

# **Journal of Architectural Research and Development**

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## Journal of Architectural Research and Development

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# Technologies for Asphalt Pavement Surface Testing in Road and Bridge Construction

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**Abstract:** Asphalt pavement is currently one of the main components in the construction of roads and bridges. However, from a practical point of view, various quality problems are prone to occur in the surface layer of asphalt pavement, which will lead to the poor overall quality of road and bridge projects. Therefore, it should be applied reasonably. Advanced testing technologies are used to test the mixture quality, compaction, segregation, thickness, and other aspects of the asphalt pavement surface layer, so as to improve the quality of the asphalt pavement surface layer, and then improve the overall quality of road and bridge construction. Therefore, this paper mainly analyzes the technologies for asphalt pavement surface layer testing in road and bridge engineering construction.

**Keywords:** Asphalt pavement surface layer; Road and bridge engineering construction; Testing technology

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## 1. Introduction

In recent years, China has undergone continuous urbanization, the transportation network has been improving, and the construction of roads and bridges has received more and more attention. One of the most frequently used road surfaces in contemporary China is asphalt pavement. The durability of asphalt pavement is not only the result of the rapid improvement of road and bridge construction in China, but also a reflection of the construction technical level and working attitude of construction workers. Therefore, in the process of asphalt pavement construction, it is important to carry out a detailed inspection of the pavement base to ensure its good quality <sup>[1]</sup>. Moreover, in the actual construction process, there may be situations such as uneven distribution of surface materials, insufficient tightness of pavement joints, and unqualified raw material mixture, which may affect the safety of road operation. Therefore, it is necessary to carry out reasonable quality checking for asphalt pavement surface layer. Hence, it is of great significance to analyze and study the technologies for asphalt pavement surface layer testing in road and bridge construction.

## 2. Construction problems of asphalt pavement surface

During the construction of road and bridge projects, the construction problems of the asphalt pavement surface that may occur are cracks, upper layer problems, and raw material quality problems. These occur quite frequently, and any one of them will affect the overall quality of the road and bridge. Therefore, it is necessary to conduct in-depth exploration on the points regarding problem detection to ensure that problems can be detected quickly in the quality checking process.

(1) Crack detection and repair

Cracks are a common problem in the construction of asphalt pavement of roads and bridges. Cracks can easily affect the overall strength of the pavement and are not conducive to prolonging the service life of the road. Therefore, it is very important to effectively detect and repair cracks in the asphalt pavement surface in time. At the same time, the problem of cracks in the pavement surface can also extend to the expansion and contraction of the pavement surface. Although the possibility of debris falling is small, the waterproof performance of road bridges will inevitably be affected, and it can form a pavement, and the safety of road bridges will then be affected, so it is necessary to efficiently detect and repair cracks in the asphalt pavement surface of road bridges <sup>[2]</sup>.

(2) Upper-layer problems

Upper layer problems lead to many other problems in the construction of road and bridge asphalt pavement surface. If the traces of the joints of the layers are too obvious, local segregation may occur in the beginning of construction of the pavement or near the end of its construction. At the same time, uneven compaction is also one of the important problems in the upper layer. In most cases, although the upper layer and the degree of compaction of each section of most the pavement can basically meet the relevant requirements, there are still some measuring points with low compaction degree, especially the position near the hard shoulder and the central divider, where there are many cases of the compaction degree not meeting the requirements. The aforementioned problems will likely affect the construction effect and service life of the asphalt road bridge pavement surface layer.

(3) Raw material problems

Quality problems in the raw material will significantly affect asphalt pavement surfacing. Generally speaking, raw material quality problems are inconsistent raw material quality. For example, the content of dust particles in aggregates exceeds the standard or the size of the materials is too large, which can affect the overall quality of the raw material mixture. Moreover, due to the different sources of aggregates, the gradation of aggregates may be inconsistent, which will affect the construction effect of the asphalt pavement surface.

### **3. Asphalt pavement surface detection technology in road and bridge construction**

A comprehensive inspection of the asphalt pavement surface layer is an important basis for improving the overall quality and safety, and prolonging the service life of road and bridge projects. Therefore, it is very important to analyze related detection technologies.

(1) Mixture analysis

Mixture analysis includes testing mainly the strength and toughness of the asphalt pavement surface layer mixture. Therefore, it is necessary to reasonably control the proportion of materials of the asphalt mixture while ensuring that the construction materials are most consistent with the construction requirements of the pavement surface layer. When mixing asphalt mixture, technicians should pay attention to the precise control of the time and temperature. If the mixing time is too long, too short, or the temperature is too high, asphalt aging or uneven mixing may occur. Therefore, it is necessary to properly control the quality of raw materials, proportioning, mixing time, and mixing temperature of the asphalt mixture. Afterwards, the rutting test should be carried out. Generally, the mixing temperature should be set at 60°C and a suitable load should be selected run over the test track repeatedly, and the deformation of the test piece should be calculated. The dynamic stability of asphalt mixture is determined based on the number of wheel travel. In addition, an appropriate amount of asphalt mixture can also be placed in water for freezing, and through the erosion of water, the asphalt mixture's anti-loosening, anti-dropping, anti-stripping and other anti-destructive capabilities can be determined, so as to understand its water stability <sup>[3]</sup>.

## (2) Compaction analysis

When performing asphalt pavement surface construction work, the asphalt material is not just pasted on the pavement, but it needs to be rolled several times. There are many precautions in the rolling process. The degree of compaction of the asphalt pavement surface layer is closely related to the smoothness of the pavement. A smooth road surface will ensure good anti-skid effect and load capacity, which is conducive to improving the safety of the asphalt pavement. Over-compaction will cause the asphalt mixture to become too dense, and the bleeding will easily occur in a high-temperature environment, which will lead to a decrease in the static friction coefficient of the road surface, which may cause accidents such as skidding, and affect driving safety. Therefore, the degree of compaction of the asphalt pavement surface must be controlled within a reasonable range, and it is of great significance to detect the degree of compaction of the asphalt pavement surface. In the past, the main method for testing the compactness of asphalt pavement was the Marshall compactness test, but with the development of modern technology, more convenient methods emerged. For example, in the wax seal method, the sample is first molded based on the Marshall method, then the weight of the specimen in air is measured. Next, the open pores of the specimen is filled with melted wax, and the specimen is immersed into the melted wax for repeated rolling to seal all the pores around it until the melted wax condenses. The wax-sealed test piece is pressed into the mold, the excess wax is scraped off using the edge of an abrasive tool, a scraper is used to repair the two sides of the test piece so that the volume of the test piece is the same as that of the test piece that has not been sealed with wax. After that, the weights of the wax-sealed specimen in air and in water are measured, and the compactness of the asphalt pavement is calculated [4].

## (3) Resolution analysis

The segregation of the asphalt pavement surface layer is mainly caused by the uneven distribution of the mixture, and it causes safety hazards, especially in cases of hot weather, bad weather, overloading, and many more, which severely shortens the service life of the pavement, causing further aggravation of the hidden dangers. The determination of the particle size of the asphalt pavement surface layer can be done by eye, but this method is only suitable for large particles and coarse mixtures, which makes it highly subjective and limited, and cannot be quantified. Therefore, it is easy to cause disputes between parties [5]. The degree of segregation of the surface layer can also be determined by the sand-spreading method. After the sand-spreading operation, the surface texture depth of the area where segregation occurs and the area where segregation occurs can show significant differences, but this method is time-consuming and laborious, making it less popular. The coring method is a traditional form of destructive test. Core samples are drilled during isolation, and the gradation composition, asphalt content, density, and void ratio of the core samples are measured and compared to the standard values. The degree of segregation of the surface layer is then measured [6]. More advanced methods include infrared cameras, nuclear density meters, and ground-penetrating radar detection. The detection of segregation by temperature difference in the layers is conducive to early detection and intervention, so as to ensure the construction quality of the asphalt pavement surface layer. This method belongs to a type of segregation phenomenon detection technology with high application frequency and good application effect [7].

## (4) Thickness testing

The thickness of the asphalt pavement surface layer is crucial because it determines the overall compressive capacity of the pavement. Under normal circumstances, road surface radar detection technology can be used. It is necessary for inspectors to first use ground-penetrating radar to emit electromagnetic pulses against the road surface layer. The pulses quickly pass through the road surface layer and the data acquisition system records the return time of the pulse and the sudden change of the discontinuous dielectric constant in the pavement structure. Because the material of each structural layer

in the pavement surface layer has a dielectric constant, if there is a sudden change in the dielectric constant, that position would be the interface between different structural layers [8]. Therefore, the pavement structural layer thickness can be calculated by detecting the actual dielectric constant and beam of different pavement materials obtained. It should be noted that the detection speed should be kept below 75 km/h, the continuous detection range should be within 20 km, the detection depth should exceed 60 cm, and the detection process should be controlled by a computer to ensure that data collection, storage, and radar waveform display can be carried out simultaneously. After processing the data, the three-dimensional pavement thickness profile, color plan and thickness table of the pavement will be displayed on a computer.

#### (5) Flatness testing

The flatness of the asphalt pavement surface has a direct and important impact on the safety and comfort of driving. Unevenness will cause more significant deformation and even lead to road collapses, which is a great safety hazard. Therefore, it is very important to check the flatness of the asphalt pavement surface. The current laser flatness meter and the please change to vehicular bump-integrator belong to the instruments with high frequency of application in flatness detection [9]. The laser level meter is combination of a laser sensor and a distance sensor. It can carry out long-distance rapid automatic detection of the road surface under normal vehicle speed conditions. A computer can also be paired with the device for on-site data analysis and evaluation. It has high detection speed and accuracy. Its detection speed can reach up to 80 km/h, so it can conduct comprehensive inspections on urban roads, airport runway surfaces, and expressways. At the same time, because it is completely automated, the accuracy of the detection results can be guaranteed. The please change to vehicular bump-integrator can quickly detect the smoothness of the road surface, and it is easy to operate and cheap. The sensor is installed on the road, so the driving speed and vibration characteristics of the vehicle can affect the detection results to a certain extent [10].

## 4. Conclusion

At present, the socioeconomic status of China is rapidly improving, and the road and bridge projects are rapidly developing. The quality of mixture, segregation, compaction, thickness, and flatness can be effectively guaranteed, which can significantly improve the overall quality of the asphalt pavement surface layer, as well as the later use effect and safety. Therefore, it is clear that advanced asphalt pavement testing technology greatly contribute to the development of roads and bridges of the country.

## Disclosure statement

The author declares no conflict of interest.

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# Design Technology of Continuous Beam-Arch Combination Bridges

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**Abstract:** In this paper, a research was conducted on the design technology of continuous beam-arch composite bridges. A brief introduction is given on the of continuous beam-arch composite bridges, its basic mechanical characteristics is analyzed, and three aspects of design technology is studied, which are rise-span ratio, stiffness ratio, and bridge deck cracking. This article acts as a reference for relevant design units in China to improve the design of continuous beam-arch combination bridges.

**Keywords:** Continuous beam-arch combination; Bridge design; Analysis of rise-span ratio; Bridge deck cracking

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## 1. Introduction

Continuous beam-arch combination is a bridge type that is increasing in popularity in China because it is consumable-saving, adaptable to various soft soils, low in height, and diversified construction methods. Some examples of continuous beam-arch combination bridges are Xibao Bridge (completed in 2011), the Xianyang West Interchange Special Bridge, and the Guangyuan Jialing River Bridge (completed in 2012), and many more. In road and bridge engineering, the application of continuous beam-arch combination bridges is constantly increasing, and the development of transportation has also resulted in more requirements for the quality of bridges. Therefore, it is important to conduct further research on bridge design to promote the development of the transportation industry.

## 2. Overview of continuous beam-arch combination bridges

The components of a continuous beam-arch combination bridges include beams, suspenders, bridge deck systems, arch ribs, and tie beams. Each component is crucial, interdependent during the assembly stage to create beautiful and durable bridge. Among them, the arch rib of the bridge is mainly responsible for load bearing, the bridge beam is responsible for the thrust of the arch end of the prestressed beam load, the suspender and the bridge deck are responsible for the pressure bearing of the bridge in the application stage, and the bridge arch is the most important pressure bearing part. Stability directly affects the overall safety and lifespan of the entire continuous beam-arch composite bridge <sup>[1]</sup>. In recent years, with the emergence of new materials and technologies in the field of road and bridge engineering, the slenderness ratio of the arch ribs of continuous beam-arch composite bridges has been greatly enhanced. The bridges can be designed with or without wind braces, which puts strict requirements on the stability and reliability of arch ribs <sup>[2]</sup>.



### 3. General mechanical characteristics of continuous beam-arch combination bridges

The continuous beam-arch combination is composed of three parts: partial components, load-bearing components, and mechanical transmission components. It belongs to a very classic ternary structure bridge. The overall structure of the bridge is stable and has a long service life<sup>[3]</sup>. Among the three major components, the arch ribs and tie beams are the main load-bearing components; the main components for live load distribution are scales and bridge decks; and suspenders and columns are mainly responsible for mechanical transmission<sup>[4]</sup>. Among them, the tie beam is not only the main live load distribution structure, but also an important load-bearing member, which will bear the most force. The continuous beam-arch combination bridge is highly similar to the continuous beam in terms of external support system. and the support part only generates vertical reaction force. Based on this feature, the force characteristics of the continuous beam can be clearly understood. Therefore, continuous beam-arch combination bridges have the following mechanical characteristics<sup>[5]</sup>. In the internal structure of the bridge, the load pressure between the arch and the beam will that balance out each other. In the external structure of the bridge, the load force will be transformed into another form of energy. The total bending moment of the beam section can be converted into the force performance of arch compression and beam tension, which can maximize the stability of the bridge after it is put into operation<sup>[6]</sup>.

