Study on Surrounding Rock Classification and Parameter Determination of Tunnel Constructed by ADECO-RS

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Abstract

The traditional tunnel's surrounding rock quality classification method based on the NATM is difficult to be applied to the tunnel constructed by ADECO-RS. Based on the characteristics of a tunnel constructed by ADECO-RS in Georgia, the deformation of surrounding rock of tunnel constructed by ADECO-RS is analyzed by numerical simulation. A new quantitative index is proposed for the quantitative classification of the surrounding rock of the tunnel built by ADECO-RS method, and research is conducted to determine the parameters of the surrounding rock with varying grade. The variation trends of the extrusion deformation of the palm surface *E* and the ratio *A/R* (the the first deformation of the palm surface to the total radial displacement) under the influence of tunnel buried depth, surrounding rock cohesion, internal friction angle, elastic modulus, Poisson's ratio and bulk density are obtained. The extrusion displacement of palm surface *E* of the palm surface and the ratio *A/R* are selected as the classification factors. *A/R* = 50 % and *E* = 7 cm are used as the classification criteria. A new classification standard is proposed: Grade A surrounding rock is A/R<50 % and E<7cm; Grade B surrounding rock is A/R<50 % and E>7cm or A/R>50 % and E<7cm. Grade C surrounding rock is A/R>50 % and E>7cm. And the selected six parameters value range of the three levels of surrounding rock is obtained.

Keywords

Highway tunnel; ADECO-RS; Surrounding rock classification; Qualitative indicators; Quantitative indicators; Parameter determination.

1. INTRODUCTION

Considering engineering geology and construction needs, numerous classification methods and standards for the surrounding rock have been proposed[1-9] . With time, the accuracy and comprehensiveness of rock classification have improved, changing from qualitative to quantitative analysis. The index used for sorting has also evolved from a single-parameter index[10-11] to a single-parameter comprehensive index[12-14] and finally to a multi-parameter comprehensive index[15-24].

There are lots of methods and standards for the tunnel surrounding rock classification, but most of them and their parameters determinations are formed from the perspective of the NATM, seldom from the perspective of ADECO-RS. There are differences between NATM and ADECO-RS. The NATM can fully use the surrounding rock's self-supporting capacity and the excavation surface's spatial restraining capacity, but it requires the surrounding rock has higher quality. In contrast, ADECO-RS is suitable for complex weak surrounding rocks and has advantages such as complete-section construction, flexibility, low cost and using modern construction techniques. But the traditional tunnel surrounding rock classification methods (TSRCMs) obtained from NATM are not suitable for the ADECO-RS method. Huang et al. [9] compared and analyzed the classification methods of soft surrounding rock of the tunnel based on NATM theory and ADECO-RS, respectively. The conclusions of this paper [9] show that the classification method for tunnel surrounding rock based on ADECO-RS is more suitable than that based on NATM for the extra-long tunnel. However, this method adopts the stability classification criteria of the tunnel face of ADECO-RS as the classification of the whole surrounding rock, and the quantitative classification method for surrounding rock is not proposed in combination with the characteristics of ADECO-RS. Yan et al.[6] analyzed the deformation characteristics of surrounding rock in soft surrounding rock of tunnel by numerical simulation. In paper [6], a soft rock tunnel preliminary classification method has been proposed based on the ratio of advanced displacement of the tunnel face to the total radial displacement and whether the extrusion displacement exceeding it's threshold value. Corresponding support measures have also been suggested in this paper [6]. However, it does not analyze the impact of tunnel depth on surrounding rock deformation and does not determine the parameters of all levels of surrounding rock [6].

Therefore, this paper adopts a tunnel constructed by ADECO-RS method in Georgia as engineering background. The numerical simulation by FLAC3D is used to study the deformation characteristics of the tunnel's surrounding rock under various parameters based on the indices of categorization factors, classification standards, and working indexes. A new quantitative index for classification of the surrounding rock of tunnels constructed by ADECO-RS is proposed based on Guan's preliminary classification method for soft rock tunnels [6]. This index is for IV, V, and VI grade surrounding rock with poor strength. The physical parameters range of the surrounding rock for all levels of the tunnel constructed by ADECO-RS have been determined, and a classification system suitable for ADECO-RS is established.

2. BASIC CONCEPTS OF ADECO-RS

Pietro Lunardi[25], an Italian scholar, proposed ADECO-RS. ADECO-RS aims to strengthen the tunnel face advanced core soil and improve stiffness to control the deformation of the surrounding rock after excavation. The tunnel constructed by ADECO-RS method can be constructed in complete sections even under poor geological conditions with weak surrounding rock. ADECO-RS divides the deformation of the tunnel face into three categories: stable, short-term stable, and unstable. The corresponding advanced core soil is elastic, elastic-plastic, and failure, and the corresponding arching effect is A, B, and C, as shown in Figure 1.

