Big data mechanism of railway tunnel base void and degradation damage based on discrete element method

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Abstract: With the development of cities and the advancement of science and technology, it is no longer possible to meet the needs of modern society only by relying on ground engineering construction projects. People are paying more and more attention to the development and utilisation of underground space. This paper is based on the discrete element method to study railway tunnels, comprehensively using theoretical analysis, laboratory tests and numerical simulations and other research methods. Aiming at the deterioration of surrounding rock conditions and insufficient tunnels in the study area, the influence of the cavity after lining on the long-term safety and remaining life of the railway tunnel was studied. The experimental results show that as the degree of tunnel shortage increases, the thickness of the railway tunnel and the safety factor of the full section of the structure are significantly reduced, and they are approximately linear.

Keywords: discrete element method; deterioration of substrate shedding; damage detection; big data mechanism; railway tunnel; hole in foundation pit.

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1 Introduction

With the development of cities and the higher and higher requirements for environmental protection, the development space on the ground has become smaller and smaller, and only relying on ground engineering construction projects can no longer meet the needs of modern society. How to effectively detect and rectify tunnel defects and ensure the normal passage of trains in the tunnel and the safety of personnel is a problem that must be solved (Zhang et al., 2019). Therefore, it is necessary to conduct an in-depth study on the cavitation and deterioration of the basement, which are widespread and have serious effects on the tunnel lining, so as to provide a reference for the targeted comprehensive treatment in the later stage of the tunnel inspection.

The large-scale construction of the tunnel project also brought us great challenges. Due to the complex and changeable engineering characteristics of the surrounding rock, coupled with the influence of various factors such as complex engineering geological conditions, climatic conditions and construction technology limitations, some tunnels have suffered serious tunnel diseases during the construction or early stage of operation, such as lining cracking, thinning of the secondary lining, water leakage in the tunnel, sinking of the basement and mud turning of the inverted arch, etc. Cracks in the tunnel lining structure will directly damage the stability of the tunnel lining structure, reduce the safety and reliability of the lining structure, affect the functionality of the tunnel as a traffic channel, and endanger the safety of traffic in severe cases. The leakage of the tunnel lining structure is one of the main factors affecting the long-term safety and durability of the tunnel (Cao et al., 2019). Leaking water will increase the humidity in the tunnel, resulting in damage to the tunnel circuit, corrosion of equipment and increased crack width, which will greatly reduce the safety of the lining structure and accelerate the damage of the lining structure. Setting the base of the tunnel or lower drum is a disease that occurs at the base of the tunnel. The underlying disease will worsen the working conditions of the train and seriously affect driving safety (Zhao et al., 2019).

Feng Gang used numerical simulation methods to carry out related research on the influence of different degrees of cavities behind the lining and insufficient lining thickness on the lining structure's stress state and safety. On this basis, indoor model tests were used to investigate the lining behind the lining. The failure law of the existence of voids has been studied (Gang et al., 2019). The study concluded that the existence of voids and insufficient lining thickness changed the stress state of the lining structure, while reducing the section stiffness and safety factor at the defect location. Meguid used the elastoplastic finite element method to analyse the influence of different degrees and different ranges of cavities on the stress changes of the tunnel lining. The study found that the range of cavities has a significant influence on the circumferential stress of the lining structure. When the cavity size reaches a certain range, it may cause a sudden change in the positive and negative values of the bending moment. The paper suggests that the cavity must be treated before it reaches a certain size (Meguid et al., 2018). Richardsls carried out related research on the cracking of the tunnel lining structure and believed that: the cavity behind the lining, the deterioration of the lining material and the large surrounding rock pressure are the main reasons for the cracking of the tunnel lining structure (Richardsls et al., 2018). Singh Bhawani et al. studied the bearing characteristics of the lining structure under the condition of voids behind the lining and insufficient lining thickness through model tests. The research results obtained the relationship between the range of voids behind the lining and the degree of insufficient lining thickness and the bearing capacity of the lining (Bhawani and Lingyun, 2018). These studies have certain reference value for this paper, but due to the narrow data cited in the research, the data industry is basically limited to individual industries and has no universal effect.

This paper studies the engineering characteristics of tunnel surrounding rock such as swelling, softening, disintegration, susceptibility to disturbance, damage and deterioration, etc., and it is easy to cause damage to surrounding rock and decrease of its own bearing capacity under long-term service conditions. Based on the basic principles of tunnel mechanics, this paper establishes a mechanical model based on the stratum-structure principle for the analysis of the cavities behind the lining of the red-bed soft rock railway tunnel and the insufficient thickness of the lining to study the changing law of the stress state and safety factor of the tunnel lining structure under different defect degree and defect position. Based on the principle of reinforced concrete bond-slip, a mechanical model for the analysis of the deterioration of the surrounding rock state is established to simulate the entire process of the tunnel lining structure from normal service to crack propagation to structural failure under the condition of the surrounding rock deterioration, and to establish a structural safety evaluation by the limit crack width method.