### 4. Design technology of continuous beam-arch combination bridges

The key elements in the design of continuous beam-arch combination bridges are the rise-span ratio, stiffness ratio, and bridge deck cracking analysis.

#### 4.1. Rise-span ratio

The rise-span ratio directly affects the arch rib, the internal force value of the tie beam, and the construction method of the continuous beam-arch combination bridge. When the rise-span ratio decreases, the ratio of horizontal force and vertical force of arch rib will increase accordingly. At the same time, due to the shrinkage and creep effect of concrete and changes in temperature, the additional stress will increase as the rise-span ratio decreases. Therefore, during the design of continuous beam-arch composite bridges, it is necessary to select a reasonable value for the rise-span ratio. **Table 1** shows the internal forces of the center girder and arch under different rise-span ratios:

**Table 1.** The internal forces of the center girder and arch under the background of different rise-span ratios

Sagittal Ratio		1/6	1/5	1/4	1/3
Arch	Axial force	6578.44	5565.85	4518.45	3412.75
	Bending moment	91.19	-386.24	-289.19	-428.31
Beam	Axial force	-6574.05	-5557.30	-4511.91	-3404.11
	Bending moment	-1.75	-83.81	-127.61	-68.79

For the internal force of the structure under the action of constant load, **Table 1** shows that under the action of the continuous girder-arch composite bridge, the internal force of the structure was affected by the larger rise-span ratio, and the value of the rise-span ratio reduction was related to the axial force of the tie beam and the arch. The variation of rib horizontal thrust had the same range, that is, the range of variation = 92%. As the rise-span ratio decreased, the bending moments of tie beams and arch ribs increased; and the bending moments of tie beams increased then decreased which makes it nonlinear. The reason for this phenomenon is that under the condition of a large rise-span ratio, a small span will cause a large deviation between the reasonable arch axis of the arch rib and the parabola under the action of dead load. After

decreasing to a certain value, it will gradually increase again.

In terms of internal force of the structure under live load, the value of internal force of the structure under 1/4 cross-border is assumed to be 1. At this moment, the change of rise-span ratio greatly affected the internal force of the structure under live load. With the change of rise-span ratio, the variation law of the axial force under the action of live load was the same as that of dead load, but the value was larger [7]. When the rise-span ratio decreased, the bending moment decreased then increased, while the bending moment of arch rib decreased.

#### 4.2. Stiffness ratio

In terms of stiffness ratio, the balance of the horizontal force of a continuous beam-arch combination bridge depends on the longitudinal beam. The way that the beam and arch at the arch foot are placed on the support in a rigid manner allows the load to be borne by the beam and arch, which reduces requirements for the abutment, thus saving materials to a certain extent. In the continuous beam construction system, the stiffness ratio consists of two parts, that is, the bending stiffness of the arch rib and the stiffness of the beam. Based on the relative values of the two stiffnesses, it is divided into three kinds of stiffness, namely, steel beam with rigid-frame arch, steel beam with flexible arch, and flexible beam with rigid-frame arch. **Table 2** shows the influence of different stiffness ratios on the internal force of the continuous beam-arch composite bridge under dead load:

**Table 2.** Influence of different stiffness ratios on the internal force of continuous beam-arch composite bridge under dead load

$I_{\text{arch}}/I_{\text{beam}}$		4	3	2	1	1/2	1/3	1/4
Arch	Axial force	4343.51	4355.90	4378.39	4309.15	4279.5	4365.66	4281.66
	Bending moment	-75.20	-54.82	-49.82	-38.65	35.20	44.29	55.62
Beam	Axial force	-4337.49	-4349.81	-4371.14	-4302.79	-4273.10	-4359.25	-4275.85
	Bending moment	184.75	137.75	55.30	-17.48	-66.75	-99.19	-128.40

As shown in **Table 2**, under the action of dead load, when the cross-sectional area of the beam-arch was fixed and the stiffness ratio of the beam-arch was changed, the axial force of the structure was less affected, and the stiffness ratio only affected the distribution of the beam-arch bending moment. With the increase of beam-arch stiffness ratio, the bending moments of tie beams and arch ribs first increased then decreased, but the effect of arch ribs was greater than that of tie beams. When the beam-to-arch ratio was in the range of 0.5–1, the variation of arch rib bending moment had the largest amplitude. When the beam-to-arch ratio was in the range of 1–3, the rate of change of the bending moment of the tie beam reached the maximum, indicating the variation of the stiffness ratio of the beam bending moment in this section had the greatest influence. Therefore, this means that the influence of different stiffness ratios on the internal force of the structure under the action of dead load, the change of the stiffness ratio and the impact on the bending moment of the beam arch depend on the distribution of the bending moment. Besides, with the increase of the stiffness ratio of the arch rib, its bending moment also increased [8]. At the same time, unlike the influence of the stiffness ratio on the bending moment under the action of constant load, the change of the stiffness ratio under the action of constant load is less affected by the bending moment of the tie beam than that of the arch rib. The higher the stiffness ratio, the greater the change in the bending moment. When stiffness ratio range is between 1–2, the arch rib bending moment produced the largest change in curvature.

In addition, when the area and moment of inertia changed simultaneously, the self-weight of the arch beam changed along with the area and bending resistance, which caused change in axial force of the beam arch, followed by a linear change in the stiffness ratio. When the beam-arch area changed, the beam-arch bending moment decreased with the increase of stiffness ratio. The bending moment of the tie beam was the greatest when the stiffness ratio was 2, and the rate of change of the tie beam bending moment reached the maximum when the stiffness ratio was  $\frac{1}{4}$ :1. The minimum bending moment of the arch rib appeared when stiffness ratio = 1, and the change rate of the bending moment is in the range of stiffness ratio 0.5–3. When the stiffness ratio = 1, the beam-arch composite bridge was in its maximum stress state. When the stiffness ratio is  $< 1$ , the bending moment of the beam increased as the stiffness ratio gradually decreased. Therefore, the optimal stiffness ratio should be within 0.5–2.

### 4.3. Bridge deck cracking prevention

In the design stage of continuous beam-arch composite bridge, it is necessary to consider the problem of cracking. At present, there are three ways to solve the problem of cracking. The first is to use micro-expansion concrete in the secondary pouring of the bridge deck to form compressive pre-stress in the bridge deck. The second method is to design the bridge in a way that the compressive pre-stress in the bridge deck is lower than the tensile stress of concrete, so as to ensure that no cracks appear or the crack width is reduced after the bridge is completed. The third method is to add fiber materials such as polymer fiber and steel fiber into the concrete to improve its tensile capacity. The fourth method is to use the pre-loading method to reduce the internal tensile stress of the bridge deck concrete to zero or within the allowable range under the action of the second phase of dead load and live load <sup>[9]</sup>. The four methods have their own advantages and disadvantages. Among them, the first method reduces transverse shrinkage stress, but has minimal effect on the longitudinal shrinkage stress. The second method can make bridge deck cracks more scattered and thinner, but it is not economical and costs a lot <sup>[10]</sup>. The third method can achieve the purpose of no cracks, but it can only be applied to the bridge deck situation when the main longitudinal beam and arch of the bridge deck are jointly stressed and then poured. The fourth method is effective, but it requires a huge ballast. Therefore, the nature of the bridge project needs to be considered to select the optimal method or a combination of methods, so as to effectively solve the cracking problem of the bridge <sup>[11]</sup>.

## 5. Conclusion

The design of beam-arch combination bridges is highly technical, and there are many influencing factors in the design stage. Therefore, the influence of rise-span ratio and stiffness ratio and the solution for cracking in the later use should be considered in the design stage, so as to effectively improve the design quality and meet the requirements for bridges.

### Disclosure statement

The author declares no conflict of interest.

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# Analysis on Effectiveness of Testing and Evaluation of Bridge Repair and Reinforcement

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**Abstract:** Bridge engineering is an important part of basic engineering in today's transportation field, and its quality and performance have a vital impact on the improvement and development of modern transportation engineering. With the continuous development of transportation engineering, the maintenance and reinforcement of existing bridges are also being given more emphasis. In order to scientifically evaluate the effectiveness of bridge maintenance and reinforcement, this paper analyzes its detection and evaluation, including the significance, key points, and main methods of detection and evaluation. Therefore, this analysis aim to provide some reference for the maintenance and reinforcement and the quality improvement of bridge engineering.

**Keywords:** Bridge engineering; Maintenance and reinforcement; Testing and evaluation method

**Online publication:** March 28, 2023

## 1. Introduction

The objectives and the important points needs to be outlined for the inspection and evaluation of the maintenance and reinforcement effect of bridge engineering. Then, based on the outline while considering the characteristics of the project or bridge itself, a reasonable method is adopted to detect and evaluate the effectiveness of its maintenance and reinforcement. Only in this way can the effect of maintenance and reinforcement of bridge engineering be well guaranteed, the application quality and safety of existing bridges can be improved to the greatest extent, and the coordinated development of existing bridge engineering and modern transportation industry can be promoted.

## 2. Overview of effectiveness of current testing and evaluation methods

### 2.1. Significance of testing and evaluation

With the development of the social economy and transportation engineering, the original structures of many existing bridge projects are gradually unable to meet the actual transportation needs. Under such circumstances, the relevant units need to carry out proper maintenance and reinforcement of the existing bridge project, so as to improve its safety and reliability, and prolong the service life of the existing bridge. However, if the effect of the corresponding maintenance and reinforcement work is not tested and evaluated properly, there will be hidden risks in the existing bridge structure, thereby affecting its subsequent application effect, and in severe cases, it may even lead to major safety accidents, posing a greater threat to the quality and safety of transportation <sup>[1]</sup>. Therefore, reasonable measures need to be taken to test and evaluate the condition of the repaired and reinforced bridge, so that problems can be detected and rectified in time. This is very important for the quality assurance of bridge engineering maintenance and

reinforcement and the improvement of safety.

## **2.2. Key points of testing and evaluation**

For the repaired and strengthened bridge project, relevant units and staff should pay attention to the following key points when performing inspection and evaluation of repair: firstly, on-site investigation needs to be done, including on-site geological conditions, environmental conditions, and traffic load, and many more, so as to clarify the actual operation and maintenance status and requirements of the bridge project. Secondly, the original design and repair and reinforcement design drawings of the bridge project needs to be fully understood, and the key repair parts need to be identified. The third step is to choose a reasonable detection and evaluation method depending on the repair and reinforcement methods and the situation on-site. In this way, not only can the evaluation be performed more efficiently, but the evaluation results will also be more accurate, thus laying a good foundation for the improvement of bridge engineering quality and safety.

## **3. Effectiveness testing and evaluation methods of bridge maintenance and reinforcement**

### **3.1. Testing and evaluation of seal grout**

Seal grout is a commonly used technology in the repair and reinforcement of bridge engineering. The effect of the treatment is then evaluated. (1) The relevant information of seal grout is collected and the inspection records are filled in on the spot to ensure the integrity and traceability of all information. (2) A good distinction needs to be made between potting and seam sealing. A column should be dedicated to each component of the inspection for data record. (3) A visual inspection of each colloid should be carried out in the repair and reinforcement of bridges. (4) During the inspection process, the specific scope where a problem is discovered and the date of discovery should be marked with a marker pen, and its development should be continuously observed in the follow-up inspection. As for typical issues found in the inspection, it is necessary to take pictures and save them, and put them in the records. (5) For bridge components with a long construction period and relatively high seam sealing efficiency, there is a need to confirm whether there is any plans for re-construction in the near future. (6) The surrounding environment of the bridge project needs to be well analyzed, including conditions such as direct sunlight and water damage. If water damage is found in the repaired and reinforced position, it is necessary to focus on its outer structure and observe whether there is any water leakage<sup>[2]</sup>. Through the method above, the effect of the bridge seal grout can be effectively tested and evaluated. Hence, corresponding problems can be found and dealt with in time.

### **3.2. Testing and evaluation of the effectiveness of steel plate reinforcement**

Steel plate paste is an effective method in the repair and reinforcement of existing bridges. The effect of this treatment can be evaluated through a few steps. (1) Collect all relevant information of the steel plates and accurately record the various inspection contents after the steel plate is pasted and strengthened, and confirm the specific processing time, steel plate material, steel plate thickness, and manufacturer and other information<sup>[3]</sup>. (2) The steel plates are observed; its geometric dimensions are measured along the edge of the steel plate with a steel tape, and its length, width and actual pasting direction are recorded; position and area any hollow in the steel plate by are detected by tapping, and make a mark with a marker pen good record. (3) For some typical issues found in the inspection, photos should be taken and saved for future processes<sup>[4]</sup>. (4) The steel plates, bolts and other materials are observed, and the degree of corrosion is determined according to their appearance<sup>[5]</sup>. (5) The number of bolts used in the pasting of steel plates per square meter are calculated on site, one of the steel plates is used as the sample in which its reflection and water stains are observed and recorded (6) The effect of the steel plate is evaluated through a comprehensive calculation of the total number of steel plates, the weight of a single steel plate, the load of the bridge

structure, and the performance parameters of the bolts. In this way, the defects or problems existing in the steel plate paste treatment can be discovered in time and a treatment plan can be formulated accordingly, so as to ensure the good effect steel plate paste reinforcement technology in the bridge repair and reinforcement treatment <sup>[6]</sup>.

