, the aforementioned sewerage plan will be implemented in developed urban areas of Taichung, which have a heavy population, narrow roads, dense residential buildings, heavy traffic, and a limited range for pipe-jacking tunneling operation and for material accumulation inconvenience construction. To enable smooth construction of the sewerage system and accomplish the sewerage project, identifying and solving the problems in construction is imperative. Four case studies are discussed in Section 2. The processes of establishing the factor structures are discussed in Section 3. Factor weighting analysis is performed in Section 4. Brief conclusion is stated in Section 5.

2. **Case Studies.** Numerous factors affect the progresses of sewerage pipe-jacking construction [6] such as critical geological factors and pipe-jacking machine selection [7]. Currently, sewerage projects in Taiwan are actively executed. Because the urban areas of Taichung are located on the most solid bedrock in Taiwan, sewerage construction in that area is the slowest. This paper reviews the sewerage pipe-jacking construction in Taichung, where the primary geology is gravel and the pipe diameters are primarily 500 mm, 600 mm, 800 mm, and 1000 mm.

2.1. **Comparison of case characteristics.** This paper discusses four cases of sewerage pipe-jacking construction, Cases A, B, C, and D (Figure 1), the construction of which was located on Chongqing Road, Zhongming South Road, Dongguang Road, and Jinhua Road, respectively. The design lengths of the pipelines in Cases A, B, C, and D were 3,487 m, 3,504 m, 3,825 m, and 3,035 m, respectively. The geology conditions of the areas in the four cases are solid gravel.

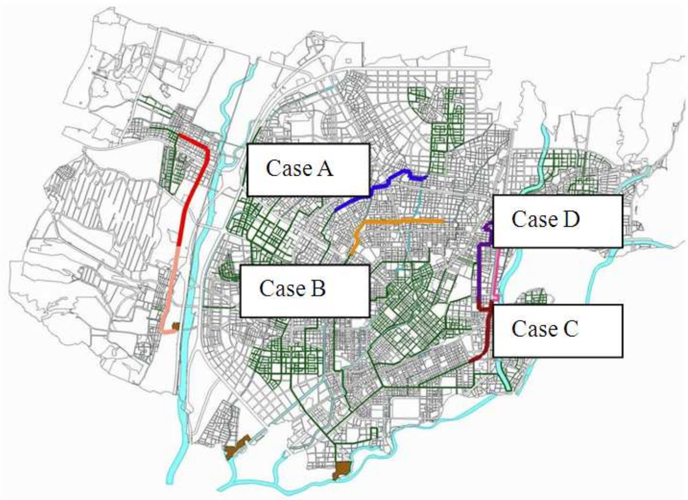

Figure 1. Locations of the four cases

2.2. **Problem discussion.** All four cases discussed in this paper involved numerous obstacles to pipe-jacking during construction. The following is a brief summary of such obstacles:

A. Natural driftwood (Figure 2), which was detected and removed by establishing shafts (Figure 3). Figure 4 illustrates a shaft during excavation.
B. Rail piles (Figure 5)
C. Construction waste (Figure 6)
D. Natural large gravel (Figure 7)

Among the four cases, in Cases B and C, the workers were experienced in construction in Taichung and had reference data for selecting machines. Therefore, except for the obstacles requiring removal, overall construction was relatively smooth and accomplished on time. In Cases A and D, the workers lacked experience related to sewerage construction in Taichung and encountered numerous problems during construction. Because the

Figure 2. Driftwood

Figure 3. A shaft established for removing subsurface obstacles

Figure 4. Excavating obstacles

Figure 5. Rail piles

Figure 6. Construction waste

Figure 7. Large gravel

workers fell behind schedule, they had numerous construction meetings to discuss causes of delay, during which the following solutions to encountered problems were proposed: (a) Expand the pipe-jacking area and obtain assistance from subcontractors with experience in pipe-jacking tunneling in gravel formation, preventing further delay in the progress; (b) Adjust the pipe-jacking machines with the assistance of related machinery manufacturers to adapt pipe-jacking modes to appropriate construction areas for operation, improving pipe-jacking rate; (c) Increase the number of spare parts for repair, thereby reducing the waiting time and increasing the speed of preparing the machines. After implementing these solutions, the construction team in Cases A and D caught up and accomplished the projects on time.