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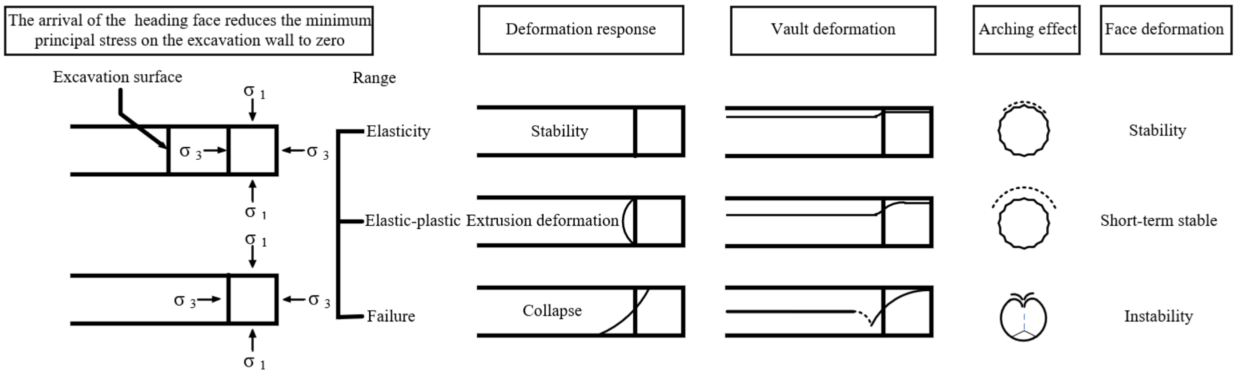

Figure 1. Classification of deformation and arching effect of the tunnel constructed by ADECO-RS

The ADECO-RS theory holds that a tunnel's excavation and support measures should be continuously adapted to account for the surrounding rock's stress and strain state under construction to create an arching effect. The formation and location of the arch determine the deformation of the surrounding rock and the stability of the tunnel. The deformation of the tunnel is divided into three categories: the first deformation in front of the tunnel face, the extrusion deformation of the tunnel face, and the deformation behind the tunnel face [16]. The advanced displacement in front of the tunnel face refers to a deformation towards the direction of the tunnel excavation space yielded by the surrounding rock in front of the unexcavated tunnel face and out-side the theoretical soil silhouette. The extruded deformation of the tunnel face refers to a horizontal extrusion deformation of the tunnel face under excavating and affected by ground stress adjustment. The displacement behind the tunnel face refers to the deformation of the excavated tunnel's surrounding rock behind the tunnel face, as shown in Figure 2.

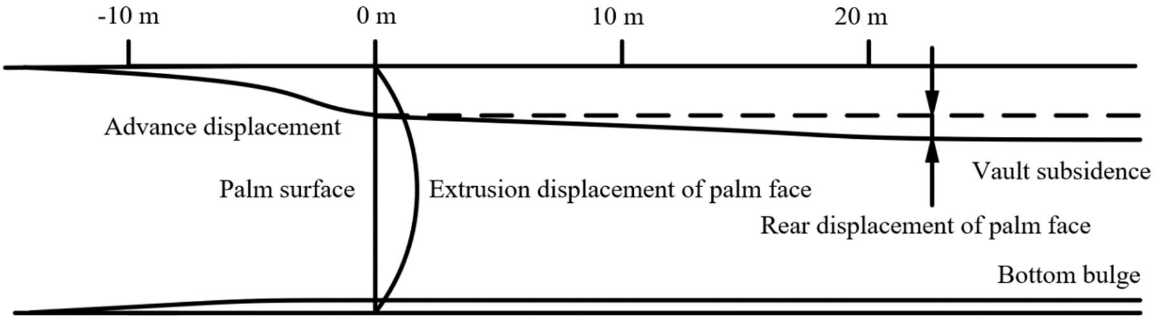

Figure 2. The main deformation of the tunnel constructed by ADECO-RS

3. ENGINEERING BACKGROUND AND NUMERICAL SIMULATION MODEL CONSTRUCTIO

The tunnel project is located in the section from Shuhari to Zetanibo of the E60 highway in Imereti, Georgia, with a total length of 6.768 km, a total of 5 tunnels, and a single length of 6.879 km. The overall layout of the project construction is shown in Figure 3. This project is a double-line highway tunnel. The radius of the tunnel face is 5.5 m, and ADECO-RS Construction, namely the rock and soil control deformation analysis method, is adopted.

