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Optimization of cutting method for aging pipeline in utility tunnel with AHP approach

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ABSTRACT

The underground utility tunnel serves as a crucial infrastructure component in urban areas, integrating vital urban lifelines such as water supply and sewage systems, electricity, gas, heating, and telecommunications cables. As urban cities expand and the need for sustainable lifeline maintenance increases, long-term management of utility tunnels has become a significant concern. In specific, aging water supply and heating pipelines pose serious issues within the complex systems of utility tunnels. Traditional open-cut pipeline replacement methods may jeopardize long-term ground stability, underscoring the necessity for innovative utility management solutions. Selecting an appropriate cutting method in the confined underground space presents a multi-criteria decision-making challenge. This study analyzes various pipeline cutting methods to identify the optimal approach using the Analytical Hierarchy Process (AHP). Based on the AHP model outcomes, the evaluation criteria were structured into a hierarchy, and the weights of each criterion was assessed through a questionnaire survey. Ultimately, the development of pipe cutting technology within utility tunnels is anticipated to enhance safety and efficiency in long-term utility tunnel maintenance.

INTRODUCTION

The underground utility tunnel is an underground structure that accommodates essential lifelines including water supply, heating pipelines, and telecommunication cables (Su, 2007, Canto-Perello and Curiel-Esparza, 2013, Luo et al., 2020). With the expand of urban areas, need for infrastructures and long-term management system has rapidly increased (Kang and Choi, 2015). However, conventional utility tunnels lack standards and systems for maintenance, as it was initially designed without considering replacement (Parriaux et al., 2004).

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Most of the water supply pipelines in utility tunnels are made of cast iron which oxidize rapidly as they age. Aging water pipelines within utility tunnels can cause serious accidents, entailing economic loses and casualties (Baker, 1997, Dennis, 1998, Kim and Sung, 2003). However, traditional pipeline repair focuses on temporal treatment such as welding of aged parts or applying bituminous materials. As a result, long-term maintenance of aging pipelines in utility tunnels is crucial. This study aims to explore on optimal cutting method applicable within the utility tunnel. It is necessary to determine the appropriate cutting tool considering characteristics of utility tunnel.

The Analytic Hierarchy Process (AHP) is a multi-criteria decision-making method that deals with complex multi-attribute decisions (Saaty, 1977). In the analysis, evaluation criteria for pipe cutting process within utility tunnel has been suggested. Moreover, three alternative cutting tools were considered: a waterjet cutter, laser cuter, and a diamond wire saw. Ultimately, optimal cutting method for pipeline replacement within limited space in utility tunnel has been determined.

METHODS - ANALYTIC HIERARCHY PROCESS

The evaluation criteria for pipe cutting process have been suggested considering the characteristics of utility tunnel. The safety criterion must be considered crucially as utility tunnels accommodates more than one essential lifelines. Safety criterion is further divided into worker safety and utility safety. Moreover, workability of cutting tools in limited method must be regarded. The workability criterion is divided into system size and material applicability of cutting tool. Lastly, working efficiency of cutting tool is considered. Cutting performance on cast iron pipes and overall cutting costs have been evaluated. Consequently, relative weights of each criterion have been calculated through comparison analysis (Fig. 1). The working safety factors including worker safety and utility safety weighted the highest over another criterion.

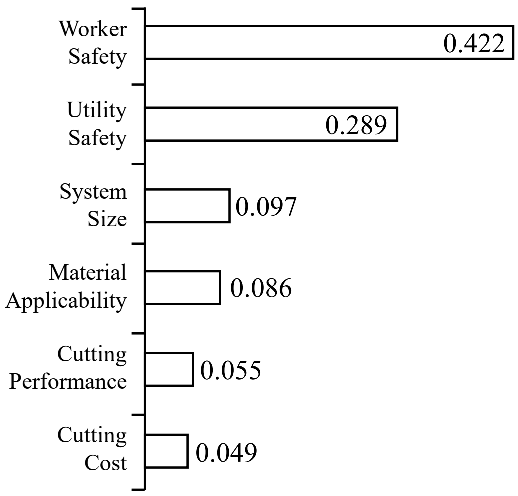

Fig. 1 Relative weights of criteria

In the result section, the properties of alternatives are analyzed. Moreover, comparison analysis of alternatives on each criterion is performed.

RESULTS - PAIRWISE COMPARISON

The properties of each alternative are studied through literature review and questionary survey on experts. Fig. 2 presents the detailed properties of alternatives on suggested criteria. The waterjet cutter dominated laser cutter and diamond wire saw in work safety and workability factors. In terms of safety factor, all three alternatives inherent significant risks towards both operators and other utilities. As a result, adherence to the safety protocols and the maintenance of precautionary measures are crucial to prevent serious accidents. However, a moderate-risk situations like minor injuries or operational defects are determined to be less occurred in the operations with waterjet cutter. Moreover, in terms of workability factor, the waterjet cutter was weighted the highest for its advantages in material applicability.