3. Establishing the Factor Structures.

3.1. Fish bone diagram of the factors affecting the pipe-jacking construction.

By using a fish bone diagram, the cause-and-effect relationships between the problem's phenomena become apparent [8]. The primary problems impeding the sewerage pipe-jacking construction were underground obstacles, uneven geology, traffic factors, resident factors, and project mismanagement [9]. The traffic and resident factors, involved in all cases, were excluded in this study. Instead, we discuss uneven geology, mismanagement during construction, and underground obstacles [10] (Figure 8).

Expert interviews were conducted to establish the factors affecting the construction projects. Interviewees comprised general contractors, supervisors, and construction sponsorship agents that possessed more than 10 years of experience on sewerage pipe-jacking construction. Specifically, three owners, four supervisors, four general contractors, and two pipe-jacking equipment manufacturers were interviewed, constituting a total of 13 experts. Thus, the factors affecting sewerage pipe-jacking construction progress were determined and subsequent solutions were proposed.

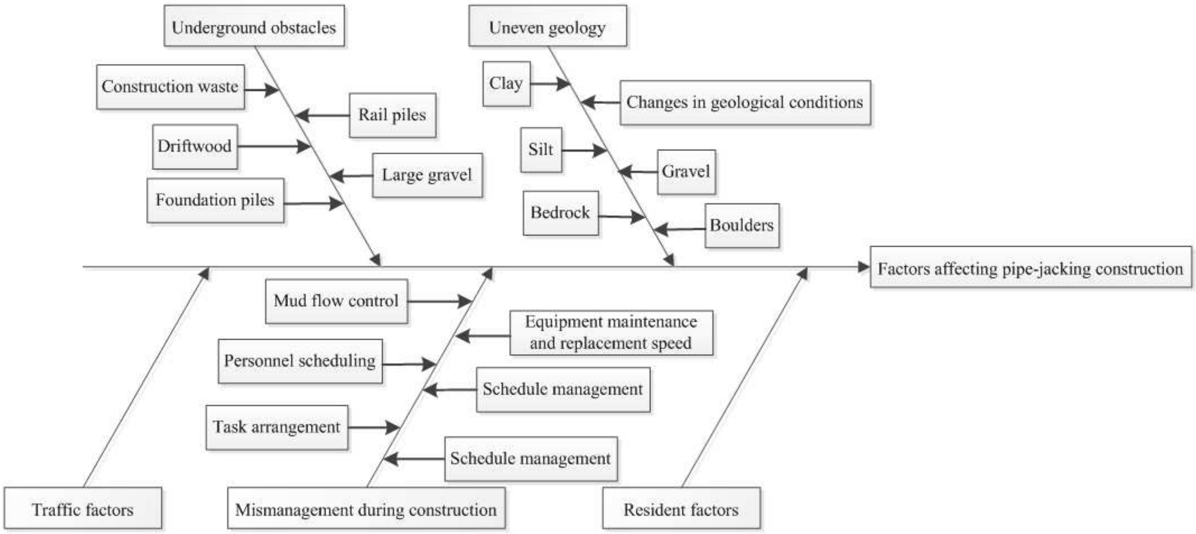

Figure 8. Cause and effect diagram of factors affecting pipe-jacking construction