2 Research methods of vacancy and deterioration damage of railway tunnel base

2.1 Discrete element method

The material deterioration of operating tunnels includes deterioration of lining materials and deterioration of surrounding rock materials. Deterioration of lining materials includes decreased concrete strength, fuzzing, spalling, and looseness. It is mainly used to study the progressive failure of rock slopes and evaluate the impact of joints, cracks, faults, and layers of rock masses on underground engineering and rock foundations. Discrete element is an ideal tool for studying the potential damage model of discontinuous features (Jinxue, 2019).

Water leakage is the cause of further deterioration of the lining material and further increase of external load, as well as the result of material deterioration and increase of external load. The joints in the discrete element method can be generated according to actual engineering programming or use random joints carried by the software itself. The presentation in the joint model allows a lot of variation. The menu drawing tool can watch the set joints at any time, and the unsatisfactory and inappropriate joints can be changed and deleted at any time until satisfied (Jianping, 2017).

The joint material parameters are input according to the actual engineering joint material data. The joints include four constitutive models. Generally, the Coulomb sliding criterion model is used. The parameters required for the model include normal stiffness, tangential stiffness, internal friction angle, cohesion, dilatancy angle and tensile strength (Yanbin, 2016). As the simulation progresses, the structural surface is displaced, and the cohesion and tensile strength become smaller. This is where improvements are needed. When assigning material properties to a joint, it can be assigned to a single joint or a group of joints. What needs to be clear is that although many joints on geological maps are straight segments, their roughness can be represented by material properties. At the same time, materials should be given to the block according to the strength of the surrounding rock. The required parameters include density, bulk modulus, shear modulus, internal friction angle, cohesion, dilatancy angle and tensile strength.

The model established by the discrete element method can be used for static analysis or dynamic analysis. When performing dynamic calculations, directly input the corresponding dynamic parameters, such as the speed or the magnitude of the stress wave as boundary constraints or internal excitations into the model. At the same time, the software also comes with a dynamic wave library, which can directly extract the parameters. When performing static calculations, two constraint conditions, stress boundary and displacement boundary, need to be imposed. The constraint boundary can take different values and positions according to the actual project. The boundary that needs to be set in the simulation of infinite elastic boundary is the boundary element boundary (Xin et al., 2019).

The discrete element method software discretises the deformed block into the finite-difference triangle element that is the constant strain zone connected by nodes, and the vertices of the divided elements are the finite-difference nodes. The motion equation of the node is:

$$u = \frac{J_s \theta_{ij} n_j d_s + G_i}{m} + g_i \tag{1}$$

Among them, s represents the surface with mass blocks on the node, Gi represents the external force on the node, and gi represents the acceleration of gravity. The block area is:

$$S = [1/2] \sum (x_i - x_{i-1})(y_j + y_{j+1}) \tag{2}$$

Centroid coordinates:

$$x_c = (-1/6s) \sum (y_j - y_{j-1}) \left[(x_i - x_{i-1})(x_i + 2x_{i-1}) + 3x_{i-1}^2 \right] \tag{3}$$

$$\frac{m_{1,2} d^2 u_n}{dt^2} + \frac{c_n du_n}{dt} + F_n y_n = T_n \tag{4}$$

The tangential vibration motion of the particle contact process is manifested as tangential sliding and particle rolling:

$$\frac{m_{1,2} d^2 u_m}{dt^2} + \frac{cmdu_m}{dt} + F_m y_m = T_m \tag{5}$$

$$\frac{I_{1,2} d^2 \alpha}{dt^2} + \left(\frac{c_m du_m}{dt} + K_m u_m \right) m = S \tag{6}$$

where $m_{1,2}$ is the equivalent mass of particles i and j; $I_{1,2}$ is the equivalent moment of inertia of the particle; S is the radius of rotation; and u_n, u_m is the relative displacement of the particle in the tangential and normal directions; the rotation angle of the particle itself.

2.2 Voiding and deterioration damage of railway tunnel base

The technical status of the lining structure of the operating railway tunnel is directly related to the safety of railway traffic. The soft rock in the study area has the characteristics of water swelling, softening, disintegration, susceptibility to disturbance, damage and deterioration, plus the impact of construction quality and comprehensive environmental effects, and various diseases will inevitably occur in soft rock operating tunnels under long-term service conditions. Severely reduce the long-term safety of the tunnel lining structure and shorten the maintenance cycle and remaining life of the tunnel. As a result, it is very important to carry out a structural degradation analysis and a long-term safety assessment of red and soft rail tunnels; In view of this, this paper comprehensively uses theoretical analysis, laboratory tests, and numerical simulations to study the influence of the deterioration of the surrounding rock condition of the tunnel in the study area, the insufficient thickness of the tunnel lining and the cavity behind the lining on the long-term safety and remaining life of the lining structure (Ziqiang et al., 2018).

The biggest difference between the tunnel and other ground structures is its concealment. The concealment is the main reason why tunnel diseases are not easy to be found, which increases the difficulty of judging the cause of tunnel diseases to a certain extent. Railway tunnels have large spans, many types of lining structures, complex and changeable engineering characteristics of the surrounding rock in the tunnel area, and the preliminary survey cannot fully grasp the tunnel geological conditions in the study area, resulting in a comprehensive and accurate design during tunnel design (Lei, 2020); the existing railway tunnel design theories and calculation methods are not mature enough; the stress states of design, construction, and operation are different. Under the interactive influence of the above-mentioned various factors, the shape of the tunnel structural disease is complex and changeable, and the reasons behind it are also analysed. The difficulty is greater.