### **3.3. Testing and evaluation of the effectiveness of carbon fiber cloth paste reinforcement**

Carbon fiber cloth is a new type of material widely used in the repair and reinforcement of bridge engineering. After the carbon fiber cloth is pasted and reinforced, in order to scientifically test and evaluate. (1) All processing and construction data are collected, including pasting time, carbon fiber cloth manufacturers, technical units, so as to lay a good foundation for subsequent testing and evaluation work <sup>[7]</sup>. (2) The appearance and bonding effect of carbon fiber cloth are observed. Carbon fiber cloth with poor appearance quality or is weakly bonded should be marked with a marker pen on site, and corresponding inspections should be made, including specific quality problems, testing date, and testing personnel, etc., in order to provide sufficient basis for the follow-up processing work. (3) For some typical carbon fiber cloth pasting issues, the staff should take pictures and save them, so as to provide reference for subsequent engineering inspection, evaluation and problem solving. (4) If the surface of the carbon fiber cloth falls off during the inspection, that particular area needs to be measured along the edge of the with a steel tape, which will be used as a basis for the calculation of the surface disconnection rate of the carbon fiber cloth <sup>[8]</sup>. In this way, it is possible to determine the treatment method for the detachment of the cloth, and to make a scientific evaluation of its effectiveness, so as to provide a strong reference for its subsequent further processing and maintenance, and maximize the effectiveness of carbon fiber cloth repair and reinforcement in bridge engineering <sup>[9]</sup>.

### **3.4. Testing and evaluation of effectiveness of prestressed steel strand repair and reinforcement**

Prestressed steel strands are also commonly applied to the outside of the structure in bridge repair and reinforcement treatment, which is carried out in a few steps. (1) Relevant information including the time taken for this method of treatment, quality of prestressed steel strands, performance parameters, manufacturer details, construction units, are collected in order to evaluate the basic quality of the prestressed steel strand. (2) The microcosm of the steel strand is observed including the deformation of the steel strand, anchoring effect, and many more. Any problems discovered should be photographed and saved, and detailed inspection records should be made <sup>[10]</sup>. (3) The appearance of all anchor blocks, steering blocks and polyethylene (PE) sheaths are observed, and their condition should be recorded. Any problems discovered should be photographed and saved. (4) The environment of the steel strands should be evaluated by combining existing data and field investigations; the number of steel strands used in each reinforcement treatment are counted, and then the number of damaged components is determined. The number of damaged bridge components is then used as the basis to calculate the actual steel strand prestressing requirements, and finally the effectiveness of its reinforcement treatment is evaluated by comparing the actual prestressing requirements with the actual treatment conditions <sup>[11]</sup>. In this way, the quality of the prestressed steel strand and also its effectiveness in bridge repair and reinforcement can be evaluated, which will be helpful for the operation and maintenance of the bridge.

## **4. Conclusion:**

In conclusion, due to the continuous increase of traffic load and various external factors, the quality and performance of many bridge structures will continue to decrease. To effectively ensure the application effect of bridge engineering and meet the quality and safety requirements of modern transportation engineering for bridges, suitable technical measures need to be taken to repair and strengthen existing

bridges. Besides, reasonable measures also need to be taken to test and evaluate the effect of repair and reinforcement, such as testing and evaluating the treatment effect of seal grout, steel plate pasting, carbon fiber cloth pasting, prestressed steel strand, and many more. In this way, problems in the repair and reinforcement of bridge engineering can be discovered and dealt with in a targeted manner.

### Disclosure statement

The authors declare no conflict of interest.

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# Optimization Strategy of Road Traffic System in Urban Renewal Area

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**Abstract:** At present, problems such as insufficient road infrastructure and supporting facilities, and limited parking spaces are increasingly prevalent, and there are large conflicts of interest in the process of urban renewal. Therefore, it is crucial to improve the quality of the road network. This paper presents an analysis on the current situation of the road traffic system in a completed area outside the Third Ring Road in Xindu District, Chengdu, and provides corresponding road traffic optimization strategies, with aims of solving the existing road traffic problems, improve road service levels, and promote the overall development of the area and improve the quality of urban space.

**Keywords:** Urban renewal; Road traffic system; Road network service

**Online publication:** March 29, 2023

## 1. Introduction

Under the background of the accelerating urbanization in China, urban renewal has become an inevitable trend of urban development, and the transformation brought about by urban renewal is a very important part of “organic renewal.” Urban renewal refers to the reuse and re-creation of urban space resources, which is an advanced stage of urban development. Since 2003, our country’s urbanization process has been accelerating, and major cities have formulated corresponding urban renewal plans and put them into practice. At present, our country’s economy is in a transition period from high-speed growth to high-quality development. Therefore, it is crucial to improve the urban space and the living environment of residents. In this context, many places in China have adopted the concept of “organic renewal” to renovate old urban areas and improve the quality of space. The road network, which is an important aspect of urban development, needs to be improved. The early research on road traffic system in our country mainly focused on road width, driving speed, and intersection setting; since the 1990s, scholars at home and abroad began to study the structure and design methods of road traffic system. Many scholars in our country have also proposed ideas for improving the traffic network in old urban areas under the background of urban renewal. Liu, et al. <sup>[1]</sup> conducted research on the problems in the old urban road network in the perspective of “organic renewal,” and proposed that it was useful for solving the current traffic problems in old cities. Yang <sup>[2]</sup> used the strengths, weaknesses, opportunities, and threats (SWOT) model to analyze the old city of Xi’an and had put forward suggestions for improvement. Wang et al. <sup>[3]</sup> carried out research on the traffic optimization of old urban areas based on “organic renewal,” and optimized the design of parking space, slow traffic system, and public transportation system. With the continuous urbanization of China and the increasing demand for a better living environment, the improvement of the overall urban spatial quality in the process of urban renewal needs to be emphasized. The main goal of road traffic planning and design is to improve

traffic efficiency and ensure travel safety. Yin <sup>[4]</sup> used analytic hierarchy process (AHP) to study the pedestrian road network system of historical and cultural districts in Guangzhou, evaluated its road design scheme and put forward relevant improvement suggestions. Qin <sup>[5]</sup> carried out 3D model construction and spatial analysis using 3D laser scanning technology and GIS method on the residential buildings and public spaces on both sides of Heping Street in Fengjing Town, Shanghai. Chen <sup>[6]</sup> used a combination of factor analysis and back propagation (BP) neural network method to study urban design of 179 neighborhoods in Huangpu District. After the analysis, it was proposed that the research on road capacity and traffic management should be strengthened in the reconstruction of the old urban area. Hu *et al.* <sup>[7]</sup> used a geographic information system (GIS) to analyze the characteristics of the road network in two districts of Tianjin and optimized the design. Huang *et al.* <sup>[8]</sup> conducted research on the road traffic status of Tuanjie Community, Zhan Road Street, Xicheng District, Beijing, and proposed measures to improve the internal traffic organization of the region, optimize the spatial layout of alleys, improve the pedestrian walkway system, and increase non-motor vehicles and barrier-free passages, and other measures that can improve the traffic capacity and environmental quality of the area. These research on the road traffic system is mostly concentrated on the theoretical aspects and lacks certain practical significance. Therefore, this paper will use road traffic system in a completed area outside the Third Ring Road in Xindu District, Chengdu as an example to discuss the corresponding optimization strategy through the analysis of its problems. Based on the background of urban renewal, it is of great significance to study the optimization of road traffic system. On one hand, the overall development of the region and the improvement of urban space quality can be promoted by improving the service level of the road network in and around the region; on the other hand, it can also as a reference for future urban renewal on the basis of existing theories.

## 2. Research overview

Xindu Street is located in the core area of Xindu District, which is a traffic-heavy location. The area of research, which is outside the Third Ring Road, is located on both sides of the central axis of Xindu Street, close to key development areas such as Xindu City, Hi-tech West District, and other key development areas. The buildings in the area are mainly multistorey residences, apartments, and residential mid-rise and high-rise buildings, which means that land use functions are mainly residential and commercial land. At the same time, there is an extension line of Metro Line 1 that was under construction in the area. According to the requirements of the Chengdu City Master Plan (2012–2030), Xindu Street is “an important space for the northward expansion of the central urban area,” and its function is defined as “a sub-center for northward vitality” and “a service center for city-industry integration.” The planning area extends to Huahua 3rd Road in the east, Xindu Road (Third Ring Road) in the west, Chengdu-Kunming Railway in the north, and Nanhe West Road in the south (under planning), totaling up to about 538 km<sup>2</sup> of land, and the planning area includes 10 communities and the Third People’s Hospital of Xindu District. The rail transit network in the region is also very developed, and there are subway lines 1, 7, and line 5 (under planning) in the surrounding area. The internal road network of the area is composed of north-south and east-west roads. The existing roads are mainly divided into three parts: north-south road, which is the Nanhe West-Xindu-Xingye road; east-west road, which is the Shulong-Jujin-Xingye-North Gaosheng road; an area outside the Third Ring Road has been built. Generally speaking, the current road network structure of a completed area outside the Third Ring Road is dominated by north-south roads, supplemented by east-west roads. Through on-site investigation of the main road sections in the area, it was found that there are mainly five types of traffic mode in the area: walking + public transport + slow lane (sidewalk + non-motorized vehicle lane), bus lane + non-motorized vehicle lane + sidewalk (occupy the road), pedestrian lanes + non-motor vehicle lanes (occupy the road), and intersections without traffic lights. Most of the intersections do not have traffic lights, and pedestrians show undesirable behaviors on the road. Besides, it was found that the road facilities in this

area are not perfect, where there are insufficient bus stations and parking spaces for non-motorized vehicles. Due to the high population density and amount business activities, the area is rich and diverse, and the crowd is relatively big. Therefore, the number of parking spaces is far from enough due to the growing parking demand, and it has been increasingly difficult to find parking. In addition, it was found that many bus stops only have one platform, which can only accommodate 1 to 2 buses. At the same time, there are many land plots in this area with relatively complete public facilities, but there is no dedicated bus line. Therefore, there are often long queues for buses and severe traffic congestion.

### **3. Analysis on the status and problems of the transportation system reconstruction in the urban renewal area**

#### **3.1. Poor road construction and traffic jam at transport hubs in some areas**

The old city is lively, leading to problems such as road occupation, pedestrian and vehicles moving simultaneously on the road, and parking difficulties. Therefore, the development of road network has a great impact on traffic safety, efficiency, and order. The intersection is a “bottleneck” in the urban road transportation system, which is not only related to the comprehensive efficiency of the entire road network, but also a key link that affects the capacity of the regional road network. Because some intersections in this area have not been channelized and expanded, and traffic lights have not been optimally placed, the actual traffic flow is much smaller than the designed capacity.

#### **3.2. Lack of sufficient parking spaces, occupying roads and public places**

Due to the long history of the old urban area, problems such as urbanization, rapid increase in the number of cars, and insufficient supply of road traffic parking services were not fully recognized at the early stage of planning, resulting in parking facilities that could not meet the level of economic development in the area, which in turn caused serious traffic congestion at certain critical nodes and local segments in the area during peak hours.

#### **3.3. Influence of rapidly developing motorization on low-speed transportation**

Due to the development of our country and the continuous improvement of living standards per capita, the number of private cars of urban residents in China has increased rapidly. In road construction, excessive emphasis on cars is dominant. In the development of cities, the slow lanes are somewhat inferior, and the space for slow lanes has not been fully considered in the road planning. The urban rail transit and public transport system are not well-connected, which is mainly manifested in unideal urban spatial layout and insufficient facility capacity. In addition, the separation between the lanes for motorized vehicles and non-motorized vehicles is not obvious, the traffic signs and markings are not clear, the slow lanes are illegally occupied by pedestrians, and the traffic management is poor, which makes the slow lanes even narrower.

### **4. Reconstruction of road traffic system in urban renewal areas**

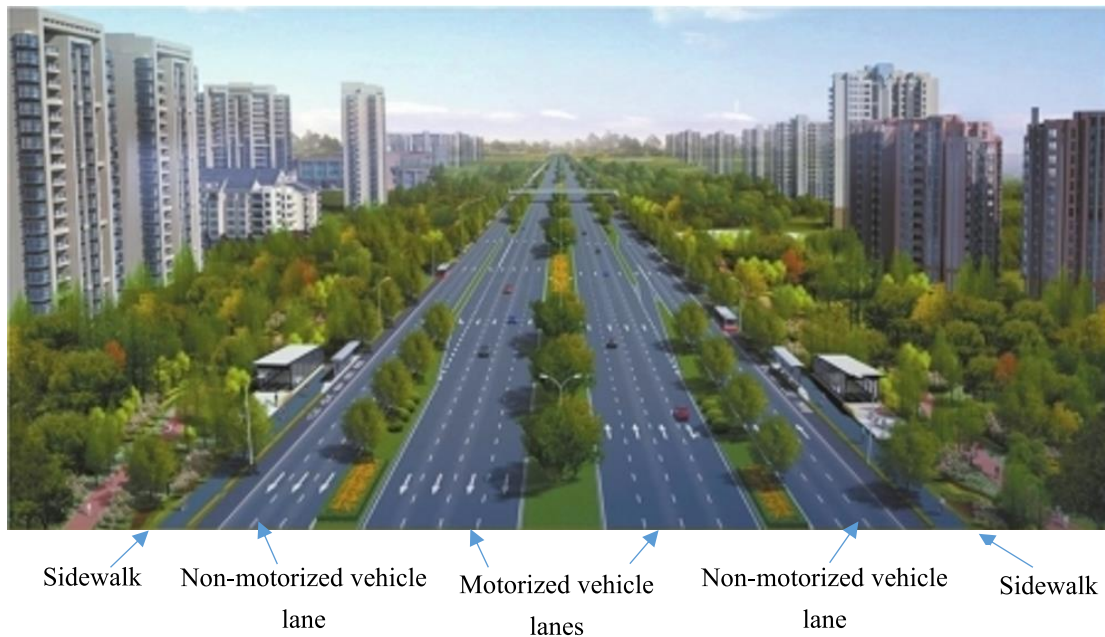
The renewal of the road transportation system in the region should adopt the method of “embroidery.” According to the actual situation, corresponding countermeasures should be formulated to establish a road network system that is people-oriented and promotes microcirculation, so as to stimulate the vitality of the road network.

