ISSN: 1813-4890

Research status of infrastructure stability in karst areas

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Abstract

The research on the stability of infrastructure in karst areas serves as a crucial theoretical guide for engineering construction in these regions, offering both theoretical assurance and technical support. This article takes the stability of infrastructure in karst areas as the background, and analyzes the current research status of the stability and bearing capacity of infrastructure in karst areas, including pile foundations, tunnels, and roadbeds, from three aspects: numerical simulation, theoretical research, and experimental analysis. It is found that the research focus of infrastructure in karst areas is on the roof, location, and shape of karst caves. The safe thickness of the roof on karst caves is still a research focus and challenge at present. This article summarizes the current research status and discusses and prospects the future development trends of infrastructure research in karst areas.

Keywords

Karst, Pile Foundation, Tunnel, Subgrade, Numerical Simulation.

1. Introduction

Generally speaking, karstification refers to the erosion or destruction of soluble rocks under the action of water, mainly through chemical and mechanical processes. The karst morphology formed by the destruction of these rocks is called karst landforms[1]. Karst includes two aspects: karst phenomena and processes. Rocks are mainly affected by dissolution, supplemented by mechanical processes such as erosion and scouring by flowing water. The overall process and phenomena are closely related[1]. The hazards of karst caves to engineering are mainly manifested in the suspension of bridge and culvert foundations or insufficient rock embedding depth of pile foundations; The roof of the cave is too thin to withstand sudden collapse under load[2]. Meanwhile, the carrying capacity and stability of infrastructure are closely related to factors such as the geometric dimensions, distribution characteristics, surrounding rock properties, and degree of karst development of karst caves. In the research process, many scholars both inside and outside China have used methods such as model experiments, numerical simulations, and theoretical experiments to study the impact and characteristics of karst on infrastructure. In terms of hazard management, measures such as foundation grouting, foundation reinforcement, addition of support systems, cave filling, and shield tunneling can be taken. Therefore, it is necessary to review the current research status of the stability and bearing characteristics of infrastructure in karst areas, which will lay a solid foundation for proposing more reliable governance plans for future research. Although there have been many research achievements, there are still some limitations in the current research on infrastructure under complex geological conditions in the region. Due to the complexity of karst geology, the understanding of hidden karst is not yet deep, and the applicability of disposal techniques is not mature[3]; The impact of dissolution pore structure in karst strata on the stability of engineering rock masses lacks a profound understanding[4], therefore further exploration and gradual improvement are urgently needed.

2. Current research status on the impact of karst development on infrastructure

With the comprehensive promotion of infrastructure construction, the engineering difficulties in karst areas are becoming increasingly prominent. The development of karst poses a serious threat to the stability of key infrastructure such as pile foundations, roadbeds, and tunnels, which in turn profoundly affects the quality, safety, and progress of engineering projects.

2.1. Current research status on the impact of karst development on pile foundations

According to geological survey results and engineering requirements, the commonly used pile foundation types in karst foundations include end bearing piles and friction piles, among which end bearing piles are suitable for areas with well-developed karst and high requirements for pile foundation bearing capacity; Friction piles are suitable for areas with underdeveloped karst and low requirements for pile foundation bearing capacity[5]. During the construction process of pile foundation engineering in karst areas, geological phenomena such as karst caves, soil caves, and underground rivers often lead to a decrease in pile body friction, pile side friction, and end bearing capacity, as well as pile foundation damage, which affects the normal performance of pile foundation bearing capacity[6]. The methods used by many domestic scholars to study the influence of pile foundation bearing capacity and stability in karst areas are mainly divided into three categories: numerical simulation, theoretical analysis, and experimental analysis. Among them, numerical simulation methods include finite difference method, finite element method, semi analytical element method, and Lagrangian method. Domestic researchers have achieved considerable research results in numerical simulation research, which is also one of the reliable and accurate methods for studying engineering problems.