They are influenced by factors such as construction conditions, groundwater and the circular load of trains, there is a gap between the tunnel base structure and the surrounding rock in bottom part. The two cannot bear the force together, forming a multi-span continuous beam structure similar to the tensile stress of the base structure. The shear stress increased rapidly, leading to the destruction of the tunnel base structure (Shuangcun, 2019).

Due to various influences, poor contact between the lining and the surrounding rock is a common problem in tunnel engineering. It is the main factor causing the deterioration of the tunnel lining structure, laying hidden dangers to the safety of the tunnel structure. The cracks in the tunnel lining are usually accompanied by water leakage, which poses a threat to the normal traffic safety of the tunnel, and also affects the electrical circuits and equipment of the tunnel pipe network. The tunnel cavity affects the stress state of the lining structure and endangers the overall safety of the structure. Experts and engineers at home and abroad use theoretical research, engineering experiments and finite element calculations to analyse the stress mechanism of the lining with voids and the expansion trend of void cracks (Minglu, 2018). According to the current research status, most of the tunnel dynamic stability research is based on the theoretical state of the tunnel, that is, it is believed that the lining and the surrounding rock are closely attached. However, this does not conform to the actual situation of the tunnel site and cannot really reflect the high-speed rail train. The dynamic response under load, and the research on the corresponding reinforcement of the cavity according to the requirements of high-speed railway tunnels is also lacking (Wenhao et al., 2016).

At present, the existence of cavities in the lining leads to voiding and degrading damage to the base, but there is no relevant analysis on the voiding and degrading damage of the base under the influence of train load. Therefore, the research on the degradation of the stressed state of the base is necessary to ensure the safety of trains in the tunnel. From the technical level, based on the mathematical statistical analysis and theoretical research of the high-speed railway tunnel detection data, the finite element numerical simulation technology is used to analyse the geometric characteristics of the cavity on the base vacancy and deterioration damage mechanism to make up for the existing safety assessment; at the national level, it is in line with the national development of the ‘13th Five-Year’ comprehensive transportation system planning direction, to improve the quality of the project, through technological innovation, to enhance the science and technology of tunnel engineering in the transportation industry; finally, from the scientific research level, to improve the quality of the high-speed rail tunnel lining Test and evaluation provide reference (Jian, 2017). After careful analysis, summarise the defect characteristics of railway tunnels and supplement the tunnel inspection and evaluation methods, including a complete system of daily maintenance, defect detection and quality feedback. Numerical analysis and finite element theory are used to study typical tunnel cavities, and the distribution rules and geometric size characteristics of cavities are obtained to meet the needs of informatisation target management and improve the conventional maintenance and disease treatment level of operating tunnels (Ning et al., 2016).

2.3 Tunnel damage detection method

In countries with advanced tunnel technology such as Germany, the United States, Switzerland and Japan, their railway and highway tunnel management and monitoring departments have corresponding tunnel design, management, operation, monitoring, inspection and maintenance work links. Including specific tunnel lining monitoring, inspection methods, inspection cycles, inspection criteria and later corresponding remediation methods. The tunnel detection ideas selected by different countries are basically the same, but the detection technology and detection methods are slightly different, but these countries have a set of standardised tunnel detection procedures. Some of these countries with a high degree of standardisation, such as Germany and the United States, will also establish tunnel electronic files for railway tunnels, which contain tunnel design, maintenance, and inspection data. Later, real-time monitoring data fed back on site will be used to ensure the safe operation of the tunnel (Wenguang, 2019).

The tunnel site quality inspection includes specific tunnel lining monitoring, inspection methods, inspection cycles, inspection criteria and later corresponding remediation methods. The tunnel detection ideas selected by different countries are basically the same, but the detection technology and detection methods are slightly different, but these countries have a set of standardised tunnel detection procedures. Some of these countries with a high degree of standardisation, such as Germany and the US, will also establish tunnel electronic files for railway tunnels, which contain tunnel design, maintenance, and inspection data. Later, real-time monitoring data fed back on site will be used to ensure the safe operation of the tunnel (Shidong, 2020). Therefore, in order to make the tunnel renovation method timely and effective, this chapter organises and analyses the detection data of tunnel lining structural defects and diseases, which will help improve the efficiency of tunnel detection and tunnel maintenance. On the one hand, the detection data analysis can realise the monitoring of the working status of the high-speed rail tunnel. To ensure the safety of tunnel opening to traffic, on the other hand, it can extend the normal service life of the tunnel.

The on-site quality inspection of the tunnel adopts non-destructive inspection techniques such as rebound method, ultrasonic method and phenolphthalein reagent method. The inspection parameters include the compressive strength of lining concrete, the elastic modulus of lining concrete, the depth of concrete carbonisation, etc., considering the drilling sampling method to detect concrete strength The bearing capacity of the damaged ring structure and the waterproof layer of the lining are therefore only tested and used under special circumstances (Hanyi and Shidong, 2019). Appropriately select the lining surface test area, and use the rebound test method, ultrasonic rebound method and phenolphthalein reagent method to detect the strength and carbonisation depth of the lining concrete. The number of inspection test areas is determined according to the actual degree of defects at the tunnel site, and evenly covers the inspection section of the line.