#### **4.1. Comprehensive and optimal road network repair**

##### **4.1.1. Renovating the cross-section of the road**

The sidewalks, non-motorized lanes, and motorized lanes (see **Figure 1**) should be well separated so that the roles of the lanes can be clearly defined. Damaged roadsides and sidewalks and subsiding pavement

should be repaired. The upstream and downstream pavement should be conditioned properly, and should be leveled and strengthened. In addition, the overall landscape and greenery should be coherent depending on the characteristics of the area.



**Figure 1.** Road streetscape and road function zoning map after updating and renovation

#### **4.1.2. Optimization of node design to improve road network capacity**

Taking the complex intersection of multiple traffic lines in the region as the main hub, the regional road network should form a supply and demand relationship, and the scheduling and design should be optimized.

#### **4.1.3. Opening up dead ends to improve traffic network layout**

Different renovation countermeasures should be taken for dead ends in the area depending on the causes, and detailed planning should be carried out to pen up the dead ends in the area.

### **4.2. Increasing parking spaces**

#### **4.2.1. Increase the inventory mining of the parking lot**

In the case of meeting the parking needs of the community, without affecting vehicles and pedestrians, take corresponding countermeasures, and combine the roads conditions in the community, according to the living environment and parking needs in the community, flexibly set up roadside parking, which is mainly on secondary arterial roads and branch roads (see **Figure 2**), and the vehicle flow in the community should be reduced as far as possible, and the layout should be in parallel.



**Figure 2.** Schematic diagram of newly added parking spaces around the community after upgrading and renovation

The number of parking spots should be maximized; the layout of above-ground or underground public parking should be optimized, and idle land and public green spaces can be transformed into parking spaces with the consent of the residents and if the conditions permit without causing adverse consequences to the surrounding environment. The area of parking spaces at outdoor above-ground parking lots should be within 25–30 m<sup>2</sup>; the area of parking spaces should be within 30–40m<sup>2</sup> for indoor and underground parking lots [9].

#### **4.2.2. Unified utilization and sharing of parking lots**

Non-residential land such as commercial, office and public facilities can be utilized for parking lots. According to the public service project planned and constructed in the area, 20% of the new parking spaces will be free of charge, whereas 50% of the new parking spaces will be commercial parking spaces. The parking lot is not used as commercial land. The parking space and fee of the primary and secondary trunk roads are scientifically designed on the premise of ensuring traffic safety. The building functions should match the main public facilities and supplementary facilities. For residents of the old city, if there are no sufficient parking spaces, public parking spaces can be created around them; if there are no available spaces for parking lot construction, temporary parking spaces should be set up at the roadside. When economic conditions permit, commercial facilities in the area should be developed more parking lots should be created. To achieve complementarity, it is necessary to clarify the business objectives and scale of the parking lot. For example, on national statutory holidays, weekends, and evenings, the use of on-street parking and public parking facilities in the community will peak; during working hours on weekdays, the use of parking lots such as commercial centers and office buildings built in support of the community will peak.



### **4.3. Expansion to improve quality of slow lanes**

#### **4.3.1. Improving the connectivity between cities and expand the space for urban slow lanes**

The public service facilities, station facilities, commercial service facilities and community service facilities in the region should be expanded. The non-motorized vehicles in the area have been reasonably planned to meet the individual and short-term needs for transportation for connection, transfer, and various leisure and entertainment activities. According to traffic demand, the “B + R” (bike + ride) transportation mode should be improved, non-motor vehicle parking spots should be strategically allocated in areas such as public transport stations, parks and green spaces, near public facilities, and on both sides of roads, so as to connect and enrich the “last mile” of the area, and to encourage the use of non-motorized vehicles, improve the radius and accessibility of public transportation services, and then increase the connectivity of public transportation.

#### **4.3.2. Smooth slow traffic flow while preserving monuments**

The historical and cultural features of the block and its original style should be retained throughout the renovation of the city. The traditional style and features of the region and the texture of traditional streets and alleys should be retained, while taking into account the regional environment, the proportion and scale of streets and alleys. The slow lanes on urban roads and the diversification and complexity of the land on both sides of the streets and alleys should be enhanced, and the main trail nodes should be connected <sup>[10,11]</sup>.

### **5. Conclusion**

In conclusion, the components of the road traffic system should be further optimized to meet the needs of residents and maintain the efficiency of the road traffic system. On the other hand, in the process of road network optimization, the long-term development of the roads should be fully considered, leaving room for further amendments of the road network structure in the township area.

### **Disclosure statement**

The author declares no conflict of interest.

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# Analysis on On-Site Asphalt Pavement Quality Inspection Technology in Highway Engineering

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**Abstract:** The acceleration of urbanization has promoted the increase in the number of urban highway projects, resulting in an increase of emphasis on the quality of urban highway projects. The quality and safety of highway construction directly affects the driving comfort, safety, and service life after it is put into operation. Among them, asphalt pavement is an important structure in highway construction, and it is also a key link that directly affects the construction quality. In order to ensure the quality of construction, it is necessary to strengthen on-site testing during the construction process to discover problems in time, and to ensure that the construction is up to standard. This paper mainly presents an analysis on the necessity and application of on-site quality inspection technology for asphalt pavement construction of highway engineering, and outlines measures to improve highway engineering construction testing technology.

**Keywords:** Highway engineering; Asphalt pavement; Construction site; Testing technology

**Online publication:** March 29, 2023

## 1. Introduction

Asphalt pavement is an important part of highway engineering construction. Asphalt pavement has good performance, and it is cheap and easy to maintain. However, if the ratio of material is unideal and the strength is not up to standard during the construction of asphalt pavement, the asphalt pavement might crack. Therefore, in the construction of highway asphalt pavement, it is necessary to inspect the construction site carefully to ensure that all parameters involved in the construction are up to standard. In this way, the probability of hidden problems such as cracking and bulging on the road surface can be reduced, and the safety and service life of the road surface can be improved.

## 2. The importance of on-site asphalt pavement quality inspection in highway engineering

Through the process of modernization, the economy has been significantly improved, and the number of car ownership has increased. At present, most households in both urban and rural areas own private vehicles, so higher requirements are placed on transportation. In addition, the development of e-commerce and the logistics industry has also increased the pressure on traffic. To ensure a safe travelling experience, it is necessary to pay more attention to the construction quality, adopt scientific quality assurance measures, improve the level of road construction, and prolong the service life of roads <sup>[1]</sup>. Asphalt pavement is widely used in highway engineering, which directly affects the development and quality of the project. At the same time, the construction of asphalt pavement is complex and difficult, and is easily affected by the external environment. Therefore, in the construction of asphalt pavement, it is important to test the road construction conditions and various parameters, look out for problems, and come up with effective solutions. At the



same time, road testing technology can improve construction safety and reduce traffic accidents.

### **3. Main tests and technologies in asphalt pavement quality inspection in highway engineering**

#### **3.1. Construction material tests**

There are many materials used in the construction of asphalt pavement, including concrete, aggregate, and various additives. The quality of raw materials will be tested to determine whether they are up to standard. In particular, the test before the start of aggregation plays an important role in ensuring road safety. Aggregate testing is one of the most important tests. A standard mold should be used in aggregate sampling to ensure the consistency of sampling. The properties of aggregate samples should be similar to general aggregates to ensure the performance of aggregates. After the testing of the mechanical properties of the aggregate is completed, the thermodynamic properties, density and particle size content of the aggregate are determined. The particle size and diameter, and the concentration of particles of the aggregate can be determined can be measured by a vernier caliper. The thermodynamic performance is performed using the stamping method to measure the hardness. At the same time, the polished stone value of the surface of the test mold is measured by a light meter. All tests performed require the use of instruments and equipment, thus the equipment should be regularly calibrated and inspected to ensure the operability of the equipment and the accuracy of the test results. Before the construction of asphalt pavement, a suitable ratio of construction materials should be determined depending on the project, which will be the standard for testing results. In the material ratio test, a simulation test can be performed to determine the ratio of ingredients in the mixture, and adjustments can be made in combination according to test results to achieve the ideal raw material ratio <sup>[2]</sup>. The quality standards of the material test should be strictly followed, and the test content should be adjusted according to the nature of the project. The changes and the tensile and softening of the material should be observed, so as to lay the foundation for the subsequent construction work.

#### **3.2. Asphalt mixture gradation test**

The gradation of asphalt mixture directly affects the standardization of mixture construction and the quality of ingredients, which will in turn affect the quality of road construction. Therefore, it is necessary to conduct a gradation test on the asphalt mixture before construction. The test is strictly carried out according to the gradation standard of the ingredients to prevent quality issues due to poor gradation. Before the test is carried out, the situation of the road project construction is simulated and analyzed to ensure the scientificity of the mixing ratio of the materials and lay the foundation for the improvement of the road quality. In addition, the amount of asphalt filling should be calculated. Tests are generally carried out indoors, but it should be noted that there are certain differences between indoor testing and outdoor testing, so it is necessary to prepare a few asphalt mixtures and measure the parameters of different functions of asphalt mixtures in the testing process, to ensure a full understanding of the performance of asphalt mixture, and to lay the foundation for the asphalt pavement construction <sup>[3]</sup>.

#### **3.3. Asphalt pavement compaction test**

After the construction of the asphalt pavement is completed, the road surface needs to be rolled to ensure the flatness of the road surface. The temperature of asphalt rolling should be reasonably controlled, and the rolling needs to be done more than 3 times at once. The degree of compaction of asphalt pavement directly affects the quality of road construction, effectively reduces hidden dangers of road construction, avoids cracks and settlements on the road surface, and ensures the service life and later maintenance of the project. Generally speaking, the technology used in highway pavement testing is core drilling, and the temperature of asphalt is detected at the same time. During the temperature inspection, the temperature can be measured by inserting a thermometer. The thermometer is inserted into the road pavement asphalt mixture to half the

depth. After compacting the surrounding area, the temperature of the mixture is recorded. Secondly, an infrared camera is used to measure the surface temperature of the entire construction area to provide reference for later works. In the temperature test, infrared camera is placed at a point and a video is recorded. The results are documented with photographs of the temperature field. Meanwhile, the pavement should not be rolled for more than 3 times <sup>[4]</sup>. The construction work can then be carried out, and the inspection and result data comparison are carried out on samples obtained through core drilling. In some special road sections where core drilling cannot be performed, a nuclear densometer can be used. The application of the nuclear density detector is more convenient, simpler, and accurate.

### **3.4. Road deflection test**

The pavement deflection test measures the bearing capacity of the pavement. The highway deflection value is mainly calculated through the numerical displacement of the road surface. The deflection is measured in millimeters, and the measured value directly affects the evaluation of the road surface. The main instrument and equipment used in the road surface deflection test is the automatic deflectometer, which is a relatively advanced equipment that is highly accurate. An automatic deflectometer works based on the principle of leverage to measure the condition of the road section. In this method, it is necessary to convert the measurement of the front and rear axles into the measurement of the chassis. The deflection is detected and recorded when the rear axle of the vehicle passes the probe. It is also possible to use the Falling Weight Deflectometer to measure road deflection. The advantage of this measurement technology is that it can dynamically measure the road surface and will not cause damage, and the results obtained are highly accurate. The operating principle is to use a hydraulic device to lift up the hammer, and then release it quickly, and when the heavy hammer falls on the bearing plate, the road surface will be slightly deformed. The signals of the deformation will then be sent to a computer to calculate the deflection value of the road surface. Lastly, the Benkelman Beam is the most widely used deflection testing device in highway construction that can accurately evaluate the bearing capacity of the pavement to guide pavement design. This method can also be applied to the measurement of rebound deflection of the subgrade, which is an important reference index for highway construction and maintenance. For this method, the ambient temperature should be kept at about 20 °C. The temperature should be adjusted if it exceeds or is less than 20 °C.

### **3.5. Asphalt flatness inspection**

In order to ensure the quality of pavement construction, it is necessary to conduct a comprehensive inspection of the flatness of the pavement. There are a few common techniques used in the determination of flatness of a pavement. Firstly, the flatness can be detected by a ruler, and the measurement is taken at the seam position. The position where the measurement is taken should be strategically determined. Under normal circumstances, the wheel marks on the side of the roadway can be used as the test point. If ruts have formed on the road, the middle position of the ruts can be used for measurements, and the debris and gravel on the road surface should be cleaned before the test. Test points of the straightedge should be set along the longitudinal direction of the road structure, and maximum distance of the gap between the bottom position of the straightedge and the is determined by eye <sup>[5]</sup>. A feeler gauge is placed in between the gap to measure its length. The second method is by using a profilometer. The profilometer is placed at the starting position of the road surface, and the wheel of profilometer is placed along the wheel track. The profilometer is then towed using a tractor, which is operated in strict accordance with the specifications. The tractor is then driven longitudinally along the road to maintain lateral stability. The status of the profilometer is then checked, and the tractor should be driven at a uniform speed. The optimal speed is 5 km/h, and the maximum speed cannot exceed 20 km/h <sup>[6]</sup>. The last method for measuring the flatness of the pavement is

a bump integrator. Before the test starts, the test speed should be set, and the device should be preheated. The test vehicle needs to stop at a position 300 to 500 meters before the starting point to ensure the warm-up distance. The parameters of the flatness test can then be set on the device. Before entering the test road section, vehicle should be driven at a constant speed, and the system record is turned after entering the test section. During the test, it is necessary to record the starting and ending positions of the tested road, as well as any special positions that need to be recorded in the system. After the test is completed, the vehicle leaves the test site to stop data recording. The data obtained should be checked immediately to ensure the scientificity of the results. If the data obtained is incomplete, a second test will be required.

