# PAPER • OPEN ACCESS

# Research on Quality Evaluation Method of TRD Cement-soil Continuous Wall Based on Analytic Hierarchy Process

To cite this article: Song Ju et al 2020 IOP Conf. Ser.: Mater. Sci. Eng. 780 042005

View the article online for updates and enhancements.

# You may also like

- <u>Surfactant-induced spreading of</u> nanoparticles is inhibited on mucus mimetic surfaces that model native lung conditions D Schenck, S Goettler and J Fiegel
- Laser trapping ionization of single human red blood cell
- M Pasquerilla, M Kelley, R Mushi et al.
- <u>Status and first Results of the CBM TRD</u> <u>Prototype Development</u> Andreas Arend and the CBM TRD Group





DISCOVER how sustainability intersects with electrochemistry & solid state science research



This content was downloaded from IP address 3.141.30.162 on 06/05/2024 at 16:17

# **Research on Quality Evaluation Method of TRD Cement-soil Continuous Wall Based on Analytic Hierarchy Process**

Song Ju<sup>1\*</sup>, Yankai Liu<sup>2</sup>, Zhanwu Dong<sup>1</sup> and Dazhuang Gui<sup>3</sup>

<sup>1</sup>Qingdao Metro Line 1 Co., Ltd, Qingdao, 266000, China;

<sup>2</sup> Geotechnical and Structural Engineering Research Center, Shandong University, Jinan, 250061, China)

<sup>3</sup>Shandong Provincial Transportation Planning and Design Institute, Jinan, 250031, China)

\*Corresponding author's e-mail: 247665309@qq.com

Abstract. In order to accurately evaluate the wall quality of cement-soil mixing wall by TRD method and reduce the risk of foundation pit excavation, this paper proposes a comprehensive evaluation method of wall quality. Based on strength analysis, impermeability analysis, borehole TV analysis and electromagnetic borehole radar analysis, the main influencing factors of TRD cement soil wall quality are analyzed and determined. Using the analytic hierarchy process, the hierarchical structure model of the wall quality evaluation index system is established and the evaluation factors are quantified. The fuzzy comprehensive evaluation method is used to evaluate the index factors. By analyzing the evaluation results, the evaluation grade standards of excellent, good, medium and poor reflecting the wall quality are established. The evaluation system and grade standard are used to evaluate the wall quality of waterproof curtain in a station foundation pit of Qingdao metro. The actual excavation of the foundation pit is basically consistent with the evaluation results. It has preliminarily realized a change from qualitative and empirical to scientific and half quantitative. The research results can be promoted and applied to the similar TRD cement soil mixing wall project in the future.

### **1. Introduction**

TRD (Trench cutting Re-mixing Deep wall) method is also called for the thickness of cement soil diaphragm wall technology, and is introduced from Japan in 2009 using a chain saws cutting box under the thick cement soil mixing construction of cement-soil diaphragm wall construction technology [1]. As TRD cement earth wall, which inaccurate or even wrong evaluation will lead to serious engineering accidents such as foundation pit collapse and surface settlement, is a hidden project. Therefore, accurate evaluation of TRD cement soil wall quality plays a crucial role in the safety of foundation pit excavation and long-term impermeability.

At present, relevant researches have been carried out on the engineering practice and wall quality evaluation of construction of equal thickness continuous cement soil wall by TRD method. Sun Z Z et al. [2] studied the application of TRD construction method in sandy and silty soil layer, and summarized various quality control factors of TRD construction in sandy and silty soil layer. Liu T et al. [3] applied the TRD method to complex strata and solved the wall formation problem of complex strata and ultradeep continuum cement soil wall. Zhang S X et al. [4] analyzed the stress of TRD continuous wall support structure, calculated the internal force of the support structure, and checked the anti-uplift

Content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI. Published under licence by IOP Publishing Ltd 1

stability of the foundation pit. Qiu G E et al. [5] tested the implementation effect of soil-cement continuous wall waterproof curtain in engineering through the strength test of wall core. At present, the research on the quality evaluation of the cement-soil wall of the TRD method is mainly focused on the use of one or more detection methods. However, these methods are only a preliminary qualitative analysis of the quality of the cement-soil continuous wall of the TRD method. They are empirical and subjective, and lack the criteria for quantitative analysis. It is impossible to evaluate the excavation safety level of the TRD cement soil wall after the wall is formed, which brings greater blindness to construction decisions such as excavation of the foundation pit after the wall is formed.