The principle of tunnel detection is based on the propagation theory of waves in consumable media. Vehicle-mounted radars emit short-pulse broadband high-frequency electromagnetic signals. If the wave hits the contact surface of different media, part of the wave energy is reflected. The receiving end transmits the radio wave signal to the host, and judges the relative permittivity of different media. After host data processing and image analysis, the quality of the lining, the existence of lining cavities, cracks and water leakage can be judged (Guizhong and Xiaogui, 2016).

2.4 Big data mechanism

Offloading part of the data in cloud computing to the fog server for processing can not only reduce data transmission delays and save energy consumption, but also reduce the pressure on the cloud data center and improve service efficiency. Mobile IoT devices are responsible for receiving data and processing the data in advance on the intranet to filter out useless or redundant data. Then, the data is transferred to the edge fog device, and the fog device converts them into a unified representation framework and merges them into the feature layer for storage. In addition, the fog device will also detect fake data and missing data. In order to reduce the risk of being attacked during data transmission, the data will be encoded and encrypted. Finally, the fog device connects the encrypted data to the cloud server. When the data user needs data, it first sends a request to the nearest fog device, and if there is data requested by the user in the fog device, it responds immediately. Otherwise, the fog device will forward the end user’s request to the cloud server, and the cloud server will search for encrypted data through the index structure and forward the data to the user. The user decrypts the data through the key, obtains the data information, and mines the useful value of the data information.

The development of the big data industry is closely related to big data technology and its applications. Although it originated from industry practice, academic research on the 'big data industry' lags far behind the development of practice. From a domestic perspective, the current research on the big data industry is mainly based on government industrial policies and plans, industrial development suggestions, comparisons of domestic and foreign big data industries, and industrial development influencing factors (Ziqiang et al., 2016; Qiujun et al., 2017). There is a lack of appropriate theoretical perspectives on the internal big data industry. Research on constituent elements and governance mechanisms; from a foreign perspective, although there are not many related studies, scholars have begun to explore the big data industry from the perspective of business ecology (Jingyu et al., 2017).

The big data ecosystem is divided into three levels, namely the core value chain at the micro level, the extended value chain at the meso level, and the big data ecosystem at the macro level. Among them, the core value chain is centred on the data value chain, including direct data suppliers and data value distribution channels; the extended value chain is centred on the core value chain, consisting of technology providers, data markets, data suppliers' suppliers, and complementary data products, and service providers, direct data end users, etc.; while the macro-level big data ecosystem mainly refers to some related organisations in the periphery of the system, such as government agencies, regulatory agencies, investors, venture capital and incubators, industry associations, academic and research institutions, standardisation organisations, start-ups and entrepreneur groups, as well as various other competitors, stakeholders, peripheral members, etc.

New data sources increase the types of data types. If the decline in data costs only promotes the growth of data volume, then the emergence of new data sources and data collection technologies has greatly increased the types of future data. The increase in data types directly leads to the increase in the dimensions of the existing data space, and thus extremely Greatly increase the complexity of future big data. When computers were born, they were only designed to perform high-speed calculations, and the calculated data was basically limited to the digital domain. This algorithm is to digitally process the continuous PID control law and write it as a difference equation, and then get the calculus equation of the PID controller:

$$u(t) = k_p \left[e(t) + \frac{1}{T_l} \int e(t)\, dt + T_D \frac{de(t)}{dt} \right] \tag{7}$$

Among them $u(t)$ is the output of the PID controller, the $e(t)$ input of the PID controller, the k_p proportional coefficient, the T_l integral time constant, and the T_D derivative time constant.

Discretise the calculus equation to obtain the difference equation $u(t)$:

$$u(k) = k_p e(k) + k_t \sum_{j=0}^{k} e(j) + k_D \left[e(k) - e(k-1) \right] \tag{8}$$

Among them k_t is the integral coefficient and the k_D differential coefficient. Incremental PID control algorithm can be introduced:

$$Q(k-1) = k_p e(k-1) + k_I \sum_{j=0}^{k} e(j) + k_D\left[e(k-1) - e(k-2)\right] \tag{9}$$

among them

$$Q = \frac{1}{2a^2r^{-1}}\left(\frac{2b^2}{a^2r^{-1}}p - t\right)^{-1}\left[a^2r^{-1}t^2 + 2\left(1-b^2\right)t\right] \tag{10}$$

in case $a \in [-1,0] \cup [0,1]$:

$$Q = \frac{1}{2a^2r^{-1}}\left(\frac{2b^2}{a^2r^{-1}}t - L\right)^{-1}\left[a^2r^{-1}L^2 + 2\left(1-a^2\right)L\right] \tag{11}$$

$$\left(\frac{2b^2}{a^2r^{-1}}I_x - t\right)Q = \frac{1}{2}t^2 + \frac{1-b^2}{a^2r^{-1}}t \tag{12}$$

$$Q^2 + \frac{2(1+b^2)}{a^2r^{-1}}Q + \frac{(1+b^2)^2}{\left(a^2r^{-1}\right)^2}I_x = \left(Q + t + \frac{1-b^2}{a^2r^{-1}}I_x\right)^2 \tag{13}$$