### **3.6. Asphalt pavement water seepage detection**

The main materials used in highway asphalt pavement construction are asphalt mixture, sand, and gravel, and gaps are prone to appear between these materials. In heavy rain, the asphalt pavement will be soaked for a long time<sup>[7]</sup>; or if snow and water puddles cannot be cleaned up in time, the quality of asphalt pavement might be affected. Therefore, it is necessary to pay more attention to the water seepage detection of asphalt pavement construction. The permeability coefficient of asphalt pavement must be kept below 300 mL. If the test result largely deviates from the standard value, it means that the water permeability of the road surface is not ideal and corresponding improvement measures are needed.

## **4. Application of on-site testing technology for asphalt pavement construction in highway engineering**

### **4.1. Building a scientific quality inspection system**

A complete testing system needs to be used as a reference in the application of on-site testing technology for highway asphalt pavement construction. From material procurement, proportioning, to pavement strength and compaction testing after completion, relevant operations must be carried out in strict accordance with the testing system<sup>[8]</sup>. Quality inspection should be carried out in strict accordance with the requirements of the design drawings; the construction standards should be determined before the inspection; the material selection standards and road paving thickness requirements should be determined; and the construction progress should be controlled to carry out inspection works. Many mechanical equipment are needed in the construction of a highway. A proper quality inspection system acts as a guide for the scientific application of equipment, ensures the accuracy of the inspection, and helps in maintaining the equipment. The quality of asphalt pavement is directly related to its construction procedures and preparations. In order to promote the development of highway construction quality inspection system, the designation of tasks of construction personnel should be clearly defined. Before the construction begins, the construction personnel should be trained to perform the operations required<sup>[9]</sup>. Quality inspection should then be carried out according to the construction progress, and relevant improvements should be made to areas that are lacking in quality. After the construction is completed, the technical issues and contents of the construction should be discussed to ensure the scientific application of construction technology and the effective implementation of the construction quality inspection system in future projects.

### **4.2. Improving the technical skills of the inspection team**

The quality inspection of asphalt pavement is particularly important for quality control and also the overall highway construction and maintenance. At present, the number of kilometers of highways in our country continues to increase, and the scale of construction is also expanding. Construction personnel and inspectors are the key to ensure construction quality. Construction personnel needs to perform material inspection and proportioning before construction, temperature measurement during construction, and many more. If the inspectors or technicians are not capable in performing their tasks or lack understanding of the equipment, the quality of the final product will be affected<sup>[10]</sup>. Therefore, it is necessary to strengthen the training of

inspectors and ensure that all personnel have a rigorous working attitude, a strong theoretical and practical foundation, so as to ensure the scientificity of the road test and the accuracy of the data.

## 5. Conclusion

In short, the application of on-site test and detection technology for asphalt pavement construction in highway engineering can effectively improve construction quality and ensure construction safety. In the construction of asphalt pavement, it is necessary to ensure the scientificity of construction materials through material test and proportion test to ensure the quality of the mixture during the construction. At the same time, the key components of the construction must be well inspected to ensure the smoothness and compactness of the road, so as to meet the driving requirements of road vehicles and prevent accidents. It is necessary to continuously introduce new technology into asphalt pavement testing to optimize the convenience, efficiency, and economy of the testing method, and rectify road construction problems in time.

## Disclosure statement

The authors declare no conflict of interest.

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# Comparative Analysis of Application of Seismic Wave Reflection Method in Advanced Geological Prediction

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**Abstract:** Seismic wave reflection method is an advanced geophysical detection method in tunnel geological prediction. It is more sensitive and effective in detecting geological anomalies such as fault fracture zone and karst. In order to verify the prediction efficacy and accuracy of the seismic wave reflection method with different instruments and equipment (tunnel geological prediction [TGP]/tunnel seismic prediction [TSP]) and different vibration modes (hammering, explosives), a comparison test was carried out in Jinping Tunnel. The test results showed that the time-consumption of the hammering source was short, which can greatly reduce the impact on the construction site; different vibration sources methods of seismic wave reflection can predict the unfavorable geological sections accurately.

**Keywords:** Seismic wave reflection method; Vibration source; TSP; TGP

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## 1. Introduction

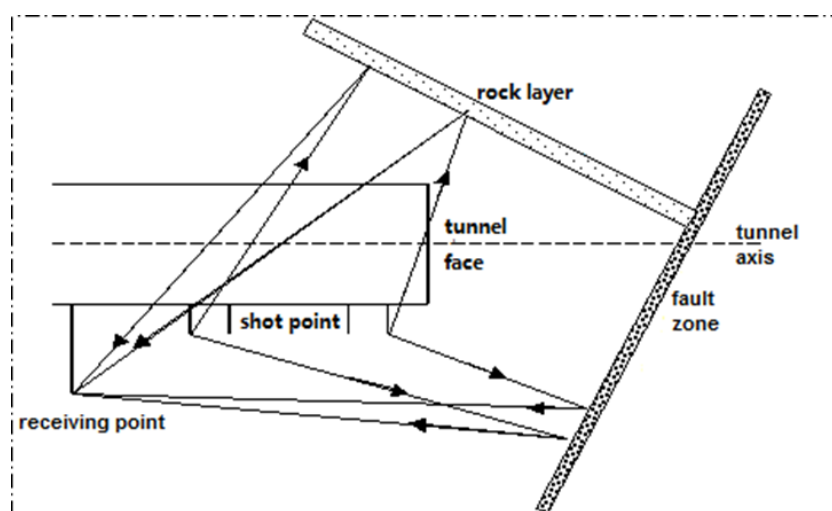
In recent years, highway tunnel construction has developed rapidly. As a concealed project, tunnel construction is complex and unpredictable, and often encounters areas with complex geological conditions, especially tunnel sites passing through hollow areas, fault structural zones, karst developed areas and dangerous areas with high gas concentration often cause geological disasters such as landslides, mud gushes, and gas explosions during construction. Carrying out advanced geological prediction of tunnels can timely detect the location, type, and possible risks of unfavorable geological bodies in front of the tunnel face. It can prevent possible geological disasters such as tunnel collapse, water gushing, mud inrush and gas explosion. At the same time, through advanced geological prediction, it is possible to grasp the geological structure conditions and surrounding rock grade types within a short distance in front of the tunnel face, and provide a more scientific basis for the construction unit to select excavation methods and support parameter types. To sum up, advanced geological prediction of tunnels has significant economic and social benefits as it increases construction efficiency, reduces construction period, ensures safe and scientific construction, and reduces construction accident losses.

There are many advanced geological prediction methods, which can be mainly divided into three categories: traditional geological analysis method, direct drilling method of face drilling and more advanced geophysical detection method [1-3]. Geophysical advanced geological prediction methods can be divided into long-range prediction and short-range prediction according to different prediction distances. In long-

distance forecast, the geological conditions at a distance of 100–200 m in front of the tunnel face is forecasted mainly through elastic wave reflection. By analyzing the kinematics and dynamics characteristics of the reflected wave received by the geophone and obtaining the imaging information of the rock mass structure, the geological conditions in front of the tunnel can be predicted <sup>[4]</sup>. According to the observation system layout, data processing method, excitation method, etc. <sup>[5]</sup>, seismic wave reflection method can be divided into tunnel seismic prediction (TSP) and tunnel geological prediction (TGP); land sonar two-dimensional advanced prediction such as the negative apparent velocity method and the tunnel seismic wave reflection tomography (TRT), tunnel seismic tomography (TST), horizontal sound probing (HSP), and underground seismic prediction system (USP) <sup>[6]</sup>; tunnel seismic detection system (TSD), and other advanced prediction methods of space observation methods. The seismic wave reflection method has a long prediction distance and has a better prediction effect on planar structures with different mechanical properties. Therefore, it has been widely used in the advance geological prediction of road tunnels <sup>[7]</sup>.

## 2. Principle of seismic wave reflection method

The seismic wave signal generated by hammering or small-dose blasting at a specific position in the tunnel propagates in the form of spherical waves along the direction of the tunnel; the seismic wave propagates at different speeds in different rock formations. Seismic waves are generated at different locations by exciting multiple source points. These source points are distributed at specific locations in the tunnel. When the seismic waves encounter abnormal bodies (broken zones, faults, cavities, and many more) in front of the tunnel, the waves will then be reflected to the sensor. The three-axis high-sensitivity sensor will receive the reflected waves (X, Y, Z) from different directions of the abnormal body, so as to obtain a large number of three-dimensional data sets (**Figure 1**). According to the location of the sensor distribution, the propagation direction of the reflected wave of the abnormal body is different from the angle of the sensor at different positions. By calculating the angle and wave velocity of each reflected wave, we can obtain the three-dimensional space position of the abnormal body.



**Figure 1.** Schematic diagram of the principle of seismic wave reflection method

## 3. Comparative analysis of application effect

### 3.1. Instrument efficacy analysis

G4216 Yanjiang Expressway is the largest single-invested expressway in China. The bridge-tunnel ratio of the Yibin-Jinyang section is as high as 92%, of which the tunnel accounts for 70%. The nature of the tunnel is complex and vulnerable, and the unfavorable geological conditions of the cave body are unfavorable, and it is facing a relatively large construction risk. Therefore, the safety and progress of the Yanjiang high-

speed tunnel project are the key to the construction of the expressway. Advanced geological prediction of the tunnel is the most important means of information construction, which provides the basis for the dynamic design and safe construction of the tunnel. In order to compare the efficacy and accuracy of long-distance prediction by seismic wave reflection method, the Chief Engineering Office of Yanjiang Yijin Company established relevant third-party testing units and instruments to conduct comparison tests in the left tunnel of XJ8 Jinping Tunnel. The main instruments and equipment and observation methods are shown in **Table 1**. Four sets of seismic wave reflection instruments were used for the test, two sets of TGP206G instruments were excited by explosive vibration sources; two sets of TSP (YWZ11-Z/305plus) instruments were excited by a hammering vibration source.

**Table 1.** Instrument and equipment layout and efficiency comparison table

Serial number	Instrument	Observation method	Vibration source	Excitation points	Receiving point	Duration forecast
1	TGP206G-1	Side wall line	Dynamite	24	2	<ul style="list-style-type: none"> <li>• 1 hour for 4 drilling rigs/4 workers to complete the drilling of the blasthole.</li> <li>• 5 minutes for 1 blasthole to charge the data.</li> <li>• 120 minutes/2 hours for 24 blastholes.</li> </ul> Total time spent: approximately 3 hours
2	TGP206G-2	Side wall line	Dynamite	24	2	<ul style="list-style-type: none"> <li>• 1 hour for 4 drilling rigs/4 workers to complete the drilling of the blasthole.</li> <li>• 5 minutes for 1 blasthole to charge the data.</li> <li>• 120 minutes/2 hours for 24 blastholes</li> </ul> Total time spent: approximately 3 hours
3	T SP YWZ11-Z	Side wall line	Hammering	24	2	<ul style="list-style-type: none"> <li>• Acquisition array layout and instrument connection time is 10 minutes.</li> <li>• Acquisition parameter setting and trial acquisition time is 2 minutes.</li> <li>• Data acquisition time is 14 minutes.</li> <li>• 4 minutes to pack up the instrument and equipment</li> </ul> Total time spent: 30 minutes/half an hour

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Serial number	Instrument	Observation method	Vibration source	Excitation points	Receiving point	Duration forecast
4	TSP305plus	Side wall line	Hammering	24	2	<ul style="list-style-type: none"> <li>• 10 minutes for geological observation, layout of measuring points, and instrument connection</li> <li>• 3 minutes for turning on the equipment and parameter setting,</li> <li>• 15 minutes for data collection</li> <li>• 5 minutes for confirming data and sorting out equipment</li> </ul> Total time spent: 33 minutes

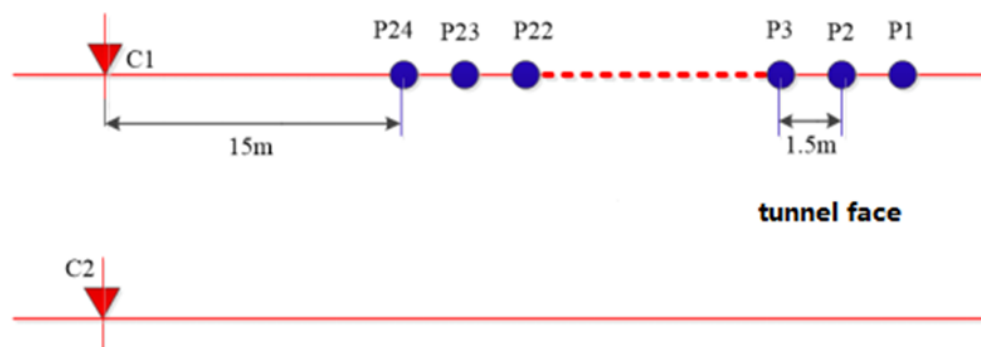


Figure 2. TGP on-site detection layout

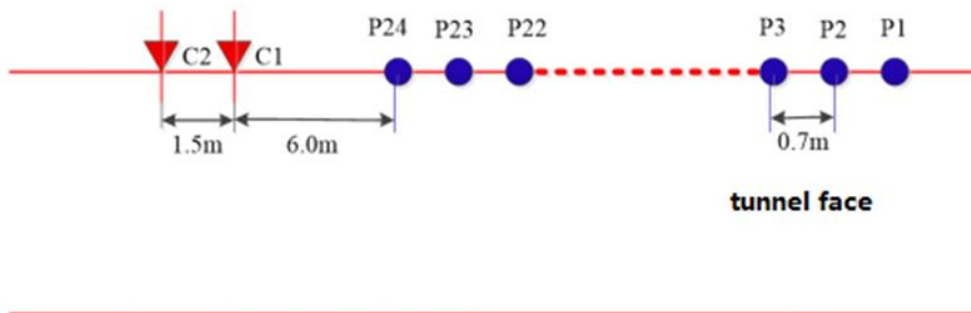


Figure 3. On-site detection layout of TSP seismic wave reflection method

The TGP measuring line was laid on the left side wall of the tunnel face, about 1.5m above the ground, and a total of 24 blastholes were arranged 1.5 m away from each other to stimulate P1–P24; two receiving points C1 and C2 were located on the left and right side walls, respectively; the offset distance was 15 m (Figure 2), and the prediction distance was 150 m. The TSP measuring line was laid on the left side wall of the tunnel face, about 1.5 m above the ground, with a total of 24 hammering points P1–P24, with a distance of 0.7 m between each point; two receiving points; C1 and C2, with a distance of 1.5 m between each other, and the moving distance was 6 m (Figure 3); and the prediction distance was 100 m.