This paper combines the wall quality evaluation method used in the construction of soil-cement continuous wall project with the TRD method of a subway station in Qingdao, applies the fuzzy mathematical theory, and adopts the analytic hierarchy process to comprehensively analyze the wall quality. In other words, the evaluation factors are quantified through the analytic hierarchy process [6], the wall quality is comprehensively analyzed based on the fuzzy comprehensive evaluation method, and the wall quality is graded and quantified.

# 2. Project Profile

Taking the quality evaluation of soil-cement continuous wall by TRD method in a station of Qingdao metro as an example, the evaluation system was constructed and verified. The length of the station is 283.4m, the width of the standard section is 19.9m, and it is 11m island platform. The station is in the form of an underground two-layer double-span rectangular frame structure, and the floor of the standard section is buried 17.5m deep. In the depth range of station foundation pit excavation, the soil layer is composed of complex, soft and permeable soil. The quaternary pore water is widely distributed in the sand layer in the form of layers, is often connected with other water layers to form the relationship of runoff and discharge, and its water volume is medium. In the field area, the bedrock fissure water mainly exists in the bedrock strong wind zone and the fissure dense zone in layers and belts. Because the crack development is not uniform, its rich water is not uniform.

# 3. Mathematical model for quality evaluation of TRD continuous wall

## 3.1. Evaluate the determination and quantification of influencing factors

The factors influencing the quality evaluation grade of cement-soil continuous wall by TRD method are complicated, interrelated and independent to some extent. Based on the analysis of the influence of various factors on the quality of cement-soil continuous wall of TRD construction method, the evaluation level of cement-soil continuous wall of TRD was established in combination with the site construction conditions and safety requirements of foundation pit excavation. In accordance with the safety requirements of TRD soil-cement continuous wall, the 28d strength of soil-cement continuous wall shall be greater than 0.8 MPa and the permeability coefficient shall be less than  $1.0 \times 10^{-7}$  cm/s. Based on the practical engineering experience in Qingdao and the specific requirements of the station water-proof curtain, the evaluation grades of the wall quality are divided into four evaluation sets, excellent, good, medium and poor. The evaluation level of wall quality and the quantification of influencing factors are shown in table 1.

	Table 1. Evaluation grade and qualitative table					
Factor of evaluation	Excellent	Good	Medium	Poor		
Strength analysis method	≥1.0MPa	[0.8MPa,1.0MPa)	[0.6MPa,0.8MPa)	< 0.6MPa		
Analysis of impermeability	$\leq 1.0 \times 10^{-7} \text{cm/s}$	(10 <sup>-7</sup> cm/s, 10 <sup>-6</sup> cm/s]	(10 <sup>-6</sup> cm/s, 10 <sup>-5</sup> cm/s]	> 1.0×10 <sup>-5</sup> cm/s		
Integrity analysis	No cracks, large voids and other bad structures	There are slight cracks and a few large voids	Many defective structures	There are many defective structures and poor integrity		
Uniformity analysis	The lithology of uniform	The lithology distribution is a little uneven	The lithology distribution is not uniform	The lithological distribution is discrete		

Table 1. Evaluation grade and quantitative table

#### 3.2. Weight determination method

According to the actual situation and expert opinions of the continuous wall quality evaluation method of TRD method used in this project, a comparative judgment matrix was established for the influencing factors of evaluation based on the hierarchical model structure. The scale of scale 1~9 was used to assign the importance of each factor and calculate the matrix. In general, the weight of  $a_{ii}$  [7-8] is defined as Equations (1).