Whereas a diamond wire saw was weighted the highest in the work efficiency factor. With the moderate ability of cast iron pipe cutting process and cost-effectiveness, diamond wire saw presented the highest working efficiency compared to the waterjet cutter and laser cutter.

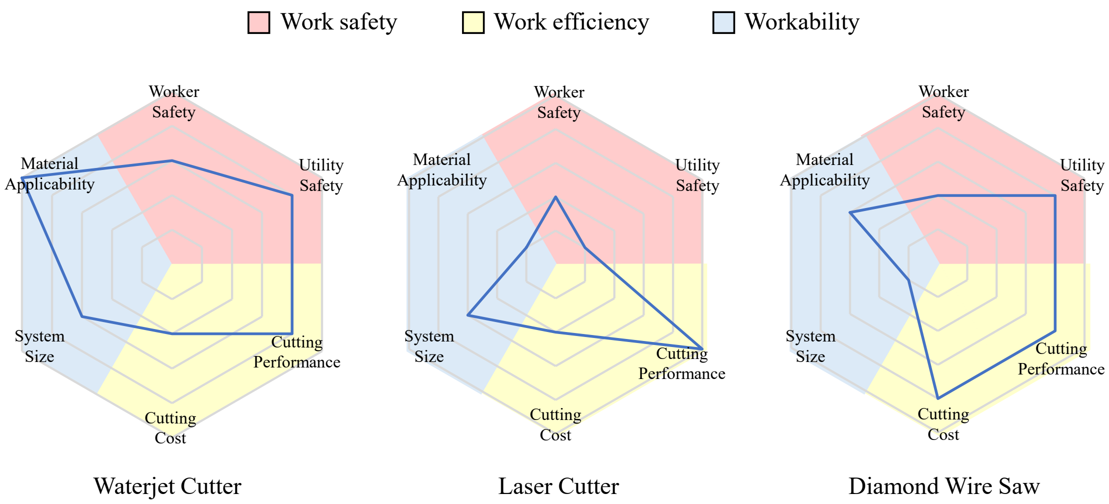

Fig. 2 Properties of alternatives on criteria

According to the detailed properties of cutting tool alternatives, pairwise comparisons with each other were conducted (Fig. 3). In the pairwise comparisons, the nine-point scale is used as a reference to convert the qualitative properties of cutting tools to the quantitative numeric values (Saaty, 1977).

In a worker safety criterion, the waterjet cutter was weighted the highest with a value of 0.539. Also in a utility safety criterion, the waterjet cutter was most prioritized with a relative weight value of 0.479, followed by diamond wire saw with a value of 0.458. Regarding the system size criterion, a waterjet cutter and a laser cutter were weighted 0.466 and 0.433 relatively, with the advantage of noncontact trait. The waterjet cutter was weighted 0.713 in the material applicability for its versatility in cutting operations. In cutting performance criterion, all three alternatives showed moderate cutting speed on cast iron cutting, where laser cutter had slight advantage with the highest cutting speed. Lastly, the diamond wire saw showed the highest cost-efficiency, weighted as 0.655.

Worker Safety	Waterjet	Laser	DWS
Waterjet	1.000	2.000	3.000
Laser	0.500	1.000	2.000
DWS	0.333	0.500	1.000

Utilities Safety	Waterjet	Laser	DWS
Waterjet	1.000	8.000	1.000
Laser	0.125	1.000	0.143
DWS	1.000	7.000	1.000

System Size	Waterjet	Laser	DWS
Waterjet	1.000	1.000	5.000
Laser	1.000	1.000	4.000
DWS	0.200	0.250	1.000

Material Applicab	Waterjet	Laser	DWS
Waterjet	1.000	9.000	4.000
Laser	0.111	1.000	0.250
DWS	0.250	4.000	1.000

Cutting Perform	Waterjet	Laser	DWS
Waterjet	1.000	0.333	0.500
Laser	3.000	1.000	3.000
DWS	2.000	0.333	1.000

Cutting Cost	Waterjet	Laser	DWS
Waterjet	1.000	2.000	0.250
Laser	0.500	1.000	0.250
DWS	4.000	4.000	1.000

Fig. 3 Pairwise comparison of alternatives for criteria

CONCLUSION

The relative weights are calculated through pairwise comparisons for suggested evaluation criteria and cutting tool alternatives. Worker safety and utility safety criterion were weighted the highest, consequently determined as the most influential criteria in selecting optimal cutting method within the utility tunnel. The final score was calculated by multiplying the weights of criterion and the corresponding value of alternatives. It is presented highest for the waterjet cutter (0.422) with its advantages in work safety factors.

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