Advance geological prediction by seismic wave reflection method is a comprehensive technical work,



in which the source is an important link, and the signal acquisition quality and detection distance are all restricted by the source [8]. At present, the seismic sources used in advanced prediction at home and abroad are mainly divided into two categories: one is the expansion point source, such as explosives and spark sources; the other is the surface impact source, such as hammering, controlled shock source, and many more [9]. The maximum energy that can be excited and generated of different sources in order from strong to weak are explosive sources > electric spark sources > vibrators > hammering; in which the order would be reversed in terms of convenience of use. Explosive sources are the most frequently used, and the development and application of many advanced geological prediction technologies based on seismic wave methods are based on them, but they are strictly controlled and have great limitations. The comparison test of the seismic wave reflection method used explosive sources and the hammering sources respectively. Affected by the control of explosives, the source of explosives has been gradually replaced by digital electronic detonators from traditional electric detonators. In the advanced geological prediction of the TGP seismic wave reflection method, it is necessary to scan codes one by one to activate blastholes, which takes a long time. It can be seen from **Table 1** that it takes about 3 hours for the advanced geological prediction of the TGP explosive seismic source from the layout and drilling to the data acquisition, whereas it only takes 30 minutes from the layout of the collection array to the data collection for the advanced geological prediction using TSP hammering source. Therefore, seismic wave reflection method using hammering source is better than explosive source in terms of efficacy.

### 3.2. Comparative analysis of prediction results

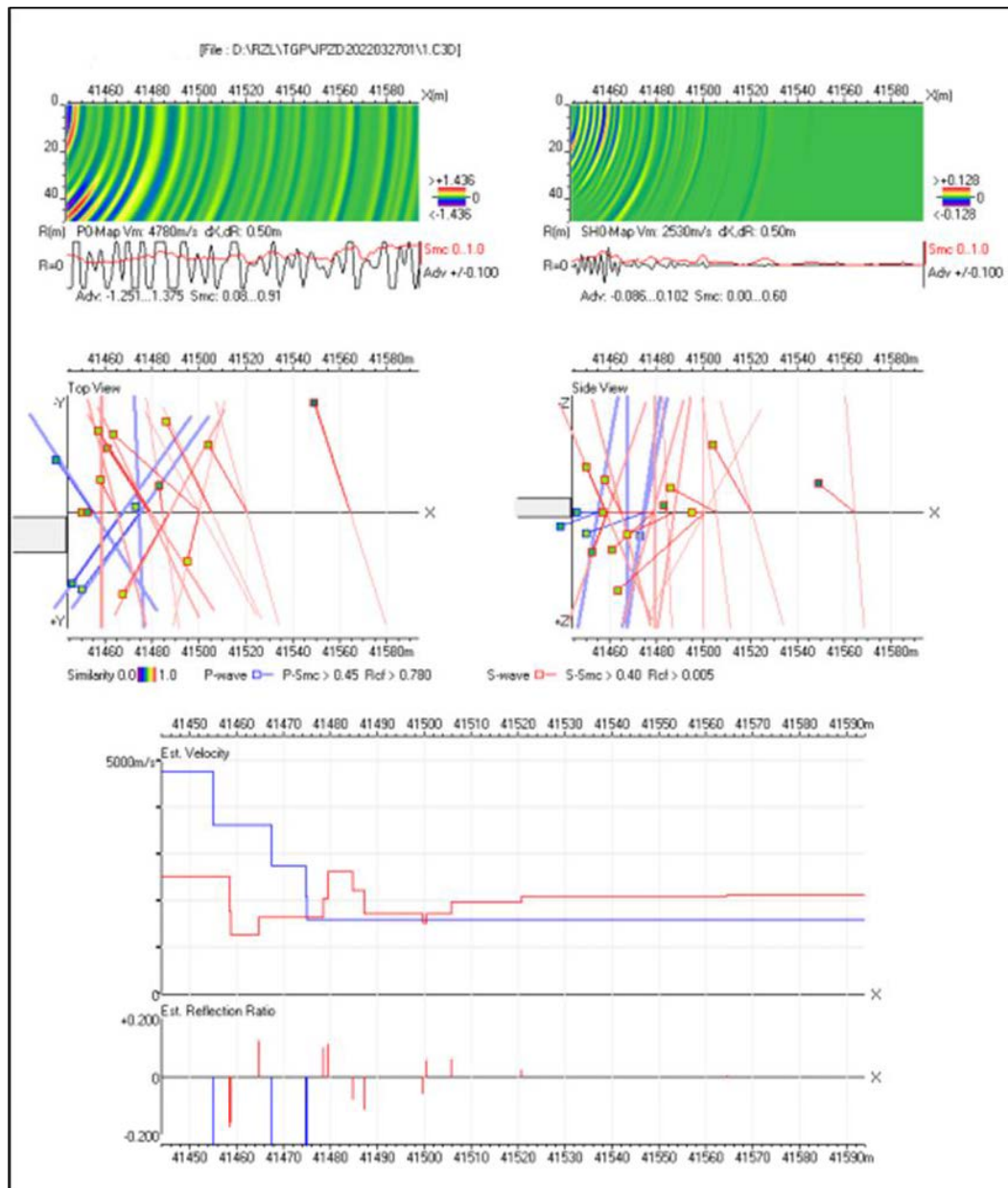
This prediction comparison test was carried out in the left tunnel of XJ8 Jinping Tunnel, the pile number of the tunnel face is ZK41+444, and full-section excavation was carried out. The surrounding rock of the tunnel face was mainly blue-gray limestone, with a gently dipping, nearly horizontal layered, thin-to-medium-thick layered structure, and the weathered surface was light grayish white, mainly moderately weathered. Based on the hammering sound and rebound, the harder rock has more well-developed joints and fissures, which are mainly structural and weathered types, and the width of the fissures is mainly micro-extensive, mostly filled with mud, and the interlayer bonding force and stability are poor; the surrounding rocks were generally broken, showing massive to sub-massive structure. Moreover, the arch and the surrounding rock of the vault were easy to fall off or collapse, underground fissure water had been developed, the tunnel face was wet, and the vault top was sporadically dripping. The grade of the surrounding rock was evaluated comprehensively on site to be grade IV (**Figure 4**).



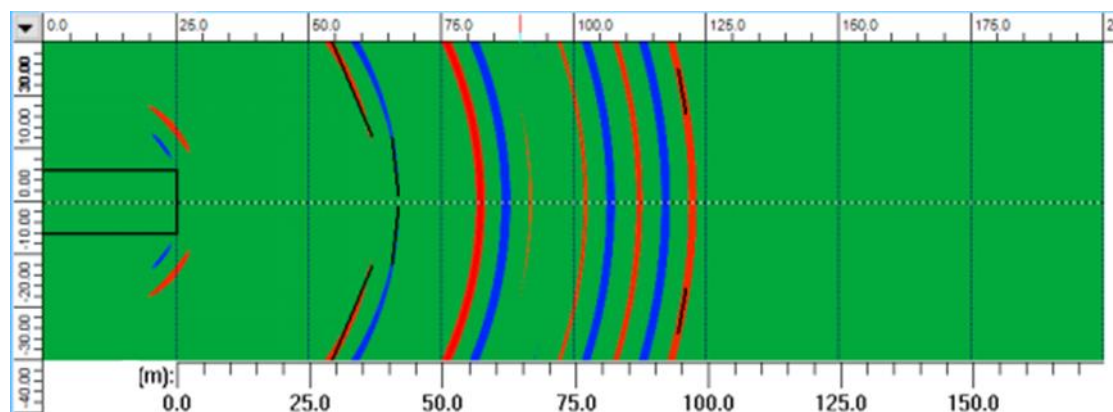
**Figure 4.** Photos of the surrounding rock conditions of ZK41+444 tunnel face

TGP206G explosive source and the TSP hammering source were used respectively to carry out advanced geological prediction work on the tunnel face ZK41+444. Through data processing, the main

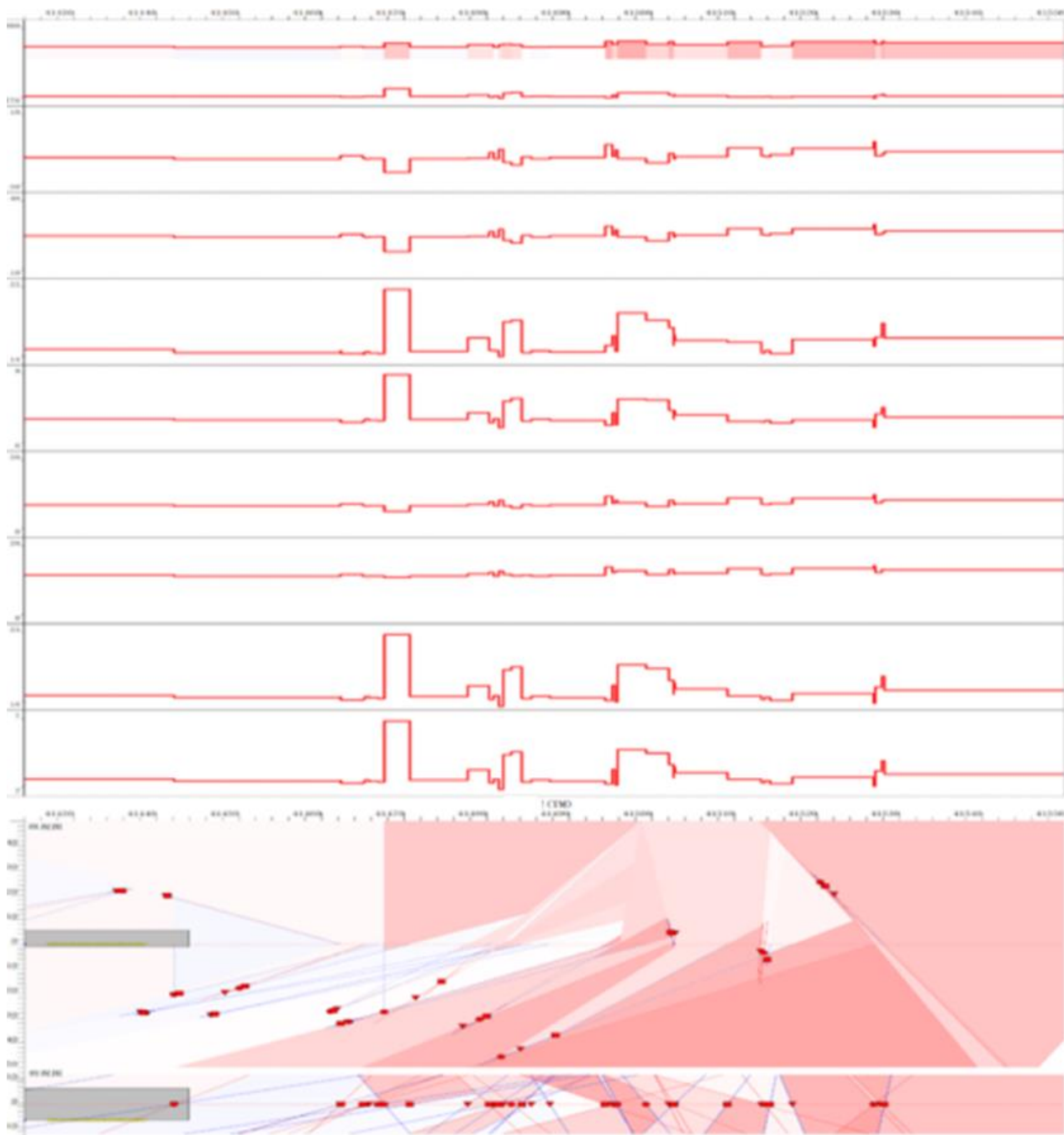
results are shown in **Figures 5–7**.



**Figure 5.** Reflection interface diagram of TGP ipsilateral diffraction migration imaging (TGP206G)



**Figure 6.** TSP method P-wave reflection interface display forecast map (YWZ11-Z)



**Figure 7.** TSP method reflection horizon and physical and mechanical parameters result map (TSP305 PLUS)

The main forecast conclusions are shown in **Table 2**.