$$A = \begin{pmatrix} 1 & \mathbf{L} & a_{1j} \\ \mathbf{M} & 1 & \mathbf{M} \\ a_{i1} & \mathbf{L} & 1 \end{pmatrix}$$
(1)

The summation method is adopted to normalize the judgment matrix, and the average value of all elements of the normalized matrix is calculated as follows.

$$x_{i} = \frac{1}{n} \sum_{j=1}^{n} A(a_{ij})$$
(i=1,2,3) (2)

Obtain the feature vector corresponding to the maximum eigenvalue, namely the weight vector.

$$w = (x_1, x_2, L, x_n)^T$$
 (3)

#### *3.3. Check consistency*

Consistency index CI is used to measure consistency [6].

$$CI = \frac{\lambda_{\max} - n}{n - 1}$$

$$\lambda_{\max} = \sum_{i=1}^{n} \sum_{j=1}^{n} A(a_{ij}) x_i$$
(5)

Where *CI* is Causing index,  $\lambda_{max}$  is the maximum eigenvalue of the judgment matrix and *n* is order of judgment matrix.

Because people have a certain subjective understanding of objective things, it is not sufficient to judge whether the matrix has consistency only by the value of CI. Therefore, the mean random consistency index RI is adopted to correct the CI value:

$$CR = \frac{CI}{RI} \tag{6}$$

Where *CR* is consistency ratio, *CI* is consistency indicator and *RI* is random one-time indicator. When  $CR \le 0.1$ , the judgment matrix is considered to have acceptable consistency. Otherwise, it needs to be adjusted to obtain the judgment matrix that passes the consistency test.

#### 4. Quality evaluation and analysis of TRD continuous wall

# 4.1. Strength analysis of TRD diaphragm wall

In order to evaluate the strength characteristics of cement-soil continuous wall stone bodies at different depths, field drilling was conducted on the continuous wall to test the uniaxial compressive strength after core samples were taken out.

After testing, the average uniaxial compressive strength of the four boreholes was 0.89 MPa, 0.91 MPa, 0.70 MPa and 0.90 MPa, respectively. Considering the damage compensation coefficient 1.3 in the drilling process, the average uniaxial compressive strength of the four boreholes after correction is 1.16MPa, 1.18MPa, 0.91MPa and 1.17MPa. It can be seen from the above core uniaxial compressive strength data that the strength of soil-cement continuous wall meets the design requirements, but the fluctuation of the value also reflects the inhomogeneity of the cement wall to some extent.

The strength test results of TRD continuous wall core samples are of great dispersion, and the strength change is significantly correlated with the nature of soil layer exposed by drilling coring. The distribution of core strength with the formation is shown in figure 1. From the perspective of stratigraphic distribution, the strength of continuous wall stones in sand layer is generally higher and more complete than that in clay layer.



Figure 1. Distribution of borehole core sample strength with stratum

#### 4.2. TRD continuous wall impermeability test

In this paper, the variable-head pressure test is used to determine the permeability of the continuous wall to test the permeability of the continuous wall. The borehole pressure test is to measure the unit water absorption of the continuous wall and calculate the permeability coefficient of the continuous wall. Water permeability and internal fissures and their variation with borehole depth. Based on the actual conditions on site, the 1 #, 3 # and 4 # boreholes were selected for pressure water test to determine the permeability coefficient. Change the drilling water level every 5 minutes until the rate of water level change becomes stable. Use the Equations (2) to calculate the permeability coefficient *k*.

$$k = \frac{\pi r^2 \ln(h_1/h_2)}{A(t_2 - t_1)} \tag{7}$$

Where k is the permeability coefficient of the wall of the test section (cm / s), r is drilling radius (mm),  $t_1$ ,  $t_2$  is starting and ending time of observation (min),  $h_1$ ,  $h_2$  is height difference between the water injection surface and the groundwater level in the borehole at time  $t_1$  and  $t_2$  (m) and A is form factor, for the same homogeneous soil layer.

$$A = \frac{2\pi l}{\ln(1/r)} \tag{8}$$

Where l is length of test section (m).

