The Technique Selection of Sewer Trenchless Rehabilitation in Metropolis of South China: A study case in Guangzhou city

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Abstract: In the central urban area of metropolis of South China, where there are dense population, active commerce and heavy traffic, trenchless rehabilitation technology is suitable for sewer pipeline reconstruction because the open cut construction's difficulty, long construction period and high cost. According to the typical defects of sewer pipeline in the central urban area of Guangzhou City and multi-factor, multi-level and multi-target characteristics of trenchless rehabilitation technology decision, Analytic Hierarchy Process (AHP) is applied to select available techniques for sewer trenchless rehabilitation from 300 to 600 millimetres by analyzing their construction condition, cost, benefit etc. Results show that cured-in-place pipe in several available techniques, i.e. spiral wound lining, cured-in-place pipe and slip lining, is preferable for the studied sewer pipeline.

Keywords: Sewer Pipeline; Trenchless Rehabilitation; Technique Selection; Analytic Hierarchy Process

1. INTRODUCTION

Trenchless rehabilitation of sewer pipeline is an environmentally construction technique, which can rehab or renew the deteriorated pipe with no excavation or less excavation [1]. Several techniques such as cured-in-place pipe, slip lining, fold and form lining spiral wound lining, pipe bursting, diameter reduction slipping and splice segment lining etc., are used at home and abroad [2]. There is a certain difference among the common defect types and damage extent of sewer pipelines from place to place; therefore the trenchless rehabilitation technique involved in various factors and aspects belongs to the typical multi-factor, multi-level and multi-target problem. Traditional selection methods, like experience evaluation and expert scoring etc., are difficult to solve this kind of problem effectively. However, Analytic Hierarchy Process (AHP), which was put forward as a multi-criteria decision method by T.L.Saaty in 1970s, can improve the accuracy, and comprehensiveness of complex system through combining qualitative analysis and quantitative analysis. AHP divides a problem into different component elements and recombines according to different layers, then constructs judgment matrix after pairwise comparison at the same layer, to calculate and obtain the maximum eigenvalue and the corresponding eigenvector, which ultimately arrive at weighing the importance of each scheme to determine the best available technique or plan to be implemented [3].

In Guangzhou City, a typical metropolis of South China, the investigation of sewer pipelines in the central urban area shown that the current damages are mainly: cracks, joint displacement, open joints, collapse etc., of which severe pipes, whose diameters range from 300 to 600 mm and service life is over 30 years for the most part. The sewers are mostly located in the area with dense buildings and heavy traffic and account for 73.92% of investigated total length [4]. It will encounter difficult technique implementation and high cost if trench rehabilitation is applied to repair the pipelines. In available trenchless rehabilitation techniques in Guangzhou, the main ones are cured-in-place pipe, spiral wound lining and slip lining, which the techniques are own characters. The selection of implementation technique may guarantees a fast and effective rehabilitation for

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sewer pipelines. AHP can help to organize the logic relationship among the complex factors; and suggestion is helpful to repair defected sewer pipelines.

2. AVAILABLE TECHNIQUE SELECTION OF SEWER TRENCHLESS REHABILITATION

2.1 Typical Sewer to be Repaired

Pipelines systems in metropolis like Guangzhou are complex, and they are changing greatly with the Chinese urbanization. Considering typical sewers in the city, selected section A was studied, which has the characteristics of sewer pipelines of Guangzhou City including the surroundings and defects of pipes to be repaired, a certain richness and complexity. It may be taken example by the pipes of this sort. Table 1 and table 2 show the condition parameters and assessment of pipe A after sewer inspection, respectively.

Items	Parameters of Selected Pipe A	Remarks
Cross-section Shape	Circular	Circular pipes account for 96.54% of all investigated pipes.
Pipe Diameter(mm)	400	Small diameter, heavily damaged
Allowable Decrease/Increase of Cross-section	Decrease within 15% or increase to 450mm	Too much decrease will greatly change discharge capacity of existing sewer pipelines, too much increase produce high cost and the technical difficulties.
Pipe Material	Concrete	Concrete pipes account for 82.66% of all pipes.
Buried Depth(m)	3.2	Construction depth between 3 to 5m accounts for 60%.
Groundwater Level(m)	1.05	Groundwater stable level is between 0.85 to 2.4m, mostly 1m.
Soil Category	Drifting sand soil, loose soil texture	Typical soil characteristics of Guangzhou
Road Grade	Traffic artery, heavy transportation	Narrow roads, heavy traffic load
Allowable Excavated Volume	Trenchless or only allowing to set starting shaft and reception pit	Great effect on the urban environment, especially worse in old urban district
Site Restrict	Dense population, hospitals, difficult division facility installation	High density of buildings, big service population