2.1.1. Research Status in Numerical Simulation

Domestic researchers have considered numerous factors that affect the bearing capacity of pile foundations in numerical simulations of karst caves in karst areas. In 2012, Sun, Zhang, and others[7] used the finite difference method to simulate the stability of karst foundations under the action of pile foundations. They found that the thickness of the karst cave roof is related to the failure mode of the pile foundation, and also studied the influence of other factors on the stability of the foundation. On this basis, in 2022, Zhang and Wang[8] used MADIS GTS finite element numerical simulation to calculate the deformation of the cave roof, which is closely related to the properties of the bedrock and soil. The results showed that the stability of the roof is poor when it is a soil layer, and the stability is better when it is a moderately weathered mudstone. In addition to the influence of cave roof thickness on the stability of pile foundations, domestic researchers have also achieved reliable research results in other factors in recent years. In 2023, Hu, Zhang, and others[9] used MIDAS GTS NX to establish a simulation analysis of pile foundation models in karst areas, and studied the effects of cave roof thickness, cave vertical spacing, and cave height on pile foundation settlement. The study found that as the thickness decreases below 4m, the settlement slightly increases, while above 4m, it remains unchanged; It increases with the increase of vertical spacing; The height of the karst cave will not significantly affect the settlement of the pile body. In 2023, Li[10] used the pile foundation project of the Nan Yu Railway Cross Li Zhan Extra Large Bridge from Nanning to Yulin as the background, and used PLAXIS finite element software to establish a model to compare the working characteristics of ultra long pile foundations in formations with and without karst caves. It was found that under the condition of karst development, the allowable bearing capacity of the pile foundation was reduced by 22.2% compared to the condition without karst caves, which weakened the stiffness of the karst foundation and caused complex stress redistribution. The axial force of foundation piles with karst caves locally increases by twice that of piles without karst caves. When there are karst caves, the contour lines bend around the caves and the asymmetrical distribution of caves can exacerbate the uneven axial force of piles, which may lead to local failure of pile foundations. Due to the complex foundation of karst areas, domestic researchers have also conducted research on columnar karst areas. In 2013, Tang[11] studied the bearing capacity and stability of pile foundations in bead shaped karst cave areas. Using FLAC3D, a numerical analysis model was established to investigate the influence of the number and height of karst caves on the stability of pile foundations. In 2017, Zhang[12] conducted research on the bearing capacity and stability of bridge pile foundations in bead shaped karst cave foundations, and studied the influence of cave roof on pile foundations. In 2018, Ma[13] studied the influence of pile side karst caves on the bearing capacity of single piles in bead shaped karst areas, and used MIDAS GTS finite element software to investigate the effects of cave spatial location, cave size, and cave quantity on the stability and bearing capacity of pile foundations. Due to the uncertainty of the appearance and development of karst caves, in 2014, Cui[14] used ANAYS finite element software to establish a stochastic karst cave model to simulate and analyze the settlement of pile foundations in karst areas. The results showed that the settlement deformation at the top of the cave and the compression deformation of the soil between the pile end and the cave caused the settlement of pile foundations in karst development areas. The development of karst caves in karst areas has a certain degree of randomness, which makes the settlement of pile foundations highly discrete. In order to study the feasibility of numerical simulation and the reliability of its application to practical problems, Lin[15] used the construction area of Hongfang Interchange in Longyan City, Fujian Province as the background, and simulated the displacement of pile foundation under karst development using FLAC3D finite difference analysis software. After comparing with the calculation results in the code, it was found that the finite element method was similar to the calculation results in the "Code for Building Pile Foundations". Due to the limited number of researchers in this area, further exploration by scholars is still needed.

2.1.2. Research Status in Theoretical Analysis

Zhao, Cao, and others[16] developed a mechanical calculation model that reflects the actual engineering characteristics of karst pile foundation stability, taking into account the engineering characteristics of rock socketed piles in karst areas and the stress characteristics of karst cave roofs, based on commonly used calculations of the stability of karst cave roofs at the end of pile foundations; Based on the principle of elasticity theory, a stress calculation formula for the roof of karst caves has been derived. At the same time, a new method for determining the safe thickness and pile foundation load has been established based on the modified Mohr Coulomb theory, which is called the stability analysis method for karst cave roof based on the statistical strength theory of rock damage[16]. Gu[17] constructed three failure modes for the roof of karst caves, namely punching, shearing, and bending, based on the generalized Hoek Brown measurement and limit upper limit method mentioned above. He derived the calculation formulas for the resistance of the roof of karst caves at the pile end for these three modes, and analyzed the influence of rock mass quality indicators in depth. He also provided the rules for determining the safe thickness of the roof: (1) When the roof of karst caves is punched and damaged, the higher the rock mass quality and hardness, the smaller the safe thickness, and the roof of Grade I-IV rock mass needs to exceed 0.94-3.92 times the pile diameter; (2) When the top plate of a karst cave is cut and damaged, the higher the quality and hardness of the rock mass, the smaller the safe thickness. The top plate of Grade I-IV rock mass needs to exceed 0.94-3.92 times the pile diameter; (3) When subjected to bending and tensile failure, the larger the rock mass quality and pile diameter, the more favorable it is. The pile diameter of grade I-II rock mass is 0.8-1.5m according to the specifications, and grade III-IV rock mass with a diameter less than 0.9-1.1m needs to be thickened to ensure safety. On this basis, in 2024, Dan[18] conducted research on the resistance of the pile side and pile end. Based on the generalized Hoek Brown standard measurement, limit upper limit method, Mohr rock failure criterion, and thin plate small deflection theory, punching shear, bending tensile failure models were constructed. At the same time, the calculation method for the bearing capacity of the rock socketed pile end was obtained:

$$Q = \frac{16\pi\sigma_t D^6 h^2}{15(1+\upsilon)d^2(4D^6-6d^2D^4+4d^4D^2-d^6)} \tag{1}$$

In the formula: D is the diameter of the roof, d is the diameter of the pile, h is the thickness of the roof, ν is Poisson's ratio, andσ_t is the tensile strength of the roof rock. [18]

2.1.3. Research Status in Experimental Analysis

In terms of experimental analysis, Liu[19], Yan[20], Zhou[21], and others conducted physical model tests on pile foundations in karst development areas based on the principle of similarity. In 2003, Liu[19] proposed a semi empirical and semi theoretical calculation method for verifying the safe thickness of top plates in karst development areas through a large number of model tests and the use of different test schemes. The formula is as follows:

$$\sigma_{max} = \frac{3\gamma L^2}{4h} + \frac{3F(2L-d)}{4Bh^2} = \xi[R_t] \tag{2}$$

式中： σ_{max} —— Maximum tensile stress (Mpa)

γ ——unit weight (KN/m^3)

F ——Ultimate load(KN)

$[R_t]$——Bending strength of the sample(Mpa)

L、B、h ——The length, width, and thickness of the sample(m)

Yan[20] took limestone samples from the construction site for indoor tests. Using a self-made model test platform, he carried out the ultimate bearing capacity failure test on the model specimens and obtained the corresponding stress-strain curves. By analyzing these curves, he determined the ultimate bearing capacity of the karst roof. When the span of the underlying karst cave is 6 meters, the width is 4 meters, and the thickness ranges from 2 meters to 2.4 meters, the roof can bear an ultimate load value greater than 10,000 kilonewtons. Zhou[21] built on the work of predecessors and used materials such as sand, diatomite, marl, gypsum, red clay, and cement. By adopting different test schemes, he designed uniaxial compression tests and direct shear tests, and obtained the fitted Q-S curve. According to its characteristics, it was analyzed that the load value corresponding to the starting point where the curve shows an obvious steep drop can be used as the ultimate bearing capacity value of the uniaxial compressive strength. At the same time, three groups of the best mix ratios were selected to simulate marls with different weathering degrees. During the experiment, FBG experimental data were collected and the strain curve at the position of the surrounding rock was drawn. According to this curve, it can be concluded that the strain increment of the karst cave roof is small, and the structure is stable. When the upper part of the karst cave is under load, the load is evenly transmitted to both sides through the roof, and the main rock formations on both sides bear most of the load transmitted from the pile foundation.

In conclusion, domestic researchers' studies on the stability of piles in karst areas mainly explore, but are not limited to, aspects such as pile length, roof thickness, karst cave size, and the positional relationship between the pile foundation and the karst cave, and have achieved relatively mature research results in these areas. When studying the influence of karst development on the stability of pile foundations, the upper roof of karst caves is one of the aspects that domestic scholars have studied more. In this paper, researchers such as Sun, Zhang[7], Zhang, Wang[8], and Zhang[12] have conducted research on this aspect using numerical simulation methods. They have found that factors such as the thickness and span of the roof, and the geotechnical properties of the roof will affect the stability and bearing capacity of the pile foundation, and also influence the failure mode. Researchers such as Zhao , Jiang , Cao[16], Gu[17], and Shan[18] have conducted research on this aspect using theoretical analysis methods. They have established the calculation of the stability of the karst cave roof, constructed three failure modes for the karst cave roof, summarized the rules for determining the thickness of the roof, and provided the calculation formula for the bearing capacity of the pile foundation. Scholars such as Liu[19], Yan[20], and Zhou[21] have used experimental analysis to provide a semi-theoretical and semi-empirical formula for the thickness of the roof, and also obtained the bearing capacity of the pile foundation. However, there are also some deficiencies in the research process. The calculation formulas in the above research results take into account limited factors, mostly considering the thickness of the roof, the strength of the rock, and the diameter of the pile, etc. But as we know from existing knowledge, these aspects are only part of the factors affecting the stability of the pile foundation. For example, factors such as groundwater seepage and rock formation vibration will also affect the stability. There is still a lack of research on the derivation of the calculation formula for the bearing capacity of a single pile foundation considering the influence of multiple factors when the roof is damaged, as well as the derivation of the settlement formula for group piles. Among them, the determination of the relative safe thickness of the roof remains a difficult problem for researchers.