The results of the drilling pressure test are shown in Table 2.

Table 2. Comp	arison of	f permeability	coefficient	between	original	stratum	and T	RD	undergi	ound
			diaphragm	n wall						

	Permeability coefficient (cm/s)						
Soil layer	In-situ formation	Drilling 1#	Drilling 3#	Drilling 4#			
Plain fill	1.2×10 <sup>-2</sup>	5.6×10 <sup>-7</sup>	4.5×10 <sup>-7</sup>	3.8×10 <sup>-7</sup>			
Miscellaneous fill	3.5×10 <sup>-2</sup>	5.6×10 <sup>-7</sup>	4.5×10 <sup>-7</sup>	3.8×10 <sup>-7</sup>			
Silty clay	2.3×10 <sup>-5</sup>	3.7×10 <sup>-7</sup>	4.8×10 <sup>-7</sup>	3.8×10 <sup>-7</sup>			
Coarse sand	2.5×10 <sup>-2</sup>	3.7×10 <sup>-7</sup>	4.8×10 <sup>-7</sup>	3.8×10 <sup>-7</sup>			
Coarse gravel	3.5×10 <sup>-2</sup>	2.8×10 <sup>-7</sup>	4.5×10 <sup>-7</sup>	5.4×10 <sup>-7</sup>			
Clay	$1.2 \times 10^{-6}$	3.9×10 <sup>-7</sup>	3.3×10 <sup>-7</sup>	4.2×10 <sup>-7</sup>			
Gravelly sand	5.8×10 <sup>-2</sup>	3.9×10 <sup>-7</sup>	3.3×10 <sup>-7</sup>	4.2×10 <sup>-7</sup>			
Clay	$1.2 \times 10^{-6}$	3.0×10 <sup>-7</sup>	3.3×10 <sup>-7</sup>	7.3×10 <sup>-7</sup>			
Coarse sand in cohesive soil	2.3×10 <sup>-2</sup>	3.0×10 <sup>-7</sup>	1.8×10 <sup>-6</sup>	7.3×10 <sup>-7</sup>			
Coarse gravel	3.4×10 <sup>-2</sup>	2.6×10 <sup>-7</sup>	$1.7 \times 10^{-6}$	5.4×10 <sup>-7</sup>			
Clay	1.2×10 <sup>-6</sup>	2.6×10 <sup>-7</sup>	1.7×10 <sup>-6</sup>	5.4×10 <sup>-7</sup>			
Gravel with gravel	5.8×10 <sup>-2</sup>	2.6×10 <sup>-7</sup>	1.7×10 <sup>-6</sup>	5.4×10 <sup>-7</sup>			

From the comparison of the in situ permeability coefficient test results of the TRD underground diaphragm wall in Table 3 with the permeability coefficient of the original soil layer, it can be seen that the permeability coefficient of the TRD underground diaphragm wall in the full depth stratum is less than  $10^{-7}$  cm / s, and the permeability is significantly improved , and distributed evenly over the full depth of the formation. The continuous wall under equal thickness of cement soil significantly changes the permeability coefficient of each soil layer, especially the sand layer's impermeability effect is significantly improved, and this improvement of impermeability is distributed uniformly along the full depth of the continuous wall.

#### 4.3. TRD Continuous Wall HD Drilling TV Imaging

The most obvious advantage of distinguishing between the TRD method and other interception methods is the continuity and homogeneity of the TRD method. In previous studies, the physical and mechanical characteristics and permeability of the core samples were used as the main detection indicators. And lack of intuitive understanding of the integrity and uniformity of the interior wall. High-definition drilling television cameras were used to scan the inner walls of each borehole, to observe the cement slurry and undisturbed soil cementation in the borehole, and check whether there are defects such as cracks, collapse, honeycomb, and seepage, and visually observe the integrity and uniformity of the continuous wall. The observation depth and the inner wall defects of the borehole were recorded. Figure 2 shows the internal image of the borehole TV.