**Table 2.** Statistics table of TSP advanced geological prediction results

Serial number	Instruments/sources used	Forecast range and length	Forecast conclusion	Unfavorable geological body range
1	TGP206G/Dynamite	ZK41+444–ZK41+544	Grade IV surrounding rock	<ul style="list-style-type: none"> <li>There was a weak interface near ZK41+464, ZK41+477–ZK41+487, multiple weak interfaces near ZK41+510–ZK41+528, and a weak interface near ZK41+540. It was speculated that the rock mass in this mileage segment was broken and developed fissures or dissolved cavities. There may be seepage of dissolved water, local strands of water may flow out, poor interlayer bonding.</li> </ul>
2	TGP206G/Dynamite	ZK41+444–ZK41+544	Grade IV surrounding rock	<ul style="list-style-type: none"> <li>In the mileage section ZK41+455–ZK41+470, there were locally developed dissolved fracture zones, weak interlayers and dissolved pipes on the right middle side, and the cracks and interlayers were mostly filled with mud and sand.</li> <li>In the mileage section ZK41+474–ZK41+480, there were dense cracked broken zones locally on the right-middle side.</li> <li>In the mileage section ZK41+485–ZK41+510, there were locally dissolved broken cracked zones, dissolved pipes, or dissolved cavities developed on the right middle side, and the cracks and interlayers were mostly filled with mud and sand, the groundwater is relatively developed, and the local karst pipeline water is exposed. Therefore, during the excavation process, it was necessary to pay attention to the impact of ZK41+467, ZK41+487, ZK41+499, ZK41+508 anomalies on the tunnel.</li> <li>The ZK41+516–ZK41+528 mileage section had locally developed dissolved cracks and broken zones, and local weak interlayers, it was inferred that in the ZK41+560–ZK41+572 mileage section, there were locally developed dissolved cracks and broken zones, and local weak interlayers.</li> </ul>

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Serial number	Instruments/sources used	Forecast range and length	Forecast conclusion	Unfavorable geological body range
3	TSP YWZ11-Z /hammering	ZK41+444– ZK41+544	Grade IV surrounding rock	<ul style="list-style-type: none"> <li>In the vicinity of ZK41+482, ZK41+486, ZK41+498, and ZK41+508, the joints and fissures in the ZK41+519–ZK41+541 section were relatively developed, with some areas having densely developed joint and fissures or interbed with weak interlayers. The surrounding rocks were relatively broken, and karst was relatively developed. Dissolved structures such as dissolved pores, dissolved pipes, and caves had developed. Groundwater had developed, showing seepage or strands.</li> </ul>
4	TSP305PLUS/hammering	ZK41+444– ZK41+544	Grade IV surrounding rock	<ul style="list-style-type: none"> <li>ZK41+465–ZK41+471, ZK41+477–ZK41+486 sections had strong reflective surfaces, and it was speculated that dissolved fissures, pipes, or joint fissures had densely developed. Groundwater had developed in the sections, and strands of water may occur nearby. ZK41+494–ZK41+503, ZK41+509–ZK41+518, ZK41+526–ZK41+530 may have had dense joint fissures or dissolved fissures and pipelines.</li> </ul>

Geological sketches of the face of ZK41+444–ZK41+544 were drawn by professional geologists. According to the sketches of the face of the site, the surrounding rocks of ZK41+444–ZK41+544 were mainly limestones. The rocks were mostly hard rocks that were thin to medium-thick, with broken rock mass, well-developed joints and fissures, local mud inclusions in the fissures, and poor bonding between structures, which make them Grade IV. The differences between the sketches were the degree of fragmentation of the surrounding rock and the development of underground fissure water. The situation of the surrounding rocks at section ZK41+444–ZK41+516 was similar. After ZK41+516, the surrounding rock became thin layered, and the overall integrity became poor. At the same time, ZK41+477 began to develop fissure water, at ZK41+497–ZK41+533, it became drizzling water, and there was no crack water after ZK41+533.

**Table 3.** Comparison table of forecast and excavation of ZK41+444, ZK41+477, ZK41+497, ZK41+516, ZK41+533

Excavation results	No obvious geological anomalies	Fissure water	Drizzling water	Drizzling water with thin surrounding rocks	Thin surrounding rocks
1	It was predicted that there was no abnormality in this section.	ZK41+477–ZK41+487 had strongly reflective interface, which meant that the surrounding rocks were broken, and there might be water seepage from the cracks.	There were multiple weak interfaces in ZK41+510–ZK41+528, which meant that rock mass was broken, and there might be strands of water gushing out.	There were multiple weak interfaces in ZK41+510–ZK41+528, which meant that the rock mass was broken, and there might be strands of water gushing out.	The surrounding rocks were broken.
Consistency analysis	Unanimous	Unanimous	Similar	Similar	Unanimous
Accuracy	77%				
2	From ZK41+455 to ZK41+470, there were locally developed fracture zones, weak interlayers, and dissolved pipes on the right middle side, and the gaps and interlayers were mostly refilled with mud and sand.	ZK41+474–ZK41+480 had developed dense fracture zone.	In the right middle part of ZK41+485–ZK41+510, there were dissolved fracture zones, corrosion pipes or dissolved cavities, most of the fissures and interlayers were refilled with mud and sand; groundwater had developed, and water in local karst pipes was exposed.	ZK41+516–ZK41+528 mileage section had locally developed dissolved fracture zone, partially interbedded with weak interlayers.	The surrounding rocks were broken.
Consistency analysis	Unanimous	Similar	Different	Similar	Unanimous
Accuracy	80 %				

*(Continued on next page)*

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Excavation results	No obvious geological anomalies	Fissure water	Drizzling water	Drizzling water with thin surrounding rocks	Thin surrounding rocks
3	The hardness of the surrounding rock is basically the same as that of the tunnel face, the rock mass is relatively complete, the joints and fissures are well developed, the bonding degree of the structural plane is average, and the stability is poor	ZK41+482, ZK41+486, ZK41+498 strong reflection interface, surrounding rock broken, groundwater developed	Strong reflection interface of ZK41+498 and ZK41+508, development of dissolved fracture zone and development of groundwater	There were joints and fissures in ZK41+519–ZK41+541, where some areas had dense ones.	There were joints and fissures in ZK41+519–ZK41+541, where some areas had dense ones.
Consistency analysis	Unanimous	Similar	Different	Similar	Unanimous
Accuracy	79%				
4	The hardness of the surrounding rocks was basically the same as that of the tunnel face, the rock mass was relatively complete, the joints and fissures were well developed, the bonding between the structural planes was average, and the stability is poor	ZK41+472–ZK41+486 had a strong reflective surface, it was speculated that there might be a dense zone of dissolved fissures, pipes or joint fissures, and groundwater had developed in that area	ZK41+486–ZK41+503 might have dissolved fractures, karst, and well-developed groundwater	ZK41+503–ZK41+521 might have weak interlayers or dissolved fracture zones. There might be rain strands of water on the face after excavation	The surrounding rocks were broken.
Consistency analysis	Unanimous	Different	Similar	Similar	Unanimous
Accuracy	75%				



The comparison between forecast results and excavation results is shown in **Table 3**. The advanced geological prediction by seismic wave reflection method carried out using different sources, instruments, and equipment all predicted the surrounding rock 100 m in front of the tunnel face to be Grade IV, which was basically consistent with the geological conditions of the site excavation. The seismic wave reflection method of different instruments and equipment all predict that the ZK41+516–ZK41+533 section has developed fissure water and the surrounding rock was broken. The accuracy of the prediction was above 70%. The main reasons for the discrepancy with the actual excavation are explained below.

(1) Selection of direct wave velocity

In the seismic wave reflection method, the direct wave is received before the reflected wave. For the initial value picking, different personal understandings and selection points will result in different velocity values. The difference in the selection of the direct wave speed will lead to differences in the final results, which will affect the accuracy of the conclusion.

(2) Selection of band-pass filter parameters

Improper selection of band-pass filters will often cause loss of valuable waveform signals, or selection of clutter interference within 300 ms. This requires experience and understanding of the site, and a summary and analysis of the filter selection methods for different strata and different lithologies in order to make a breakthrough.

(3) Selection of forecast distance

Assuming that the data collected were valid, with the same initial value and band-pass filter parameters, different forecast distances were selected for the same data, and comparisons and inferences were made through verification and comparison from multiple excavations. As the forecast distance increases, the forecast accuracy rate decreases linearly <sup>[10]</sup>. The empirical forecast distance is roughly 100 m for the geologically complex section; the forecast distance for the normal section is between 120 and 180 m.

(4) The impact of excavation footage

The left hole ZK41+444–ZK41+544 of the Jinping Tunnel in the predicted section underwent full-face excavation, and the single-cycle footage was relatively large, so it was difficult to fully reveal the predicted anomalies such as small, dissolved channels, and there were certain differences between the excavation and forecast results.

#### 4. Conclusion

- (1) The hammering source seismic wave reflection method is superior to the explosive source in terms of efficacy, 2.5 hours can be saved in one forecast, which greatly reduces the impact on construction.
- (2) In this test, the seismic wave reflection method using different instruments and shock modes can predict the subsurface section of ZK41+516 to ZK41+533 in the left tunnel of Jinping Tunnel more accurately, where underground fissure water had developed and the surrounding rock was broken. The seismic wave reflection method is sensitive to geological anomalies with differences in elastic wave impedance and has a good detection effect on unfavorable geological factors that affect the integrity of surrounding rocks (joint fissure development, faults and fracture zones, karst, alteration, and many more).
- (3) Although the hammering source is a widely used non-explosive source, its characteristics of weak energy, instability, uncontrollability and poor anti-interference ability should also be considered.
- (4) Affected by the subjective factors of the geological description of the tunnel face, the excavation of the surrounding rock was not very accurate, and there were no major adverse geological phenomena in the forecast section. Therefore, more research and improvements need to be done. On one hand, professional geologists need to conduct macroscopic geological understanding analysis; on the other hand, it is also necessary for geophysical exploration personnel with theoretical knowledge and field



experience to carry out geophysical exploration interpretation, eliminate interference anomalies and multiple solutions, and carry out advanced geological prediction truthfully and objectively.

- (5) The single geophysical prospecting method utilizes the characteristics of geological body for advanced geological prediction. For example, the seismic wave reflection method uses the difference in wave impedance of the surrounding rock; the geological radar uses the difference in the dielectric constant of the surrounding rock; and the transient electromagnetic method uses difference in the surrounding rock. These methods have their limitations with solutions to them. The comprehensive overdue geological prediction method of geological analysis, geophysical prospecting, and drilling should be used for prediction to improve the accuracy of the forecast and ensure safe construction of the tunnel project.

### Disclosure statement

The authors declare no conflict of interest.

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# Weight Analysis of the Influencing Factors of Homestay Competitiveness in Rural Guangzhou, China

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**Abstract:** At present, Guangzhou homestay industry is facing a bottleneck. Therefore, it is particularly important to analyze the factors that influence the competitiveness of rural homestays in Guangzhou, determine the evaluation system of competitiveness, and determine the weight of each factor. Based on Porter's diamond theory, this paper analyzes and summarizes the influencing factors of homestay competitiveness, and divides the influencing factors into 5 primary factors and 34 secondary factors. The analytic hierarchy process (AHP) was used to determine the judgment matrix to form the weight results of each factor, and the results show that product characteristics account for the largest proportion among first level factors. Secondary factors such as theme creativity, personalized brand and the overall score account for a large proportion. The research results can act as a reference for the construction of competitiveness evaluation mechanism and model of local rural quality homestays.

**Keywords:** Homestay competitiveness; Influencing factors; Weight analysis

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## 1. Introduction

Globalization has enhanced global knowledge of the natural wonders and manufactured attractions found in various countries. Indeed, in the last few years, an increasing number of travelers have sought out novel and exciting destinations, such as natural tourism attractions <sup>[1]</sup>. However, the COVID-19 pandemic has had a detrimental effect on service sectors worldwide, most notably the tourism sector <sup>[2]</sup>, as travelers' trust in destinations' response to pandemic dangers has been eroded <sup>[3]</sup>. According to the World Tourism Organization, over 900 million tourists visit major rural destinations each year, implying that homestay tourism could help a place remain competitive during and after the epidemic <sup>[4]</sup>.

## 2. Current situation of rural homestays in Guangzhou

With the growth of China's economy and the improvement of the people's living conditions, the tourism business in China has exploded, and an increasing number of individuals have embraced the homestay tourism concept. To further encourage homestay tourism, Guangzhou has developed programs such as "Beautiful Village" and "Rural Revitalization Strategy." In 2019, China's homestay market was worth 20 billion yuan, and as of September 30, 2019, there are 169,800 homestays in mainland China <sup>[5]</sup>.

Guangdong Province's homestay industry benefits from the province's economic strength, the large

population of boutique tourism consumers, and the local government's homestay policies. According to the "2018 National Homestay Industry Development Research Report," the number of homestays in Guangdong Province increased to 18,441 as of December 23, 2018, ranking first among all Chinese provinces, indicating rapid growth. With the construction of regional tourism and the Guangdong-Hong Kong-Macao Greater Bay Area, the Guangdong homestay industry will continue to grow in lockstep with the province's tourism economy <sup>[6]</sup>.

Notably, this study's sample includes Guangzhou homestays. As of February 2019, homestays are concentrated primarily in the Pearl River Delta economic zone of Guangdong Province's 21 cities. With 6,712 homestays, Guangzhou is the city with the most. According to statistics, Guangdong province has a proportion of luxury homestays, boutique homestays (including inns), and standard homestays (including inns) of 24.9%, 18.1%, and 57%, respectively. Compared to the total number of Guangdong homestays, the number of boutique homestay brands that generate word-of-mouth is significantly less <sup>[7]</sup>.

As the focal point of rural tourism and a novel business model for cultural tourism integration, homestays have garnered increasing attention and demand from the government, academics, capital, and variety shows. Consumers gradually recognized this, and it developed into a strong trend of brand chain clustering within a specific range. However, with the growth of homestay brands, the need for consumption upgrading, and the government's standardized management, the homestay industry is about to undergo a reshuffle, with those lacking in quality homestays being gradually phased out by the market. As a result, it is critical to conduct research on homestay tourism's competitiveness.