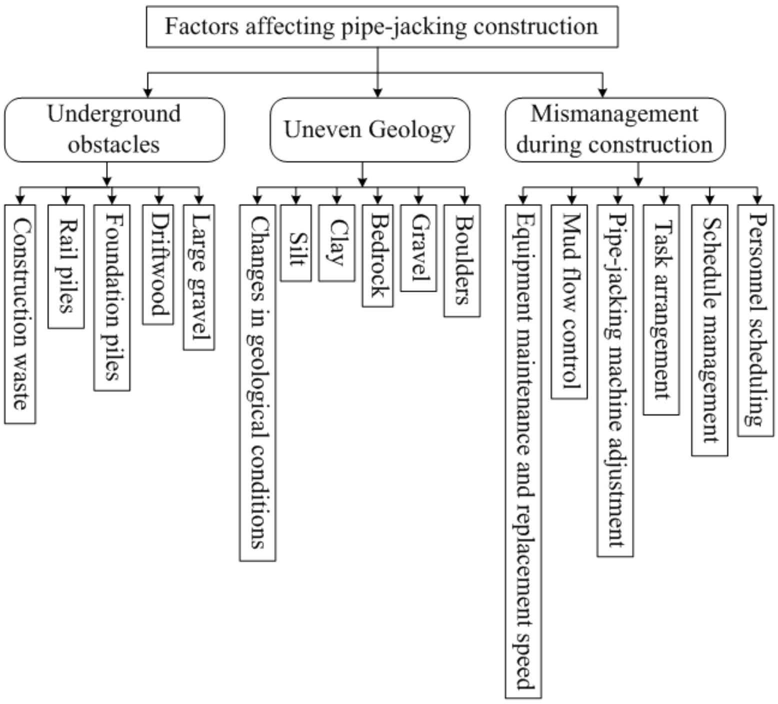

Figure 9. Hierarchical structure of factors affecting pipe-jacking construction

3.2. **Hierarchical structure of factors affecting pipe-jacking construction.** This study utilizes literature review, historical case data aggregation, as well as discussion with senior sewerage engineers to conclude five problems encountered in sewerage construction projects: underground obstacles, uneven geology, construction mismanagement, traffic obstruction and residents protest. Traffic obstruction and resident protest were excluded since all construction cases have the same problem. After the expert interviews, 17 factors affecting pipe-jacking construction were established and divided into three dimensions [11] (Figure 9).

4. **Factor Weighting Analysis.** In this study, we analyzed the factors affecting the sewerage pipe-jacking construction. The underground obstacle factor most affecting the project was construction waste, which had a weighting of 0.289, followed by rail piles,

Table 1. Weightings of factors affecting pipe-jacking construction in each dimension

Dimension	Item	Weighting	Order
Underground Obstacles	Construction waste	0.289	1
	Rail piles	0.236	2
	Foundation piles	0.190	3
	Driftwood	0.161	4
	Large gravel	0.124	5
Uneven Geology	Changes in geological conditions	0.328	1
	Gravel	0.226	2
	Boulders	0.153	3
	Bedrock	0.135	4
	Clay	0.098	5
	Silt	0.060	6
Construction Mismanagement	Mud flow control	0.355	1
	Equipment maintenance and replacement speed	0.305	2
	Pipe-jacking machine adjustment	0.236	3
	Task arrangement	0.055	4
	Personnel scheduling	0.035	5
	Schedule management	0.014	6

Table 2. First-level weightings of factors affecting pipe-jacking construction

Order	Dimension of factors affecting pipe-jacking construction	Total Weighting
1	Uneven geology	0.347
2	Underground obstacles	0.338
3	Mismanagement during construction	0.315

Table 3. Second-level weightings of factors affecting pipe-jacking constructions

Order	Aspect	Item	Weight
1	Uneven hardness for geology	Geological condition change	0.124
2	Underground obstructions encountering	Construction waste	0.121
3	Poor construction management	Mud transmission flow control regarding the machine for the pipe jacking construction	0.112
4	Underground obstructions encountering	Steel rail pile	0.099
5	Poor construction management	Maintenance and replacement speed regarding the machine equipment	0.09
6	Underground obstructions encountering	Foundation pile	0.08
7	Uneven hardness for geology	Gravel	0.078
8	Underground obstructions encountering	Log	0.057
9	Uneven hardness for geology	Large gravel	0.042
10	Uneven hardness for geology	Rock mass	0.038
11	Underground obstructions encountering	Rock basin	0.035
12	Poor construction management	Propulsion machine adjustment	0.033
13	Poor construction management	Working surface arrangement	0.028
14	Poor construction management	Personnel arrangement	0.025
15	Uneven hardness for geology	Clay	0.018
16	Uneven hardness for geology	Sand silt soil	0.012
17	Poor construction management	Schedule control	0.008

foundation piles, driftwood, and large gravel. The uneven geology factor that most affected the project was change in geological conditions, which had a weighting of 0.328, followed by boulder, bedrock, gravel, clay, and silt. The factor of mismanagement during construction that most affected the project was mud flow control, which had a weighting of 0.355, followed by equipment maintenance and replacement speed, pipe-jacking machine adjustment, task arrangement, personnel scheduling, and schedule management. Table 1 lists these factors.