Figure 2. TRD continuous wall imaging

Drilling TV test results show:

(1) The inner wall of the borehole is smooth, without obvious cracks and large pores, and there is no obvious water seepage in the hole;

(2) The boreholes at different depths are in good condition, have good continuity, have no major lithological changes, and have more uniform strata.

#### 4.4. TRD continuous wall electromagnetic wave drilling radar detection

Electromagnetic wave drilling radar was used to scan each borehole and observed whether there are obvious cracks, large gaps and other defects in the continuous wall within 2m around the borehole, and further verified the overall integrity and uniformity of the continuous wall. The total length of the survey line is about 18m, of which the survey line below the waterline is 14m long and the survey line above the waterline is 4m long.





The borehole radar detection results are shown in Figure 3. The results show that the reflection of the cement-soil continuous wall does not show significant coaxial misalignment or other discontinuous waveforms. It shows that the cement-soil continuous wall formed by the TRD method is complete and uniform, and the wall has no obvious defects such as cracks and holes.

# 5. Fuzzy comprehensive evaluation

#### 5.1. Determination of indicator weight

According to the geological characteristics of the cement-soil mixing wall by TRD method and the safety requirements of foundation pit excavation, the strength and impermeability are the most important factors for the cement-soil mixing wall by TRD method to meet the safety requirements of foundation pit excavation. Therefore, strength and impermeability are the most important indicators in the evaluation of wall quality. According to the degree of importance, the other evaluation indicators are wall integrity and uniformity in turn. The judgment matrix is given in Equation (9).

	Γ 1	1	2	
		1	3	5
	1	1	2	4
A =	-		_	
	1/3	1/2	1	2
	1/5	1/4	1/2	1
		1, 1	1, 2	

According to the available weight vector and related parameters in Section 3.2,  $w=[0.4092 \quad 0.3499 \\ 0.1585 \quad 0.0824]$ ,  $\lambda_{max}=4.0112$ , *CI*=0.0037, it can be seen that *CR*=0.0041<0.1, which passed the one-time inspection.

## 5.2. Establishing wall quality evaluation matrix

According to the wall quality grade evaluation model, we comprehensively evaluate four evaluation indicators. The grade of each evaluation factor is obtained based the actual measurement results of each field test, and a fuzzy evaluation matrix is established as table 3.

Table 5. Fuzzy evaluation matrix					
Evaluation factors	excellent	good	medium	poor	
Impermeability analysis	0.00	0.89	0.11	0.00	
Strength analysis	0.46	0.17	0.11	0.26	
Integrity analysis	0.86	0.10	0.04	0.00	
Uniformity analysis	0.82	0.09	0.09	0.00	

The evaluation matrix is multiplied by the index weight vector to obtain the fuzzy comprehensive evaluation result of the quality of underground diaphragm wall by TRD method.

$$R = w_A \times R \tag{10}$$

Where R is comprehensive evaluation result, w is the index weight vector, and R' is the evaluation matrix.

Among them,

$$R' = \begin{bmatrix} 0.00 & 0.89 & 0.11 & 0.00 \\ 0.46 & 0.17 & 0.11 & 0.26 \\ 0.86 & 0.10 & 0.04 & 0.00 \\ 0.82 & 0.09 & 0.09 & 0.00 \end{bmatrix}$$
(11)

Therefore,

$$R = w_A \times R = [0.3648 \quad 0.4469 \quad 0.0973 \quad 0.0910]$$
(12)

#### 5.3. Analysis of quality evaluation results of the cement-soil mixing wall by TRD method

The evaluation grades (the evaluation grades in this paper are excellent, good, medium, and poor) are assigned to numerical values, and the fuzzy matrix single value method is used to determine the quality grade of the cement-soil mixing wall by TRD method. Using the finally obtained evaluation index result

R, the points are weighted and averaged to obtain a point value. Generally, it is only necessary to assign specific scores to the N ranks in order with equal intervals. Therefore, 1, 2, 3, and 4 are assigned respectively. The judgment result is

 $M = 1 \times 0.3648 + 2 \times 0.4469 + 3 \times 0.0973 + 4 \times 0.0910 = 1.9145$  (13) M = 1.9145, referring to Table 4, it is considered that the quality of the diaphragm wall by TRD method is good, and the applicability effect is good. Follow-up observation is needed during the excavation process. As shown in Figure 4, during the actual excavation of the foundation pit, there was no leakage, the excavation went smoothly, and the reinforcement and anti-seepage effect was achieved.