Combined with the correlation formula, we can get

$$K = \frac{a}{2rb}\left[Q + t + \frac{1-b^2}{a^2r^{-1}}I_x - Q - \frac{1-b^2}{a^2r^{-1}}I_x\right] = \frac{a}{2br}t \tag{14}$$

3 Experiments on vacancy and deterioration of railway tunnel base

3.1 Experimental purpose

This paper mainly adopts the method of big data mechanism research and analysis, from the establishment of the particle flow concrete model to the construction of special-shaped coarse aggregates to the establishment of the tunnel base damage and deterioration mixed model. The research is carried out gradually, and the results of previous tests are compared and analysed. In-depth analysis of the relationship between the macroscopic and mesomechanical characteristics of the railway tunnel base void and deterioration damage model.

3.2 Experimental method

Orthogonal data experimental design method is currently a main analysis method for multi-factor research. It can select representative factors with uniform dispersion and uniqueness of all factors, and has advantages in randomised design and random area setting. The grouping is based on the Latin square type design as a completely random factorial design, including random area factorial design, partition factorial design, mixed factorial design, etc. The orthogonal data table used in the horizontal combination selected by the orthogonal experiment can be visually listed. If the design requires too many experimental groups, select some representative level combinations among the level components of the fractional factorial to achieve simplification, so there will be a fractional factorial design.

3.3 Determine the evaluation weight

Definite conclusions can be drawn through actual observation of objects. Generally speaking, the evaluation index system includes three levels of evaluation indexes: they are the relationship between gradual decomposition and refinement. Among them, the first-level evaluation indicators and the second-level evaluation indicators are relatively abstract and cannot be used as a direct basis for evaluation. The third-level evaluation indicators should be specific, measurable and behavior-oriented.

The index weight is a numerical index indicating the importance and function of the index. In the indicator system of the evaluation plan, the weight of each indicator is different. Even if the indicator level is the same, the weight is different. Index weight is also called weight and is usually represented by a. It is a number greater than zero but less than 1, and the sum of the weights of all the first-level indicators must be equal to 1, that is, satisfy the conditions $0 < a < 1$ and $\sum a – 1$.

3.4 Statistics

All data analysis in this paper adopts SPSS19.0, statistical test adopts double-sided test, significance is defined as 0.05, and $p < 0.05$ is considered as significant. The statistical results are displayed as mean ± standard deviation ($x \pm$ SD). When the test data follows a normal distribution, the double T test is used for comparison within the group, and the independent sample P test is used for comparison between the groups. If the regular distribution is insufficient, two independent samples and two related samples will be used for inspection.

4 Experimental analysis of vacancy and deterioration damage of road tunnel base

4.1 Railway conditions in recent years

Through literature surveys and data surveys of railway management departments, we have learned the data of problems in railway tunnels in recent years, and through data analysis, we understand the main reasons for railway tunnel problems. The specific statistics are shown in Table 1.

From Figure 1, we can see that in recent years, my country's railway tunnels have caused various accidents. The frequency of safety accidents is relatively high, and the overall situation is stable. The main safety reasons of railway tunnels are caused by poor quality of lining and materials, accounting for the overall accident For more than 40% of the total, we have made relevant statistics on the preventive measures of railway tunnels in recent years, and simulated their effects, as shown in Table 2.

Table 1 Railway tunnel conditions

	2015	*2016*	*2017*	*2018*	*2019*	*2020*
Hollow	2.03	2.25	2.05	2.08	2.39	1.96
Lining structure	2.38	2.16	2.03	2.31	1.95	2.13
Lining thickness	2.34	2.38	2.46	2.06	2.08	2.09
Material deterioration	1.82	2.33	2.43	1.91	1.82	2.45
Force state	1.9	2.05	1.95	2.35	2.39	2.18

Figure 1 Railway tunnel conditions in recent years (see online version for colours)