2.2. Current research status on the impact of karst development on subgrade

Against the backdrop of the rapid development of national infrastructure, China's expressway network is expanding day by day. Due to the extensive distribution of karst landforms in China, it is inevitable that unfavorable geological conditions such as karst caves will be encountered during the construction of expressways. Therefore, the influence of karst development on the subgrade in highway construction has become an issue of widespread concern.

Before 2007, limited by the development of drilling technology and simulation software, researchers only simplified and made assumptions about the shape and structure of karst caves when conducting theoretical and numerical simulation analyses. This led to the universality and accuracy of the research results being restricted. In 2008, JIANG[22] and others established a cusp catastrophe model for the bearing capacity and safe thickness of the subgrade roof in karst areas based on the engineering characteristics of the subgrade karst cave roof in karst areas and the catastrophe theory. On this basis, they derived the necessary conditions for the instability of the subgrade karst cave roof and conducted an in-depth analysis of the main influencing factors of the stability of the karst cave roof under the piles in karst areas.In 2013, Li[23] analyzed the engineering overview of the karst area of the Henggui Expressway in Hunan Province using FLAC3D numerical simulation. It was found that under certain conditions, the larger the span of the karst cave, the worse the stability; and as the thickness of the karst cave roof increases, the safety correspondingly improves. By combining the characteristics of karst development and conducting qualitative and semi-quantitative analyses of the stability of karst foundation caves, it was found that factors such as rock strength, occurrence, joint fractures, external loads, groundwater, and karst cave fillings have different impacts on stability.Xue[24] and Song[25] relied on the karst subgrade of the Qianzhangchang High-speed Railway. The former focused on exploring the performance of a new type of adjustable cement grout stone body. Through MIDAS numerical simulation analysis, it was found that karst grouting significantly improved the settlement of the foundation, but did not fully consider the potential impact of groundwater; on this basis, the latter, through theoretical analysis and numerical simulation methods, studied the grouting diffusion law and water blocking mechanism of cement composite grout in karst fractures under the action of groundwater. Combined with a large number of grouting test analyses, a set of composite grouting reinforcement and strengthening technologies for complex karst development foundations was improved.In 2023, Wei[26] took the subgrade in the concealed karst area of the Shanghai-Kunming High-speed Railway (Guizhou section) as an example, constructed a fluid-solid coupling model using ABAQUS, and adopted the strength reduction method to calculate and analyze the specific impacts of factors such as different soil cave scales, embankment filling heights, soil cave positions, and changes in the groundwater level on the stability of the high-speed railway subgrade and soil caves.

In conclusion, domestic and foreign scholars have carried out a series of in-depth and meticulous research works on the impact of subgrades in karst areas from multiple dimensions and levels, such as treatment methods and stability analysis.

In the research field of karst subgrade treatment, researchers have conducted in-depth discussions on traditional treatment technologies. Among them, the grouting treatment technology, as a conventional method, aims to improve the bearing capacity and stability of the foundation by injecting grouting materials into karst cavities or cracks. At the same time, emerging grouting reinforcement technologies have also been involved to further enhance the stability of karst subgrades. With the progress of science and technology, grouting materials, equipment, and technologies will continue to innovate. For different geological conditions, degrees of karst development, and subgrade requirements, grouting schemes will also become more personalized.

In the research on the influence of karst development on the stability of subgrades, the key issue is that the thickness of the roof of karst caves fails to meet the safety standards, which may lead to collapse when bearing the upper load. Although the current evaluation and detection technologies for karst stability have developed to some extent, in some complex geological environments, these technologies may have certain limitations and it is difficult to fully reveal the detailed information of the karst structure.