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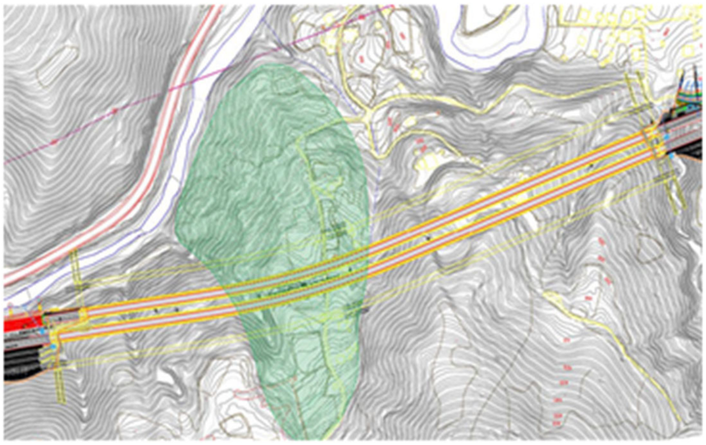

Figure 3. The overall layout of the project construction

To ensure accuracy, the numerical simulation model is created according to the design drawings. Firstly, it is established by Midas software. The size of the model in *x* (horizontal direction), *y* (tunnel axial direction) and *z* (vertical direction) direction are 120, 75.95 and 60 m, respectively. The upper boundary of the model is a free surface, and the normal displacement of the other five faces are constrained. The buried depth, span and height of the tunnel is 25, 12.9 and 10.8 m, respectively. The cross-section of the tunnel is a flat ellipse. The numerical simulation model of the tunnel constructed by ADECO-RS is shown in Figure 4.

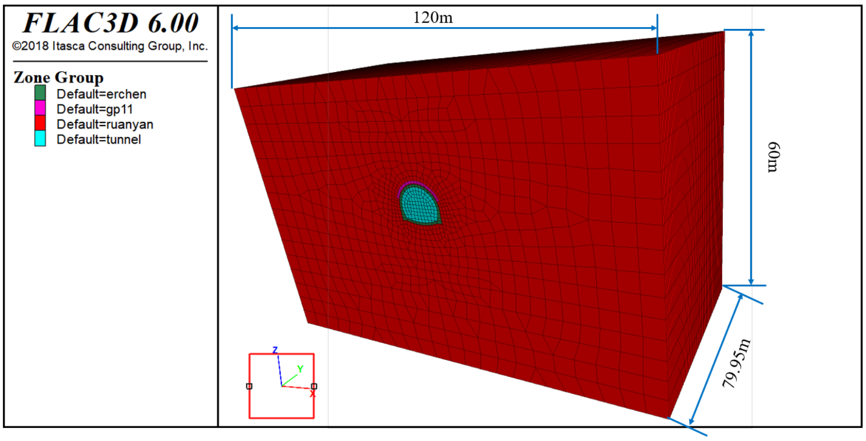

Figure 4. Numerical simulation model of tunnel construction by ADECO-RS

The tunnel surrounding rock is simulated by three-dimensional solid unit. The lining thickness is 0.25m, which is simulated by shell structural units, and its elastic modulus is 2400 MPa, Poisson ratio is 0.24, and unit weight is 22 kN/m^3. Mohr-Coulomb criteria is adopted for the tunnel's surrounding rock. After 1m excavation of each full section of the tunnel, the initial lining is applied immediately and calculating until the stress balance reaches. Then, the same procedure will be repeated until the tunnel is dug through (25 m for the numerical simulation model). During the calculation process, the total radial displacement of the tunnel, the leading displacement of the palm surface and the extrusion displacement of the palm surface are monitored.

4. DETERMINATION OF INFLUENTIAL PARAMETERS OF SURROUNDING ROCK CLASSIFICATION

The deformation and stability of the surrounding rock of the tunnel are influenced by a lot of parameters. Due to the more the parameters, the greater the amount of calculation and the higher the cost. Therefore, in this paper, six parameters, which have significantly influence on the deformation and stability of the tunnel's surrounding rock are selected to analyze their influence on the deformation and stability of the surrounding rock of the tunnel. involved in the analysis of the surrounding rock of the tunnel. The range analysis and variance analysis of the selected parameters of surrounding rock classification are carried out by orthogonal test analysis, and the sensitivity of each parameter is obtained, which lays a foundation for the follow-up study of surrounding rock classification and parameter determination of the tunnel constructed by ADECO-RS method.

According to papers [20,23], the standard values of physical parameters of surrounding rocks at all levels and the stability level of the tunnel face are obtained, as shown in Table 1. The six selected parameters of buried depth, cohesion, internal friction angle, elastic modulus, Poisson's ratio, and bulk density are determined. Table 1 shows that the tunnel face categories of grade I, II, and III surrounding rocks all belong class A, and grade IV, V, and VI surrounding rocks include all tunnel face stability categories. Therefore, the physical parameter index range involved is analyzed. Considering the surrounding rock parameters, seven factors and three levels of orthogonal experiments are carried out on the surrounding rock of grades IV, V, and VI. The surrounding rock parameters at all levels are obtained, as shown in Table 2.