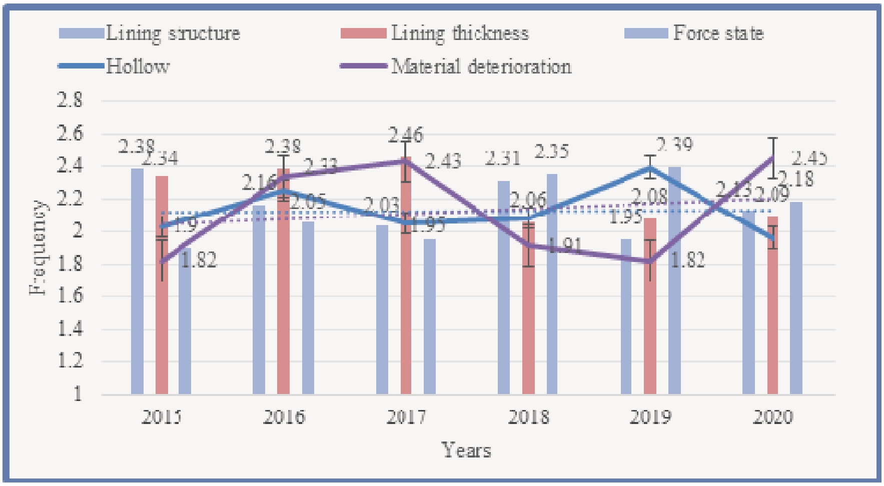


Table 2 Tunnel preventive measures

	2015	*2016*	*2017*	*2018*	*2019*	*2020*
Water absorption	4.41	4.22	4.11	4.45	3.84	4.07
Collapsible material	4.93	4.55	4.3	4.67	4.34	4.31
Compressive	5.18	5.22	5.03	5.06	4.9	5.32
Tensile	5.25	5.91	5.52	5.53	5.17	5.83
Shear resistance	6.12	6.27	6.14	5.72	5.91	6.19

As shown in Figure 2, the current methods used in the prevention of tunnel disasters do not play a key role. This is because tunnels are different from other ground structures. Concealment is the main reason why tunnel diseases are not easy to be found. To a certain extent, the above increases the difficulty of judging the cause of tunnel disease.

4.2 Problems in railway tunnels

Regarding the big data mechanism of the base vacancy and loss of railway tunnels, we conducted statistical research on 5 tunnels in this city and found that the deterioration was mainly caused by external forces, environment, design and construction, etc., and we made statistics on them as shown in Table 3 and Figure 3.

Figure 2 Tunnel preventive measures score (see online version for colours)

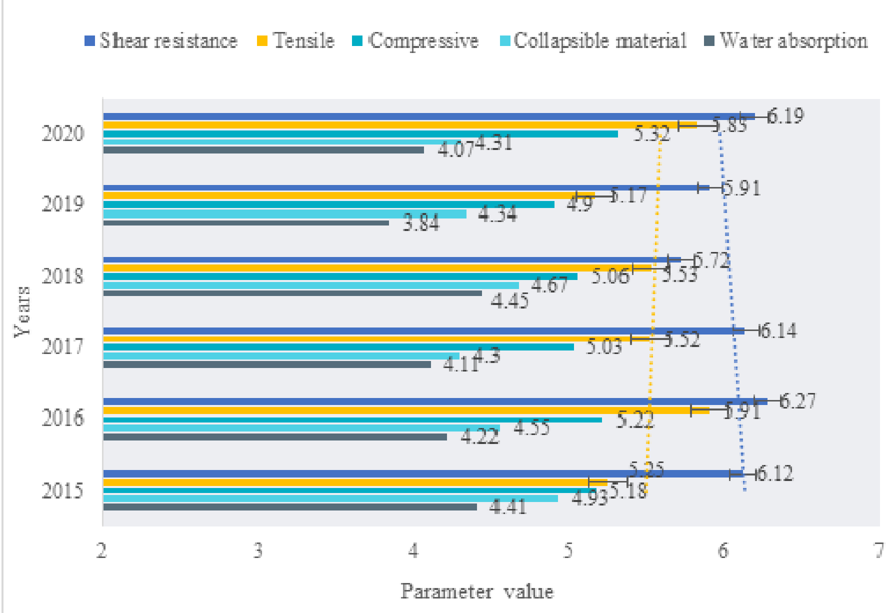


Table 3 Reasons for deterioration of tunnel base

	Swell in water	*Soften*	*Disintegrate*	*Easily disturbed*	*Damage degradation*	*Mudstone is soft*
First tunnel	5.2	5.22	5.37	5.54	5.43	5.83
Second tunnel	5.92	6.19	5.84	6.02	5.75	5.91
Third tunnel	6.45	6.97	6.51	6.42	6.95	6.75
Fourth tunnel	7.8	7.89	7.95	7.98	7.56	7.7
The fifth tunnel	8.77	8.51	8.68	7.96	8.72	7.86

For a tunnel designed and used normally, it is theoretically impossible to cause deterioration and disease. However, the red-bed soft rock itself swells, softens, disintegrates, is easily disturbed, damages and deteriorates due to its inherent characteristics. The cavities behind the lining and the insufficient thickness of the lining caused by insufficient construction technology have caused various diseases during the use of the tunnel. We make statistics on these tunnel changes, as shown in Table 4.

Figure 3 Causes of tunnel degradation (see online version for colours)