2.3. Current research status on the impact of karst development on tunnel

2.3.1. Research Status in Numerical Simulation

Liu, Xie, and Li[27][27] took the section line between Lianjie Station and Wujiaying Station on Kunming Metro Line 4 as the research object. Using MIDAS software, they constructed a three-dimensional finite element calculation model of a cylindrical cave-tunnel. By changing parameters such as cave diameter, filling material, and cave location, they studied the relationship between cavity displacement at different locations and excavation step spacing.Lei[28] used finite element software to conduct numerical simulation and analysis of specific sections of surrounding rock in Guangzhou railway transportation, considering the situation of karst caves on both sides of the tunnel. The results show that when the karst cave is on the left side of the tunnel, its geometric dimensions change, and the maximum and minimum principal stresses and maximum shear strains of the rock layer will change significantly. Moreover, the change in the diameter of the karst cave causes a shorter distance between the tunnel center and the excavation face, which will increase the longitudinal bending moment of the tunnel lining. When the cavern is located at the lower part of the tunnel and has a small distance from the excavation surface, the plastic zone is mostly located at the arch top and above. If the cave is large, the plastic zone is mainly distributed around the cave (cave roof).Researchers such as Shi[29]used soft film technology to analyze the influence of different sizes of caverns in Xiajiamiao Tunnel on the deformation and stress of surrounding rock. They established a model for the excavation process of rock mass solution zone tunnels, explored the changes in the principal stress of the roof during tunnel construction, the changes in the stress of the roof at different depths, and the differences in shadow effects and roof stability at different sections. Finally, they compared the measured data to make the obtained rules more in line with reality.Yin[30] studied the deformation law of surrounding rock, the distribution law of maximum principal stress and plastic zone during the karst development process in karst areas using FLAC3D finite difference program, based on an overlying karst cave tunnel project.The above is a series of studies conducted by researchers on karst engineering geology, which have also achieved certain research results in hydrogeology. Jia[31]used ABAQUS software to build three-dimensional models of karst caves and tunnels in front and on the side of the palm face, exploring the effects of different pore sizes, water pressures, and clearances of karst caves on the stability of the rock mass behind them.Research has found that as the diameter of the tunnel decreases, the degree of influence on the rock mass in front of the palm increases and the stability decreases; As the diameter and water pressure increase and the spacing decreases, the maximum and minimum principal stresses of the surrounding rock change towards the tensile direction. The plastic deformation and plastic zone on the right side of the cave increase and expand towards the center of the arch, resulting in a decrease in the stability of the surrounding rock. Zou Yue used finite difference software to establish a model of the palm face and conducted risk assessment of sudden water influx in karst tunnels.

2.3.2. Research Status in Theoretical Analysis

Song,and others[32] applied the theory of structural mechanics to the roof model of tunnels containing karst caves, proposing three forms: cantilever, cantilever, and quadrilateral, and provided the calculation formula for the minimum thickness of the roof.Lei[28]used a combination of indoor model experiments and numerical calculations to study the influence of factors such as size, location, and shape of underground caverns in karst areas on their stability.Zhao,and others [34] used a combination of tunnel engineering model experiments and numerical calculations to study the influence of karst caves at the top and bottom of karst areas on the stability of tunnel surrounding rock. They obtained the influence of factors such as the distance and size of the top and bottom holes on the deformation and stress of various parts of the tunnel.Zhang[33] used theoretical analysis method to analyze the stability of surrounding rock with relatively simple boundary conditions and uncomplicated medium characteristics, and compared the stress and displacement values with the allowable safe stress and displacement values of the surrounding rock to determine whether the surrounding rock is stable.

2.3.3. Research Status in Experimental Analysis

Zhao,and others [34]conducted similar model experiments to study the effects of varying distances and sizes of karst caves at the top of tunnels on tunnel stability. The research results indicate that the amount of dissolution at the top of the tunnel increases with the decrease of the spacing between the surrounding rocks, and there is a clear relationship between the release rate of rheological deformation of the surrounding rocks after tunnel excavation and the displacement of the surrounding rocks.Researchers such as Cheng[35]used a combination of field investigations and theoretical calculations in the karst area of central Huaying Mountains to explore the impact of groundwater environment on tunnel construction in karst areas.Zhang[36] used river sand, cement, and paste as reference materials, and calculated the similarity coefficient to select a material that can simulate weakly weathered limestone for simulating tunnel surrounding rock. By using a vertical platform to apply vertical loads step by step on the top plate, the stress conditions on the top, bottom, and sides of the tunnel are simulated, and the deformation and strain on the top, bottom, and sides of the tunnel are calculated to evaluate the stability of the tunnel. Research has shown that the position of the cave roof has a significant impact on the settlement of the arch crown, while its impact on the side walls and bottom plate is relatively small; Due to the fact that the cavern group is located at the bottom of the tunnel, it will not have a significant impact on the surrounding environment, nor will it change the form of damage in the surrounding area; When the cavern group is located on one side of the tunnel, it has a significant impact on the stability of the surrounding environment and may lead to the destruction of the cavern group.