Table 1 The Overall Condition of Pipe to be Repaired

Defect Indexes	Computation Results
Pipe Damage Coefficient s	3.1
Pipe Damage Maximum Coefficient S_{max}	6.0
Pipe Structural Defect Density Index S_M	0.5
Structural Defect Parameter F	6.2
Pipe Rehabilitation Index RI	6.4

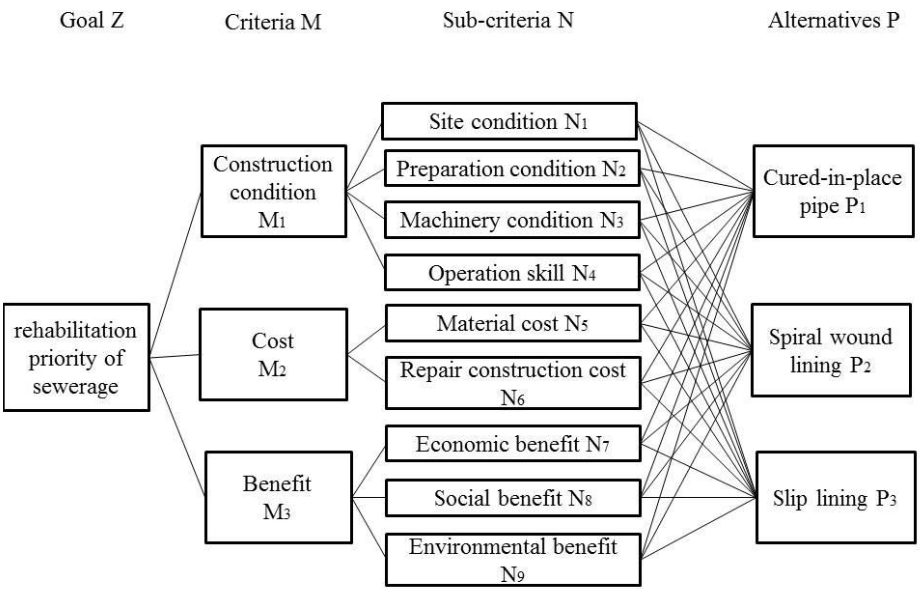
Table 2 Assessment Results of Inner Structure of Pipe A

Pipe A is located in a densely populated area, with the residential area, hospitals and schools nearby, while narrow roads, heavy traffic flow and difficult division facility installation. Because of deficient foundation treatment in the initial construction stage, some pipelines come up against uneven settlement and cracks, even wastewater leakage and groundwater penetration, resulting in the ground falling and almost impossibility of trench rehabilitation for damaged pipelines. Pipe A to be repaired, which is circular and concrete structure and whose defect types are interface material falling off, leakage and corrosion, should be repaired immediately according to the rehabilitation index RI.

2.2 Analytic Hierarchy

AHP model contains goal, criteria and alternatives in a general way. The decision problem of trenchless rehabilitation technique should be divided and several alternatives should be determined. Figure 1 shows the analytic hierarchy of sewerage rehabilitation. The goal Z is 'the best technique suitable for pipe repair', and criteria M contains: construction condition, cost and benefit. According to factors obtained in each criteria of criteria M, it can be subdivided into sub-criteria N. The alternatives P consists of: cured-in-place pipe, spiral wound lining and slip lining.

Fig.1 Analytic Hierarchy of Sewerage Rehabilitation



2.3 Judgment Matrix Construction and Sequencing by Exponents and Its Consistency Check

The critical process of AHP is selecting an appropriate scale to construct the judgment matrix. On the basis of the existing research, 1-9 scaling can be used for factors sequencing in view of its well perception, high precision and good rank preservation [5]. Therefore 1-9 scaling is adopted for pairwise comparison of all factors at the same layer to attain the judgment matrix. Table 3 shows the judgment matrix of Z-M layer of pipe A as an example.