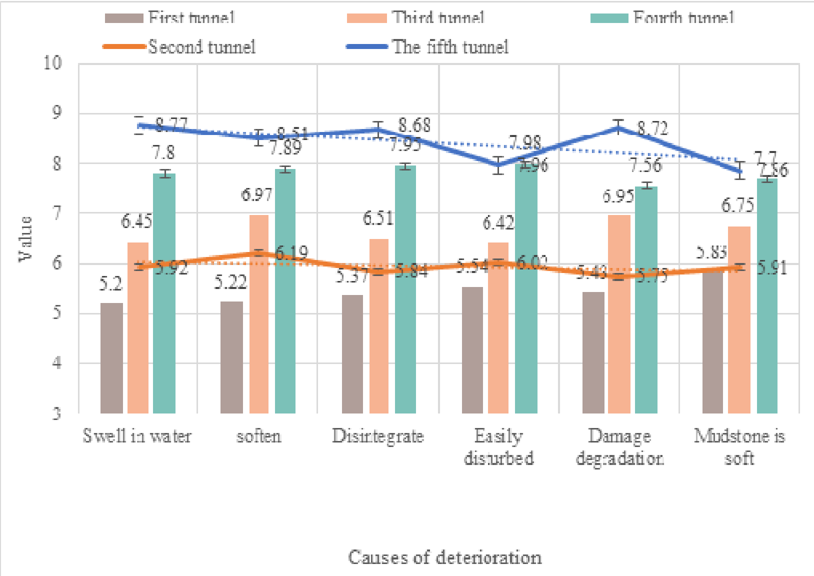


Table 4 Tunnel changes

	Swell in water	*Soften*	*Disintegrate*	*Easily disturbed*	*Damage degradation*	*Mudstone is soft*
First tunnel	0.203	0.126	0.228	0.243	0.231	0.242
Second tunnel	0.243	0.204	0.189	0.247	0.234	0.199
Third tunnel	0.222	0.204	0.228	0.227	0.205	0.237
Fourth tunnel	0.239	0.206	0.184	0.216	0.203	0.182
The fifth tunnel	0.247	0.187	0.239	0.244	0.241	0.217

It can be seen from Figure 4 that for railway tunnels, we can determine that the main factors that cause the deterioration of the tunnel lining structure include: deterioration of the surrounding rock condition, insufficient tunnel lining thickness and the existence of voids behind the lining. The overall changes in these tunnels are not large, but they are showing an upward trend, which requires attention.

4.3 *Different methods to monitor efficiency*

We use different methods to inspect and monitor these tunnels, and compare the monitoring efficiency of different methods on the big data mechanism of railway tunnel damage, as shown in Table 5.

Figure 4 Changes in railway tunnels (see online version for colours)

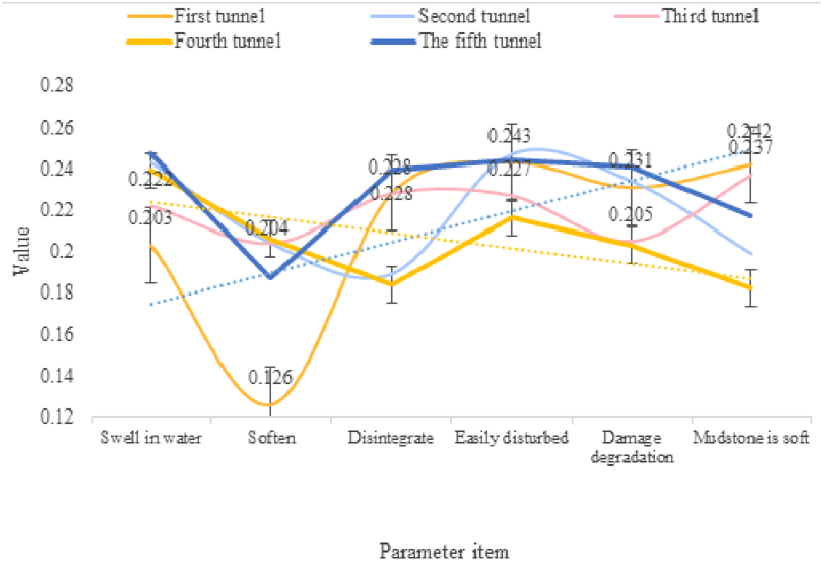


Table 5 Efficiency of different detection methods

	Speed	*Accuracy*	*Safety*	*False alarm rate*	*False negative rate*	*Cost*
Manual inspection	3.69	3.73	3.45	3.49	3.33	3.74
Void calculation	4.33	3.77	3.7	4.49	4.41	4.22
Physical mechanics calculation	4.2	4.27	4.28	4.2	4.93	4.55
Principal Component Analysis	4.7	4.76	4.82	4.74	5.18	5.22
Discrete Element Method	5.25	5.24	5.45	2.02	1.98	3.01

From Figure 5, we can see that under different methods of monitoring, the detection efficiency of railway tunnels is different. Among them, the effect of discrete element method is extremely excellent. It is ahead of other methods in terms of detection speed and efficiency, and is cost-effective. And the error is also smaller than other methods. We score different methods, as shown in Table 6.

From Figure 6, we can clearly see that among these commonly used methods, the discrete element method scores much higher than other methods. This shows that in the large data mechanism monitoring of railway tunnel damage, the discrete element method Meta law can play an important role.