In summary, domestic scholars have considered the influence of karst development on tunnel stability, including the location of karst caves, the roof of karst caves, the relationship between karst cave tunnel locations, the shape and size of karst caves, water pressure, and groundwater environment.

Domestic researchers have mostly studied the stability of tunnel surrounding rock in karst areas through engineering geology and hydrogeology, but have not paid enough attention to other important factors such as tunnel burial depth, construction, rainfall, temperature, etc. that affect tunnel stability in karst areas. Nowadays, tunnel excavation often adopts a combination of various excavation methods, among which the impact of deep buried tunnels with karst caves in karst areas still needs further research, and shallow excavation tunnels need to further improve research results.

Due to the complex geological environment of karst, the degree of degradation of surrounding rock has a significant impact on the stability of tunnels. Further research is needed to investigate the erosion rate of surrounding rock in karst environments and the expansion of joint fissures during this process.

3. Summary and Outlook

This article collects relevant literature and data from the past 20 years, summarizes the research status of the stability and bearing capacity of some infrastructure such as pile foundations and tunnels in karst areas, and elaborates on them from three aspects: numerical simulation, theoretical analysis, and experimental analysis. With the efforts and exploration of many scholars, great progress has been made in these three aspects, and a clear understanding of the stability and bearing capacity of infrastructure in karst areas has been obtained, providing theoretical support for engineering construction in karst areas and solving many engineering construction problems.With the forward development of China's infrastructure industry, it is inevitable for infrastructure personnel to carry out engineering construction under more complex geological conditions. At the same time, the country's requirements for the safety, practicality, and durability of infrastructure are becoming increasingly strict. More stringent and in-depth requirements have been put forward for the stability and carrying capacity of infrastructure in karst areas. This article mainly summarizes the following aspects:

In current research on infrastructure such as pile foundations, roadbeds, and tunnels, researchers only focus on the influence of a single factor variable on the stability of the infrastructure while considering the influence of other factors. The research is relatively one-sided, and the research results are limited to specific terrain conditions. Due to the different karst environments in different regions, the research results cannot provide general theoretical guidance and lack a widely applicable calculation system. Establishing calculation methods that can be applied to various environmental areas has become an urgent problem that researchers need to solve.

The existing analysis methods are limited to analyzing the process of rock mass instability and failure, and cannot effectively describe it. In practical engineering, the non-uniformity and anisotropy of rock mass cannot meet the requirements of medium continuity in analytical methods. So, the results obtained by analytical methods often deviate from reality and can only serve as some rules. How to fully consider the characteristics of rock mass to better fit theoretical research results with practical engineering situations is a problem that researchers still need to constantly explore today.

The existing research models are mostly established based on theoretical rigidity, elasticity, or elastoplastic, lacking mechanical research models for fracture damage. Researchers still need to fill the gaps in this research area and establish more realistic models.

The existing numerical simulation models of karst caves are mostly regular geometric shapes, and their physical and mechanical properties deviate from reality. How to establish a more realistic karst cave model is still a problem that researchers need to explore. Meanwhile, due to the uncertainty of karst development, including its shape and location, how to fully consider the randomness of karst cave development is also a problem that researchers need to conduct in-depth research on.

When analyzing the stability of infrastructure in karst areas, most scholars only consider the manager response of infrastructure, but in China, karst areas and earthquake areas overlap greatly, such as Tangshan. There is still a lot of research space in the dynamic response of infrastructure in karst areas. Researchers can combine vibration tests with vibration tables, and use numerical simulation software and theoretical analysis methods for theoretical analysis to carry out further research.

Groundwater exists around karst caves in karst areas, and its movement has a certain impact on the subsequent evolution of caves, the strength and permeability of surrounding rocks, as well as the stability of infrastructure. The movement of groundwater still needs further discussion by researchers on the development of karst and the stability of infrastructure.

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