Table 4. Grade evaluation of wall-forming effect					
evaluation grade	Index value range	grade description			
excellent	1≤M<1.5	Reinforcing effect is good, and the possibility of water leakage is extremely small			
good	1.5≤M<2.5	Reinforcement effect is good, and the possibility of water leakage is small. Follow-up observation is required			
medium	2.5≤M<3.5	Reinforcement effect is general. Grouting reinforcement should be carried out according to the excavation situation			
poor	3.5≤M<4	The reinforcement effect is poor and it is easy to leak water. Measures should be formulated in advance			



Figure 4. Site excavation of foundation pit

# 6. Conclusion

(1) The analytic hierarchy process is used to evaluate the quality of the TRD construction method of the cement-soil continuous wall. Based on the evaluation indicators, a hierarchical structure model is established, and a judgment matrix is constructed. A new TRD cement-soil wall quality evaluation method is proposed.

(2) Human subjectivity was mathematically expressed by fuzzy comprehensive evaluation method, and index factors were evaluated. By analyzing the evaluation results, four evaluation grade standards reflecting the quality of the wall were established, excellent, good, medium, and poor which makes TRD cement soil wall quality evaluation more objective and accurate.

(3) Based on the engineering background of the TRD cement soil continuous wall water-proof curtain in the foundation pit of a station in Qingdao Metro, it is obtained through the analysis of the evaluation system that the reliable conclusion that the quality of the TRD cement soil wall is good which is in line with the actual situation of excavation of foundation pits. The evaluation method is of great significance to the results of TRD cement soil wall quality evaluation and foundation pit

excavation. It can provide reference for the quality evaluation of the TRD cement soil continuous wall waterproof curtain project in the future.

# Acknowledgments

This study was financially supported by the National Basic Research Development Program of China (973 Program) (Project No. 2013CB036000) and the National Key Research and Development Program of China(2016YFC0801604). The authors would like to thank the Editors and anonymous Reviewers for their valuable and constructive comments related to this manuscript.

# References

- [1] Wang WD, Di GE, Wang XJ. (2012) Engineering practice of the constant thickness steel cementsoil wall constructed by TRD method, Building Structure, 42(5): 168–171.
- [2] Sun ZZ, Li N. (2017) Application of TRD construction method in sandy silt of Shanghai metro. Construction Technology, 46(S2): 1105–1108.
- [3] Liu T, Chu LQ, Wang JJ, Yan FJ, Hu BS. (2014) TRD construction method applied to complicated stratum. Building Construction, 36(08): 903-904+909.
- [4] Zhang SX, Yan XN, Wang CY. (2018) Application of TRD and new supporting structure of the enclosing piles in foundation pit engineering. Journal of Hubei University of Technology, 33(04): 109-112.
- [5] Wu GM, Zhang ZX, Xie ZL. (2013) Application of TRD method in non-in-situ tests on 56.73 mwall of Shanghai International Financial Center. Chinese Journal of Geotechnical Engineering, 35(s2): 814-818.
- [6] Zhang MG, Jiang JC. (2006) Fuzzy comprehensive evaluation of major hazards based on analytic hierarchy process. Journal of Nanjing Tech University(Natural Science Edition), 28(2): 31-134.
- [7] Zhou GE. (2013) On risk assessment and management of frost damage in a tunnel located in a cold region based on ANP and fuzzy theory. Modern Tunnelling Technology, 50 (1): 60-66.
- [8] Weng QN, Wu BQ, Xiang S. (2012) Model study of risk assessment about water bursting and mud gushing in tunnel. Journal of Chongqing Jiaotong University(Natural Science), 31(5): 944-947.