Based on Z	**M_1**	**M_2**	**M_3**	**Weight**	**CR Value**
M_1	1	3	2	0.5396	0.0079
M_2	1/3	1	1/2	0.1634	
M_3	1/2	2	1	0.2970	

Table 3 The Judgment Matrix of Z-M Layer of Pipe A

The computation of weight and CR value is as follows, taking table 3 as example. Formula (1) is the judgment matrix:

$$A = \begin{bmatrix} 1 & 3 & 2 \\ 1/3 & 1 & 1/2 \\ 1/2 & 2 & 1 \end{bmatrix} \quad \ldots\ldots (1)$$

The maximum eigenvalue λ_{max} and the corresponding eigenvector $W=(W_1,W_2,W_3)^T$ can be obtained through solving formula (2) :

$$|\lambda E\text{-}A| = 0 \quad \ldots\ldots (2)$$

Each component of W should be normalized, seeing formula (3):

$$w_i = \frac{W_i}{\sum_{j=1}^{n} W_j} \quad \ldots\ldots (3)$$

In the formula above, N is the number of factors, and w_1, w_2, w_3 represent the weights of M_1, M_2, M_3, respectively. The new vector $w = (w_1, w_2, w_3)^T$ is the weight vector.

Consistency check is necessary to judge whether w is practicable. Formula (4) and formula (5) are the check formulas:

$$CI=\frac{\lambda_{max}-n}{n-1} \quad \ldots\ldots (4)$$

$$CR=\frac{CI}{RI} \quad \ldots\ldots (5)$$

In the formulas above, n and CI are the number of factors and consistency index, respectively. CR is the consistency ratio and the consistency check is passed when CR < 0.1. RI is the random consistency index and its value is showed in table 4.

n	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Table 4 Value of RI

The judgment matrixes of M-N layer and N-P layer are computed in the similar way. Results are showed in table 5 and table 6.

Items	**Judgment Matrix**				**Weight**	**CR Value**
Based on M_1	1	2	4	2	0.4218	0.0356
	1/2	1	3	1/2	0.1910	
	1/4	1/3	1	1/5	0.0748	
	1/2	2	5	1	0.3123	
Based on M_2	1	4			0.8000	0
	1/4	1			0.2000	
Based on M_3	1	1/2	1/2		0.2000	0
	2	1	1		0.4000	
	2	1	1		0.4000	

Table 5 Weights and CR Values Based on Factors of M Layer of Pipe A

Items	**Judgment Matrix**			**Weight**	**CR Value**
Based on N_1	1	1	2	0.4000	0
	1	1	2	0.4000	
	1/2	1/2	1	0.2000	
Based on N_2	1	3	1/2	0.2922	0.0022
	1/3	1	1/7	0.0925	
	2	7	1	0.6153	
Based on N_3	1	2	4	0.5714	0
	1/2	1	2	0.2857	

	1/4	1/2	1	0.1429	
Based on N_4	1	3	1/2	0.3196	0.0158
	1/3	1	1/4	0.1220	
	2	4	1	0.5584	
Based on N_5	1	1	2	0.4000	0
	1	1	2	0.4000	
	1/2	1/2	1	0.2000	
Based on N_6	1	1	1/2	0.2402	0.0158
	1	1	1/3	0.2098	
	2	3	1	0.5499	
Based on N_7	1	2	5	0.5816	0.0032
	1/2	1	3	0.3090	
	1/5	1/3	1	0.1095	
Based on N_8	1	2	6	0.5876	0.0079
	1/2	1	4	0.3234	
	1/6	1/4	1	0.0890	
Based on N_9	1	3	2	0.5278	0.0462
	1/3	1	1/3	0.1396	
	1/2	3	1	0.3325	

Table 6 Weights and CR Values Based on Factors of N Layer of Pipe A

2.4 Hierarchical Population Ordering and Consistency Check

Hierarchical population ordering gives weights of each factor in different layer to the overall target. The computation is as follows.

The assumption is that the hierarchical population ordering value of A_i in A layer is a_j, and the sequencing by exponent of B_i in B layer to A_i in A layer, which is upper of B layer, is b_{ij}. Then the weight of B_i to the overall target can be expressed by formula (6):

$b_i = \sum_{j=1}^{m} a_i b_{ij}$ (m represents the number of A layer.) ………………………………………………….. (6)

Table 7 shows the hierarchical population ordering.