Table 1. The standard value of physical and mechanical indexes of surrounding rock at all grades and the stability level of tunnel face

Classification of surrounding Rock	Volumetric Weight /(kN/m3)	Modulus of deformation / (GPa)	Poisson' ratio	Internal friction /(°)	Cohesion /(MPa)	Category of palm face
I	>26.5	>33	<0.2	>60	>2.1	A
II	>26.5	20-33	0.2-0.25	50-60	1.5-2.1	A
III	26.5-24.5	6-20	0.25-0.3	39-50	0.7-1.5	A
IV	24.5-22.5	1.3-6	0.3-0.35	27-39	0.2-0.7	ABC
V	17-22.5	<1.3	0.35-0.45	20-27	0.05-0.2	BC
VI	15-17	<1	0.4-0.5	<20	<0.2	C

Table 2. Parameters of the tunnel constructed by ADECO-RS

Parameter	Value								
	Grade IV			Grade V			Grade VI		
	1	2	3	4	5	6	7	8	9
Volumetric /(kN/m3)	24.50	23.50	22.50	20.67	18.83	17.00	16.50	16.00	15.50
Elastic Modulus /(GPa)	6.00	3.65	1.30	1.20	1.10	1.00	0.80	0.60	0.40
Poisson Ratio	0.30	0.33	0.35	0.37	0.38	0.40	0.42	0.44	0.46
The angle of internal friction /(°)	39.00	33.00	27.00	24.67	22.33	20.00	19.00	18.00	17.00
Cohesion /(MPa)	0.70	0.45	0.20	0.15	0.10	0.01	0.04	0.03	0.02
Tunnel depth /(m)	40	25	10	40	25	10	40	25	10

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4.1. Extremum difference analysis

The analysis of extreme deviations can intuitively and vividly shows the order of influence of surrounding rock parameters on the deformation of the tunnel constructed by ADECO-RS method. Using the calculation formulas (1), (2), and (3), the analysis of extremization values of each parameter for the surrounding rock of grade IV, V, and VI are obtained, as shown in Table 3.

$$\overline{K_{ij}}_{\max} = \max\{\overline{K_{Aj}}, \overline{K_{Bj}}, \overline{K_{Cj}} \ldots \overline{K_{ij}}\} \tag{1}$$

$$\overline{K_{ij}}_{\min} = \min\{\overline{K_{Aj}}, \overline{K_{Bj}}, \overline{K_{Cj}} \ldots \overline{K_{ij}}\} \tag{2}$$

$$R_j = \overline{K_{ij}}_{\max} - \overline{K_{ij}}_{\min} \tag{3}$$

Where R_j is the range of factor *j*; K_{ij} is the *i*th level value of factor *j*; $\overline{K_{ij}}$ is the average value of K_{ij};

From the results of the extreme deviations analysis, it can be seen that when the surrounding rock of the tunnel is grade IV, the order of the extreme deviations of extrusion displacement is elastic modulus, buried depth, Poisson's ratio, bulk density, cohesion, internal friction angle, and the order of the extreme deviations of the ratio *A/R* is: buried depth, cohesion, elastic modulus, internal friction angle, Poisson's ratio, bulk density. As the surrounding rock of the tunnel is grade V, the order of the extreme deviations value of the extrusion displacement is buried depth, cohesion, elastic modulus, internal friction angle, bulk density, Poisson's ratio, and the order of the extreme deviations value of the ratio *A/R* is: buried depth, cohesion, internal friction angle, bulk density, elastic modulus, Poisson's ratio. If the surrounding rock of the tunnel is grade VI, the order of the extrusion displacement extreme deviations is: buried depth, cohesion, elastic modulus, Poisson's ratio, bulk density, internal friction angle, and the order of the ratio *A/R* extreme deviations is: buried depth, cohesion, elastic modulus, Poisson's ratio, internal friction angle, bulk density.

Table 3. Extreme variance analysis

Dependent Variable	Surrounding Rock Grade	Cohesion /(MPa)	Internal friction /(°)	Elastic Modulus /(GPa)	Poisson's ratio	Volumetric Weight /(kN/m3)	Tunnel depth /(m)	Error
Extrusion Displacement /(mm)	IV	0.5815	0.478334	1.658	0.794834	0.700333	1.3265	0.640834
	V	8.457717	3.733284	5.390716	2.914317	3.272216	11.351017	1.47035
	VI	70.062333	30.726667	41.8325	38.235334	33.093	88.970667	40.1775
A/R	IV	0.035383	0.019717	0.035184	0.019633	0.014266	0.122584	0.024517
	V	0.187083	0.045617	0.018117	0.0169	0.018534	0.28345	0.015367
	VI	0.213217	0.064233	0.12245	0.083717	0.045633	0.253917	0.043534

From the results of the analysis of extreme deviations, it can be seen that the primary and secondary order of the influence of each parameter on the extrusion displacement of the surrounding rock of the tunnel constructed by ADECO-RS changes for the surrounding rock of grade IV, V, and VI. With the increase of surrounding rock grade, the primary influence parameter changes from elastic modulus to buried depth, the elastic modulus decreases to the third order, and the buried depth increases from the second order to the first order. The most influential parameter is cohesion, which rises from the fifth to the second order. The bulk density, internal friction, and Poison's ratio are lower in the primary and secondary order, which are in the last three.