Figure 5 Difference in detection efficiency (see online version for colours)

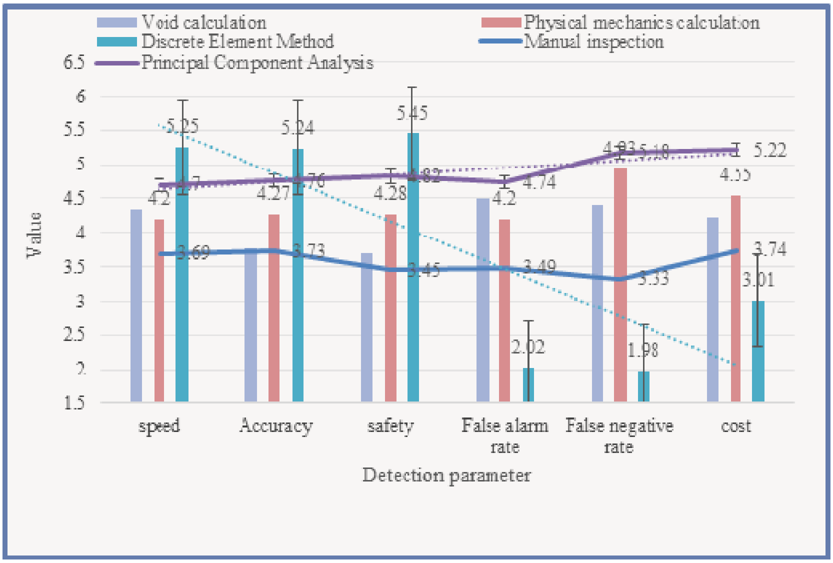
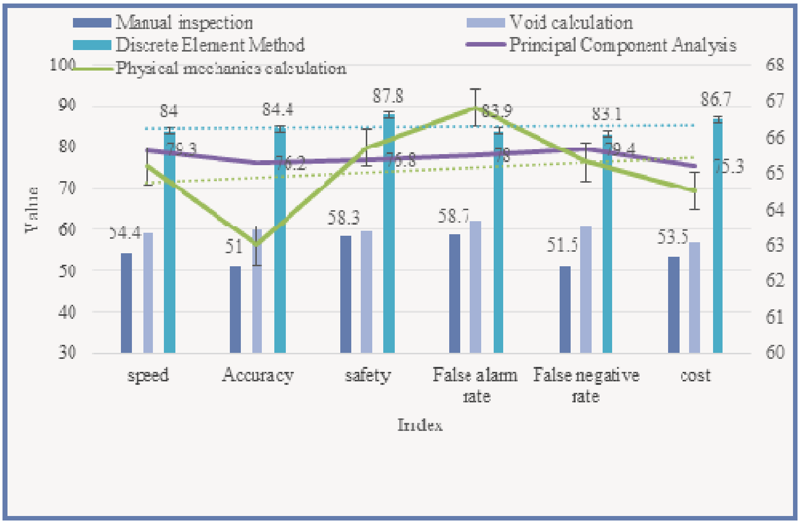


Table 6 Different method scores

	Speed	*Accuracy*	*Safety*	*False alarm rate*	*False negative rate*	*Cost*
Manual inspection	54.4	51	58.3	58.7	51.5	53.5
Void calculation	59.3	60	59.4	62.2	61	57
Physical mechanics calculation	65.2	63	65.7	66.8	65.3	64.5
Principal component analysis	79.3	76.2	76.8	78	79.4	75.3
Discrete element method	84	84.4	87.8	83.9	83.1	86.7

Figure 6 Effects of different detection methods (see online version for colours)



5 Conclusion

From the experimental results, we can see that when the grade of surrounding rock is worse and the grade of comprehensive environmental action is higher, the probability of tunnel disease is higher, the speed of deterioration of tunnel lining structure is faster, and the degree of tunnel disease is more serious; when the surrounding rock conditions are better and the comprehensive environmental effect level is lower, the tunnel disease is less and the disease degree is lower. Therefore, key precautions should be taken for tunnels with poor grades of surrounding rock and high grades of comprehensive environmental effects.

The analysis of the engineering characteristics of the tunnel soft rock combined with the experimental research results shows that the surrounding rock in the study area composed of red-bed soft rock has the characteristics of water swelling, softening, disintegration, easy disturbance, damage and deterioration. At the same time, the surrounding rock has low uniaxial compression and shear strength, and poor cohesive force, resulting in poor integrity of the surrounding rock and reduction of its own bearing capacity, causing continuous convergence and deformation of the surrounding rock and forming an excessively large surrounding rock pressure acts on the lining structure of the tunnel, resulting in varying degrees of deterioration of the lining structure.

When the overall thickness of the tunnel lining is insufficient, the overall section bending moment and axial force of the structure decrease as the degree of defects continue to increase; when a local lining thickness deficiency occurs, the degree of local defects continues to increase, and the position of the defect and the nearby point bending moment axial force keep decreasing. Therefore, the insufficient thickness of the lining will change the stress state of the lining structure and reduce the stiffness and bearing capacity of the lining. When the degree of defects is large, it may cause damage to the lining. As the overall thickness of the lining is insufficient, the disease degree increases, and the safety factor of the full section of the lining structure is significantly reduced. It is approximately linear, and the overall load-bearing performance of the structure is also significantly reduced. When the thickness of the local lining of the tunnel is insufficient, the safety factor of the lining at the defect location decreases significantly as the degree of the defect increases; at the same time, the bearing performance of the defect location is greatly affected, and the safety factor of the adjacent point of the defect location increases slightly, while the safety factor of other parts almost unchanged, indicating that the lack of local thickness has little effect on other parts of the lining, and only affects the stiffness and bearing capacity of the lining at the diseased part and its adjacent points.

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