To determine the priority weight of each factor, the weighting of each dimension was calculated. Table 2 lists the weightings of the dimensions. Regarding the weighting of each factor, the top five weighted factors were changes in geological conditions (0.124), construction waste (0.121), mud flow control (0.112), rail piles (0.099), and equipment maintenance and replacement speed (0.09). The weightings of the other factors are shown in Table 3.

5. **Conclusion.** This case analysis revealed that the weightings of the three dimensions affecting sewerage pipe-jacking construction progress were 0.347 for uneven geology, 0.338 for underground obstacles, and 0.315 for mismanagement during construction. No significant difference was observed among the three dimensions. After we verified that the construction in the four cases was completed, we formulated the following countermeasures for managing sewerage pipe-jacking construction:

A. Regarding the selection of appropriate cutter heads for tunneling machines, cone crushers are optimal for slurry shield tunnel boring machines. The size of the screw conveyor of earth pressure balance tunnel boring machines should be selected according to the gravel size.
B. During tunneling operation, lubricants may be applied to reduce resistance; the types and amount of lubricants applied must be carefully determined.
C. Within the work zone distribution, the distance interval between each pipe-jacking shaft should be shortened to prevent excessive wearing of the cutting wheel of the tunnel boring machine, which reduces the pipe-jacking rate.
D. The pressure and turning force logs of the machine must be monitored during construction. When a sudden jump occurs, the equipment and its operation must be examined.

Investigating the four cases in this study revealed the factors and their weightings affecting sewerage pipe-jacking construction progress. Suggestions from experts facilitated deriving management recommendations. These recommendations can be used as a reference for future sewerage pipe-jacking construction in Taichung and other areas with similar geologies to enable effective control of construction quality and progress. Some different sewerage projects from other cities are suggested for future study to ensure the completion of sewerage pipe-jacking construction.

REFERENCES

[1] J. Zhou and Y. J. Liu, The method and index of sustainability assessment of infrastructure projects based on system dynamics in China, *Journal of Industrial Engineering and Management*, vol.8, no.3, pp.1002-1019, 2015.
[2] A. Antonyová, P. Antony and B. Soewito, Monitoring the water quality in the recycling process, *Journal of Physics: Conference Series*, vol.622, 2015.
[3] J. L. Lin, *Relation Between Work Space and Productivity in Household Pipe-Connection Engineering of Public Sewerage System*, Master Thesis, National Kaohsiung First University of Science and Technology, 2005.
[4] G. Z. Teklehaimanot, I. Kamika, M. A. A. Coetzee and M. N. B. Momba, Population growth and its impact on the design capacity and performance of the wastewater treatment plants in Sedibeng and Soshanguve, South Africa, *Environmental Management*, 2015.

[5] C. S. Kao and K. Y. Chang, *A Study on Pipe-Jacking Construction of Sewerage Systems in Difficult Geological Layers: A Case Study of Gravel Formations in Hwalien (Mai-lun)*, Master Thesis, National Taiwan Ocean University, 2005.
[6] S. F. Tsai, *Quantitative Analysis and Risk Assessment of Sewer Network and Pipe-Jacking Constructions*, National Central University, 2006.
[7] C. S. Wang, *Investigation and Countermeasures to Factors Affecting the Sewerage Pipe-Jacking Construction*, 2008.
[8] A. A. Yazdani and R. Tavakkoli-Moghaddam, Integration of the fish bone diagram, brainstorming, and AHP method for problem solving and decision making – A case study, *International Journal of Advanced Manufacturing Technology*, vol.63, pp.651-657, 2012.
[9] M. A. Cardoso, S. T. Coelh, P. Praça, R. S. Brito and J. Matos, Technical performance assessment of urban sewer systems, *Journal of Performance Construction Factor*, vol.19, no.4, pp.339-346, 2005.
[10] G. Y. Liu, *Estimating Productivity and Influence Factors of Sewerage Household Connection Construction*, Master Thesis, National Kaohsiung First University of Science and Technology, 2005.
[11] C. H. Liao, *Small-Tube Pipe-Jacking Construction Technology*, 2006.