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The order of the primary and secondary influence on tunnel extrusion displacement changes for the surrounding rock of the tunnel constructed by ADECO-RS. With the increase of surrounding rock grade, the primary influence parameter has always been buried depth, and the influence of cohesion has not changed, which is in the second order. The buried depth has risen from the second order to the first order. The most influential parameter is the elastic modulus, which decreases from the third order to the fifth order and then rises to the third order. The influence of internal friction angle changes a little from the fourth to the third to the fifth. The bulk density and Poisson's ratio are lower in the primary and secondary order and are in the last three order.

4.2. Analysis of variance

Because the extreme deviations analysis cannot quantify the size of the test error, the variance analysis is further carried out to make up for the defects in the extreme deviations analysis, and the parameters that have the most significant influence on the deformation of the surrounding rock are analyzed. According to Formulas (4) – (9)， the variances are calculated and presented in Tables 4 and 5.

Total dispersion square sum S_T:

$$S_T = \sum_{i=1}^{n} y_i^2 - \frac{T^2}{n} \tag{4}$$

$$T = \sum_{i=1}^{n} y_i \tag{5}$$

The sum of squared deviations of factors S_j:

$$S_j = \frac{1}{r}\sum_{i=1}^{r} K_{ij}^2 - \frac{T^2}{n} \tag{6}$$

The sum of squared error deviations Se:

$$S_e = S_T - \sum_{j=1}^{m} S_j \tag{7}$$

Degree of freedom f:

$$f = r - 1 \tag{8}$$

Constructs statistic F_j:

$$F_j = \frac{S_j}{f_j}\left(\frac{S_e}{f_e}\right)^{-1} \tag{9}$$

Where n is the total number of tests; r is the number of factor levels; j is the j-th influence factor.; i is the value of the i-level of the factor j.

It can be seen from the calculation results that when the surrounding rock grade is IV, the order of influence of each parameter on the R /A value is buried depth, cohesion, elastic modulus, Poisson's ratio, internal friction angle, bulk density. The order of influence of each parameter on the extrusion displacement is elastic modulus, buried depth, Poisson's ratio, bulk density, cohesion, and internal friction angle. If the surrounding rock is grade IV, the elastic modulus is the most critical parameter influencing the tunnel deformation constructed by

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ADECO-RS. The parameter that has the most significant influence on the *A/R* value of the tunnel built by ADECO-RS is the buried depth.

Table 4. ANOVA calculation results for extrusion displacement

Parameters	Classification of surrounding rock	The sum of squared deviations	Degree of freedom	Mean Square	F
Volumetric Weight	IV	1.621	2	0.81	1.054
	V	36.959	2	18.48	11.107
	VI	3616.68	2	1808.34	0.984
Elastic Modulus	IV	9.816	2	4.908	6.382
	V	101.583	2	50.792	30.527
	VI	6858.566	2	3429.283	1.865
Poisson's ratio	IV	1.898	2	0.949	1.234
	V	32.586	2	16.293	9.793
	VI	5020.056	2	2510.028	1.365
Internal friction	IV	0.802	2	0.401	0.521
	V	52.1	2	26.05	15.657
	VI	3158.223	2	1579.111	0.859
Cohesion	IV	1.068	2	0.534	0.695
	V	252.123	2	126.062	75.767
	VI	16594.592	2	8297.296	4.513
Tunnel Depth	IV	5.555	2	2.777	3.611
	V	402.862	2	201.431	121.067
	VI	24964.93	2	12482.465	6.79

Table 5. ANOVA calculation results for *A/R* value

Parameters	Surrounding rock classification	The sum of squared deviations	Degree of freedom	Mean Square	F
Volumetric Weight	IV	0.001	2	0	0.498
	V	0.001	2	0.001	2.618
	VI	0.008	2	0.004	2.611
Elastic modulus	IV	0.004	2	0.002	3.56
	V	0.001	2	0.001	2.562
	VI	0.048	2	0.024	16.04
Poisson's ratio	IV	0.001	2	0.001	1.003
	V	0.001	2	0	2.205
	VI	0.026	2	0.013	8.91
Internal friction	IV	0.001	2	0.001	0.968
	V	0.007	2	0.003	17.176
	VI	0.015	2	0.007	4.943
Cohesion	IV	0.004	2	0.002	3.629
	V	0.111	2	0.056	274.047
	VI	0.155	2	0.078	52.267
Tunnel depth	IV	0.047	2	0.024	38.309
	V	0.249	2	0.124	611.852
	VI	0.204	2	0.102	68.54

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When the surrounding rock grade is V, the order of influence of each parameter on A/R is buried depth, cohesion, elastic modulus, Poisson's ratio, internal friction angle, and bulk density. The order of influence of each parameter on the extrusion displacement is buried depth, cohesion, elastic modulus, Poisson's ratio, internal friction angle, and bulk density. In Grade V surrounding rock, the parameter that has the most significant influence on the deformation of the tunnel constructed by ADECO-RS is the buried depth. The parameter that has the most critical influence on the total radial displacement, the advance removal and A/R of the tunnel built by ADECO-RS is bulk density, internal friction angle and tunnel depth.