A / **B**	**A_1, A_2, ……, A_m** **a_1, a_2, ……, a_m**	**The Hierarchical Population Ordering of B Layer**
B_1	b_{11}, b_{12}, ……, b_{1m}	$\sum_{j=1}^{m} a_j b_{1j} = b_1$
B_2	b_{21}, b_{22}, ……, b_{2m}	$\sum_{j=1}^{m} a_j b_{2j} = b_2$
. . .	. . .	. . .
B_n	b_{n1}, b_{n2}, ……, b_{nm}	$\sum_{j=1}^{m} a_j b_{nj} = b_n$

Table 7 The Hierarchical Population Ordering

The consistency check of hierarchical population ordering: assuming that the consistency index of each factor in B layer to the factor A_j in upper layer (A layer) is CI_j and the random consistency index is RI_j. Then the consistency ratio can be expressed by formula (7):

$$CR = \frac{a_1 CI_1 + a_2 CI_2 + \cdots + a_m CI_m}{a_1 RI_1 + a_2 RI_2 + \cdots + a_m RI_m} \text{ (m is the number of factors in A layer.)} \quad \ldots\ldots (7)$$

The consistency check is passed when CR < 0.1. Otherwise, the adjustment should be made for the judgment matrix whose consistency ratio is bigger.

The hierarchical population ordering of M layer is just the sequencing by exponent of Z-M layer. Table 8 and table 9 show the hierarchical population orderings of N and P layer.

M / N	M_1 (0.5396)	M_2 (0.1634)	M_3 (0.2970)	The total weight	CR
N_1	0.4218			0.2276	0.0263
N_2	0.1910			0.1031	
N_3	0.0748			0.0404	
N_4	0.3123			0.1685	
N_5		0.8000		0.1307	
N_6		0.2000		0.0327	
N_7			0.2000	0.0594	
N_8			0.4000	0.1188	
N_9			0.4000	0.1188	

Table 8 The Hierarchical Population Ordering of Factors in N Layer of Pipe A

P / N	P_1	P_2	P_3	CR value
N_1(0.2276)	0.4000	0.4000	0.2000	0
N_2(0.1031)	0.2922	0.0925	0.6153	0.0022
N_3(0.0404)	0.5714	0.2857	0.1429	0
N_4(0.1685)	0.3196	0.1220	0.5584	0.0158
N_5(0.1307)	0.4000	0.4000	0.2000	0
N_6(0.0327)	0.2402	0.2098	0.5499	0.0158
N_7(0.0594)	0.5816	0.3090	0.1095	0.0032
N_8(0.1188)	0.5876	0.3234	0.0890	0.0079

N_9(0.1188)	0.5278	0.1396	0.3325	0.0462
Weight	0.4253	0.2652	0.3095	0.0100

Table 9 The Hierarchical Population Ordering of Factors in P Layer of Pipe A

According to the weight values in table 9, the priority order of three techniques is cured-in-place pipe > slip lining > spiral wound lining, i.e. for the pipes of the diameter between 300 to 600mm, cured-in-place pipe is more applicable trenchless rehabilitation technique.

As is shown above, the computation process exhibits the factors with the biggest weight to the total target in M layer and N layer are construction condition and site condition, respectively. As a result, the project selection should take construction condition as the analysis focus and highlight the consideration about the influence of site condition. It will make sense to analyze moderately other factors with a relatively big weight to the total target, such as operating skill, social benefit and environmental benefit. Further analysis from the technical perspective informs that cured-in-place pipe has no require for pipe material and the lining tube joint the original pipe closely, with smooth surface and no grouting demand resulting in the convenient construction, as well as greatly improved flow performance with little loss of pipe cross-section area. However, slip lining will observably decrease the cross-section area, need grouting and have an obvious social effect. Because of the poor bearing capacity of spiral wound lining it is not suitable for the district with dense buildings and heavy traffic. From the analysis above, AHP can well reflect the real influence of various factors in the trenchless rehabilitation technique selection.

3. CONCLUSION

Rational sewer system construction and operation status are the guarantee of both urban sustainable development and city safety. Of South China the metropolis, with relatively developed economy and high degree of urbanization, is the high dense region of local economic output, so that this kind of area had better apply trenchless rehabilitation technique to repair common sewer pipeline defects containing cracks, misalignment, disconnection, collapse.

The selection of trenchless rehabilitation technique is the problem involved in multi-criteria, multi-level and multi-target, therefore Analytic Hierarchy Process is the preferable decision-making method for matters of this sort. Based on established AHP model, 1-9 scaling is applied to construct the judgment matrix. By means of constructing judgment matrix, sequencing by exponents and its consistency check, hierarchical population ordering and its consistency check, the result shows cured-in-place pipe is more suitable for trenchless rehabilitation of sewer pipelines whose diameters are between 300 to 600mm in the central urban area of Guangzhou City.

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