The primary and secondary order of the influence of each parameter on A/R value in grade VI surrounding rock is buried depth, cohesion, elastic modulus, Poisson 'ratio, internal friction angle, and bulk density. The order of influence of each parameter on the extrusion displacement is buried depth, cohesion, elastic modulus, Poisson's ratio, bulk density, and internal friction angle. For the VI-level surrounding rock, the most influential parameter on the deformation of the tunnel constructed by ADECO-RS is cohesion.

4.3. Sensitivity analysis

Combined with extreme deviations analysis and variance analysis, the sensibility of each parameter to the deformation of tunnel surrounding rock can be obtained: in the surrounding rock of grade IV, V, and VI, the primary and secondary order of the influence of each parameter on A/R has not changed, which are buried depth, cohesion, elastic modulus, Poisso's ratio, internal friction angle, and bulk density.

The primary and secondary order of the influence of each parameter on the extrusion displacement of the surrounding rock of the tunnel constructed by ADECO-RS changes, and the parameter with the most significant change is cohesion. When the tunnel surrounding rock is grade IV, the cohesion has little effect on the extrusion displacement, which is only in the fifth order. However, with the increase of tunnel surrounding rock grade, the influence of cohesion on extrusion displacement rises to the second order, the influence of buried depth on extrusion displacement increases from the second order to the first order, the influence of elastic modulus on extrusion displacement decreases from the first order to the third order, and the influence order of bulk density on extrusion displacement decreases from the fourth e to the last two order.

In summary, when the surrounding rock of the tunnel is grade IV, the primary parameter influencing the deformation of the tunnel constructed by ADECO-RS is the elastic modulus. When the surrounding rock of the tunnel is grade V, the three primary parameters influencing the deformation of the tunnel built by ADECO-RS are cohesion, bulk density, and internal friction angle. When the surrounding rock of the tunnel is grade VI, cohesion is the parameter that significantly influences the tunnel deformation constructed by ADECO-RS. The primary parameters influencing the extrusion displacement of the tunnel face are elastic modulus (low surrounding rock grade) and cohesion (high surrounding rock grade), and the primary parameter affecting the A/R value is cohesion.

5. SURROUNDING ROCK CLASSIFICATION OF TUNNEL CONSTRUCTION BY ADECO-RS

5.1. Stability criterion

Controlling the deformation of the tunnel-face-advanced-core-soil is the key to maintaining the overall stability of the tunnel by ADECO-RS. The strength of the tunnel is determined by monitoring the stress and strain of the rock around the tunnel face, according to Table 6 criteria[27].

Table 6. Stability classification criteria of the tunnel constructed by ADECO-RS

Referee condition	Grade A (stable tunnel face)	Grade B (short-term stability of the tunnel face)	Grade C (unstable tunnel face)
Stability	Stable	Short term stabe	instable
Arching effect	Near to the excavation contour surface	Far away from the excavation contour surface	No arching effect
Surrounding rock deformation	Elastic deformation, centimeter scale	Elastic-plastic Deformation, centimeter scale.	The strata in front of the tunnel face must be reinforced in advance. Otherwise, the surrounding rock will be unstable.
Palm surface	monolithic stability	short-term stable	The stratum in front of the tunnel face must be reinforced in advance.
Groundwater	As long as the groundwater does not reduce the stratum's strength, groundwater does not influence the tunnel's stability.	Groundwater will reduce the strength of the stratum, thus influencing the stability of the tunnel. Therefore, it is necessary to eliminate the dynamic water in the super-strong core soil.	Measures must be taken to exclude groundwater in the advanced core soil.
Support Pattern	General treatment, mainly to prevent the weakening of surrounding rock and maintain the stability of the excavation profile surface.	The traditional radial surrounding rock constraint is adopted behind the tunnel face; sometimes, the advance constraint in front of the tunnel face is needed.	The stratum in front of the tunnel face must be reinforced in advance to provide the artificial arching effect.

The stability of tunnels constructed by ADECO-RS is divided into three grade. Grade A can maintain the strength of the tunnel, the arch effect after excavation is close to the excavation contour, the surrounding rock deformation is in the elastic range, and the general support method is adopted. Grade B can maintain the short-term stability of the tunnel, and the arch effect is far away from the excavation contour after excavation. The deformation of the surrounding rock is in the elastic-plastic range, and the traditional radial surrounding rock constraint support method is adopted. Grade C tunnel is unstable and cannot form arch effect after excavation, so advanced reinforcement support must be adopted.

5.2. Criteria for Surrounding Rock Mass Classification

The construction of ADECO-RS is mainly based on the strength of the leading core soil and the different types of deformation forms of the tunnel face, and the deformation control construction is carried out in a targeted manner. Therefore, in the classification of confining pressure, the maximum the first deformation of the tunnel face, the maximum extrusion displacement of the tunnel face, and the total radial displacement of the working face are taken as the classification factors. The vault settlement at the tunnel face is selected as the maximum value of the first displacement of the tunnel face. The extrusion deformation of the center of the tunnel face is determined as the maximum extrusion displacement of the tunnel face. The vault subsidence at 20 m behind the tunnel face (1.5 times the span) is selected as the total radial displacement of the tunnel[28].

The deformation of surrounding rock occurs at the moment of excavation of the tunnel constructed by ADECO-RS, in which the first displacement accounts for a large proportion,

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accounting for about 20 ~ 30 % of the total radial displacement. The first deformation is usually unlimited when the surrounding rock conditions are good. However, when the surrounding rock grade of the tunnel is in the poor IV, V, and VI grade and the buried depth is extensive, the first displacement increases continuously, and the ratio of the first displacement to the total radial displacement also increases. If it (the first deformation) is not controlled, when the ratio of the first deformation to the total radial displacement exceeds 50%, the vault of the tunnel face tends to collapse partially, which becomes the main reason for the large deformation of the tunnel[6]. The extrusion displacement of the tunnel face is also one of the leading causes of the collapse of the tunnel face. The empirical control value of the extrusion displacement of the tunnel face in Japan is 7 cm [29]. Therefore, the extrusion deformation E of the tunnel face and the ratio A/R of are selected as the classification factors of the surrounding rock of the tunnel constructed by ADECO-RS. A/R = 50 % and the extrusion displacement value of the tunnel face E = 7cm are selected as the classification criteria for the surrounding rock of the tunnel constructed by ADECO-RS. The classification method of surrounding rock quality grade based on the construction concept of ADECO-RS is as follows:

The A-grade surrounding rock is A/R < 50 % and the extortion displacement of the tunnel face E < 7cm.

The B-grade surrounding rock is divided into two categories: A/R < 50 % and E > 7 cm or A/R > 50 % and the extrusion displacement value of the tunnel face E < 7cm;

The C-grade surrounding rock is A/R > 50%and E > 7 cm.

5.3. Analysis of the influence law of each parameter

According to the change of the average value of each parameter at different levels in the sensitivity analysis, the influence of each parameter can be obtained, as shown in Figure 5.

Based on the results of the influence the selected six parameters on grades IV, V, and VI surrounding rock, it can be concluded that with the increase of cohesion, the A/R value increases first and then decreases gradually. The extrusion displacement, radial total displacement, and leading displacement decrease monotonously, and the decrease is significant in the first three levels. With the increasing of internal friction angle, the A/R value rises in the first three levels and then decreases gradually. The extrusion, radial total, and the first deformations decrease monotonously and sharply in the first four levels. With the increase of elastic modulus, A/R value, extrusion displacement, total radial displacement and the first deformation decrease gradually in general, and extrusion displacement, total radial displacement and the first deformation increase slightly at the third level. With the increase of Poison's ratio, the A/R value, extrusion displacement, the first deformation, and the total radial displacement increase gradually. With the rise of bulk density, the extrusion displacement, radial total displacement, and the first deformation increase at the first levels and then decrease gradually, but the decrement is not evident. The A/R value decreases monotonously. With the increasing of tunnel burial depth, the A/R value, extrusion displacement, radial total displacement, and the first deformation all increase.

5.4. Determination of classification parameter range

According to the classification standard of the surrounding rock of the tunnel constructed by the new Italian method, the range of parameters of surrounding rock of grades IV, V, and VI under the classification standard is obtained, as shown in Table 7. Based on the influence results of the six parameters on the extrusion deformation E of the tunnel face and the ratio of A/R of the surrounding rock in grade IV, V, and VI, the parameters of the surrounding rock in grade A, B, and C are obtained, as presented in Table 8.

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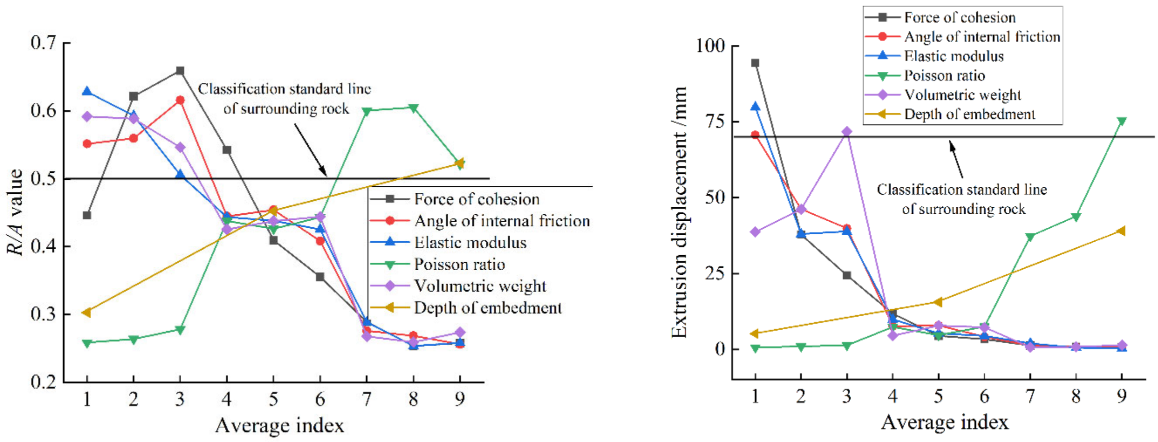

Figure 5. The influence of the six selected parameters on *A/R* and extrusion displacement

Table 7. The range of each parameter under the grading standard

Classification standard	Cohesion /(MPa)	Internal friction /(°)	Elastic Modulus /(GPa)	Poisson's ratio	Volumetric Weight /(kN/m^3)
Ratio *A/R*＜0.5	0.02-0.023 0.066-0.7	19.677-39	0.818-6	0.3-0.407	16.692-24.5
Ratio *A/R*＞0.5	0.023-0.066	17-19.677	0.4-0.818	0.407-0.46	15.5-16.692
E＜70mm	0.024-0.7	17.026-39	0.447-6	0.3-0.456	15.5-16.464 16.514-24.5
E＞70mm	0.02-0.024	17-17.026	0.4-0.447	0.456-0.46	16.464-16.514

Table 8. The parameters of surrounding rock in all grades and the stability of the tunnel face

Classification of surrounding rock	Cohesion /(MPa)	Internal friction /(°)	Elastic Modulus /(GPa)	Poisson' ratio	Volumetric Weight /(kN/m3)	Stability of the tunnel face
A	0.066-0.7	19.677-39	0.818-6	0.3-0.407	16.692-24.5	stabilization
B	0.02-0.023 0.024-0.066	17.026-19.677	0.447-0.818	0.407-0.456	15.5-16.464 16.514-16.692	metastable
C	0.023-0.024	17-17.023	0.4-0.447	0.456-0.46	16.464-16.514	instability

6. CONCLUSION

Based on the engineering background of a tunnel constructed by ADECO-RS in Georgia, this paper puts forward two new qualitative index and quantitative index for the classification of surrounding rock of tunnel constructed by ADECO-RS, and obtains the range of surrounding rock parameters at all levels. The following main conclusions are obtained:

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(1) Two new qualitative and quantitative indexes for the classification of surrounding rock of tunnel built by ADECO-RS method are put forward. A/R = 50 % and the extrusion displacement of the tunnel face E = 7 cm are proposed as the new classification standard. The tunnel constructed by ADECO-RS is divided into three levels: The A-grade surrounding rock is A/R < 50 % and E < 7 cm. The B-grade surrounding rock is A/R < 50 % and E > 7cm or A/R > 50 % and E < 7cm. The C-grade surrounding rock is A/R > 50 % and E > 7cm.

(2) The influence of the key physical and mechanical parameters on E and A/R is obtained. It is found that with the increase of cohesion, A/R value increases first and then decreases gradually, while E, the total radial displacement and the first deformation all decrease monotonously. As the internal friction angle increases. A/R value first increases and then gradually decreases. E, the total radial displacement and the leading displacement all decrease monotonously. With the increase of elastic modulus, A/R, E, total radial displacement and the first deformation gradually decrease as a whole, extrusion displacement, total radial displacement and the first deformation increase slightly at the third level. With the increase of Poisson 's ratio, A/R, E, the first deformation and total radial displacement increase gradually. With the increase of bulk density, A/R decreases monotonously, and E, radial total displacement and the first deformation increase first, and then gradually decrease, but the decrement is not obvious. With the increase of tunnel buried depth, A/R, E, radial total displacement and the first deformation all increase monotonically.

(3) According to the new qualitative and quantitative and indexes for the classification of the surrounding rock constructed by ADECO-RS method and the influence of the key six parameters on A/R and E, the physical and mechanical parameters of A, B and C grade surrounding rock of the tunnel built by ADECO-RS method are determined

In the next step, the relationship between the proposed quantitative index and the BQ value in the national standard will be studied in depth, and the influence of groundwater, initial ground stress and the occurrence of main structural planes will be considered to continuously improve the surrounding rock classification system of the tunnel constructed by the new method.

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