### **3. Problems faced by rural homestays in Guangzhou**

With the continuous development of the homestay industry, affected by internal competition, the increase of operating costs, demand upgrading and other pressures, as well as the market continues to mature, the original decentralized, small-scale extensive homestay business model, gradually transformed into a brand, chain, characteristic based quality homestay model. However, most domestic and foreign research on homestay tourism focuses on motivation, decision-making, and satisfaction of tourists choosing homestay from the perspective of homestay tourists <sup>[8]</sup>. Moreover, much research has been done on the competitiveness of tourist destinations, but not much on the competitiveness of homestay. At present, the theoretical analysis of the competitiveness of the development of homestay in a certain area becomes a mere formality. The general method of research is to interpret the concept and characteristics of homestay, analyze the status quo and development conditions, and put forward suggestions <sup>[9]</sup>. The management path to effectively enhance the competitiveness of homestay has not been explored <sup>[10]</sup>. There are various factors affecting the competitiveness of homestay. Considering the current situation of homestay in Guangzhou, the main problems are explained below.

#### **3.1. Environmental choice**

People who have lived in cities for a long time have a keen interest in natural beauty and country life. It is critical for consumers to choose a homestay that they can physically and mentally liberate themselves from the shackles of daily life. Air quality, the beauty of the natural landscape, the diversity of plants, and the distinctiveness of local conditions and customs have all become critical components for people to enjoy varied lifestyles. "The brimming waves delight the eyes on sunny days, and the dimming hills present rare view in a rainy haze" is the homestay's primary selling point <sup>[11]</sup>. Location is the most critical factor affecting the operation of homestay. Environmental elements affecting homestays with tourist and lodging characteristics, such as the natural environment, cultural environment, and manufactured environment, all contribute to the growth of homestays <sup>[12]</sup>. The environmental factors surrounding the homestay are not replicable. In other words, moving a homestay in the old town of Lijiang to a town in front of your house

may not have the same economic effect. Homestays with a good environment will attract more consumers and have greater competitiveness. For example, in the analysis of the competitiveness of homestays in different areas of Gulangyu, Xiamen, the homestays with better external environmental conditions and commercial services, and more scenic spots around have more obvious competitive advantages. Thus, this study aims to find out how the environment affects the competitiveness of rural homestay tourism.

### **3.2. Operators' quality**

According to McIntosh and Siggs, a homely feeling is a critical component of homestay, which is founded on emotions, personal touch, and hospitality <sup>[13]</sup>. Homestays is different from traditional hotels, restaurants, and guesthouses, in which they provide tourists with more “home” comfort and freedom. As the homestay is set up directly in the operator's home, it is more like visiting the host's home than staying in a particular type of hotel. Tourists can eat and live together with the host, have sufficient time and opportunity to communicate and interact, and even participate in the production and daily activities of the host family, which can shorten the psychological distance between each other and build interpersonal relationships. This is an excellent opportunity for visitors to immerse themselves in local life, a feature that no other hotel or lodge has. Besides, Lowe emphasizes that participation of operators' houses and a homey ambiance for tourists is an inherent aspect of homestay <sup>[14]</sup>. According to Marcus, a home is a reflection of its owner's personality, lifestyle, cultural values, social standards, religious views, and historical background <sup>[15]</sup>. The overall quality of Chinese operators is not high, and the general reception and service level needs to be improved. While the number of homestays in China has increased, most of them are developed by the local people that have low level of education and have not undergone professional business training. As a result, they are lacking in aspects like management and business thinking; the operator operates solely on their own subjective consciousness, only care about their own operating conditions, and ignore the overall economic environment, and they lack scientific management systems and methods. Hence, this study intends to find out how operator considerations affect the rural homestay tourist industry's competitiveness.

### **3.3. Lack of unique characteristics**

In China, the development of homestay products has progressed from an exploratory stage to the point of severe uniformity and little innovation <sup>[16]</sup>. “A high volume of assimilations” generates aesthetic fatigue in consumers, and homestays with the same style become unappealing. Diversification and creativity are critical components of homestay development. Only when the surroundings and cultural ambiance are coherent can a homestay develop its own distinct personality and qualities that will entice tourists <sup>[17]</sup>. Therefore, this study intends to find out how product characteristics affect the rural homestay tourism industry's competitiveness.

### **3.4. New marketing strategies**

Rural homestay tourism has gradually demonstrated its vitality and attraction in recent years, owing to the vital tourism demand of urban inhabitants to reconnect with nature. However, regardless of their quality, rural homestay tourism products require marketing. Because Internet marketing is a product of the network era, the combination of Internet and rural homestay tourism product marketing represents a new marketing model, paving the way for rural homestay tourism product marketing. This new marketing strategy is based on the Internet as a platform for marketing; it breaks through the traditional marketing model's high production costs and limited visibility, lowering the marketing costs of rural homestay tourism products, increasing their popularity, and ultimately promoting sustainable development of rural homestay tourism <sup>[18]</sup>. That is why this study intends to find out the degree to which marketing strategies influence the competitiveness of rural homestay tourism.

### 3.5. Low customer satisfaction

With the ongoing appearance of new types of homestays and severe competition, it is critical for homestays to maintain and improve customer satisfaction in order to capitalize on market opportunities and sustain competitive advantages. Practitioners should do an in-depth analysis of their existing conditions and work to enhance their competitiveness on all fronts, including customer happiness, which is critical for achieving competitive advantages in homestay<sup>[19]</sup>. In light of China's growing demand for tourism consumption and the low level of tourist satisfaction, it is crucial to explore and analyze consumer assessment and satisfaction in order to increase the competitiveness of boutique homestays in the homestay market<sup>[20]</sup>. Hence, this study intends to find out how customer satisfaction affects the rural homestay tourism industry's competitiveness.

Homestay is a segment of the expanding tourism sector. The market was saturated between 2013 and 2018, and the growth trajectory was short. The homestay business concept is primarily decentralized and small-scale. Internal rivalry, rising operating costs, and demand upgrading can quickly jeopardize the fragile homestay business, and the business model for efficiently boosting competitiveness has yet to be explored. To overcome bottlenecks in the development of the homestay industry, it is necessary to identify competitive advantages through environmental resources and operator characteristics, as well as to promote the competitiveness of homestay individuals and the industry as a whole through the characteristics of homestay and the diversification of publicity means. Simultaneously, the general situation and individual differences in the homestay's competitiveness in different tourist destinations must be thoroughly evaluated to develop reasonable management and optimization plans, and the state of homestay's competitiveness with different level gradients should serve as the foundation and premise for decision-making<sup>[10]</sup>. Thus, there is a relationship between environmental factors, operator consideration, product characteristic, customer satisfaction and marketing strategies, and rural homestay tourism competitiveness.

A few studies examined all the five factors (environmental factors, operator factors, product characteristic, marketing strategies, and customer satisfaction) in one study.

The purpose of this study is to research homestay's competitiveness and to ascertain the impact of five different influencing factors on the competitiveness of boutique rural homestay tourism in Guangzhou. Environmental factors, operator factors, product characteristics, and marketing and customer satisfaction are ideas that helped us in evaluating and establishing a competitive model for boutique rural homestay tourism.

### 4. Influencing factors of homestay competitiveness

There is almost no clear definition of the competitiveness of rural homestay market in domestic and foreign literature. Most of them summarize and analyze the measures to improve the competitiveness of the rural areas based on case studies. As Lin mentioned, in order to enhance the competitiveness of rural tourism market, it is necessary to distinguish the differences between rural tourism in different regions and general tourism<sup>[21]</sup>. The significance of differentiable refers to the significant uniqueness of rural tourism from other forms of business. Once this uniqueness becomes the core competitiveness of rural homestay, it will become the representative and driving force of its sustainable development. Komppula argues that rural homestay enterprises play an extremely important role in the competitiveness of the rural tourism market, and that no tourist destination can thrive without rural entrepreneurs who have the courage to innovate and take risks<sup>[22]</sup>. Yang et al. studied the competitiveness of different types of rural homestay tourism and found that the market competitiveness and strategic development direction of rural homestay tourism in different regions were inconsistent due to the personalized characteristics of each area<sup>[23]</sup>. The relatively simple qualitative description was biased to the theoretical content at the macro level and was not detailed.

In this study, homestay competitiveness refers to the ability of the homestay to stand out despite the

challenges of internal and external factors. External factors include coping with demand changes and uncertain social risks, while internal factors include survival of the fittest among competitors.

Although Porter's diamond model is relatively mature, this model focuses on the macro level, which is suitable for evaluating national competitiveness. Therefore, when determining factors, the macro characteristics of factors are obvious, such as enterprise strategy, structure, and peer competition, which reflects the integration consideration of industrial scale and enterprise scale. However, rural homestay tourism has its own characteristics, and the diamond model needs to be improvised based on the characteristics of rural homestay tourism. Based on Porter diamond model theory, this paper re-deconstructs and improves the five factors that affect the industrial competitiveness and are suitable for the rural homestay tourism market.

#### **4.1. Environmental factors**

Environmental factors have a positive impact on the competitiveness of homestay. The environment plays a significant role in determining the competitiveness of homestays. Chin et al. used the Hannah Rais homestay as a case study to examine the relationship between homestay competitiveness and environmental characteristics. They discovered that the natural and cultural heritage environments contributed to the homestay's competitiveness <sup>[24]</sup>. Additionally, the created environment, such as delectable food resources and rural infrastructure development, would affect the competitiveness of homestay tourist projects <sup>[25]</sup>. Therefore, this study proposes the hypothesis that environmental factors have a significant impact on the competitiveness of homestay.

#### **4.2. Operator factors**

The burgeoning market demand leads individuals with principles and emotions to invest in homestay. There are a variety of investors interested in the homestay market, including owners of traditional industries, teachers, decorators, café proprietors, and travel agency operators, and many others. Since homestay operators serve as both hosts and managers, they themselves contribute significantly to the competitiveness of the homestay industry. Therefore, this study proposed the hypothesis that operator factors have a significant impact on the competitiveness of homestay.

#### **4.3. Product characteristics**

A feature is a characteristic of an object or a class of objects that distinguishes it from other objects. It is determined by the specific environmental circumstances that influence the generation and development of the object and is unique to the object to which it belongs <sup>[26]</sup>. The most appealing feature of a homestay is its uniqueness, and consumers aspire to come across a unique homestay along their travel route. Therefore, this study hypothesized that product characteristic factors have a significant impact on the competitiveness of homestay.

#### **4.4. Marketing strategies**

Marketing strategies are critical for increasing homestay's competitiveness. Rural homestay tourism should also keep up with the times, utilizing a range of new media, network platforms, We-Media software, and other means to bolster propaganda efforts and marketing innovation, allowing rural homestay tourism to grow even further <sup>[27]</sup>. Therefore, this study proposed the hypothesis that marketing strategies have a significant impact on the competitiveness of homestay.

#### **4.5. Customer satisfaction**

Customer satisfaction is a critical indicator of a rural homestay's quality. Customer satisfaction has a

significant impact on tourists' return rate, which is also an intuitive expression of tourists' opinion of homestay, making it beneficial to study the components of their competitiveness<sup>[28]</sup>. Therefore, this study proposes the hypothesis that customer satisfaction has a significant impact on the competitiveness of homestay.

## 5. Weight analysis

### 5.1. Fundamental

AHP (Analytic Hierarchy Process) involves qualitative and quantitative factors combined with the multi-objective complex problems, through mathematical, modelling, and systematic analysis, decomposed into multi-level and multi-factors. The weight values of these decomposed factors are obtained through comparison and scientific calculation, and then these weight values are used for calculation and evaluation, so as to select the optimal scheme. The relative importance of each factor in the hierarchy was determined by pairwise comparison. The judgment matrix was constructed, mathematical processing was carried out, and consistency test was carried out. After consistency test, the relative weight of each index was obtained. Finally, the comprehensive ranking of index factors was determined according to the final weight value of each index.

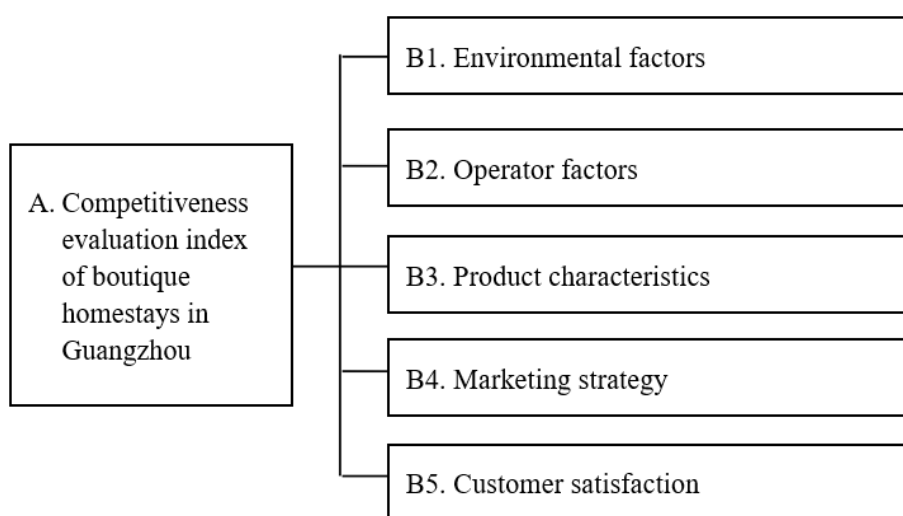
### 5.2. Evaluation indicators

#### (1) Target layer A

Target layer A is the evaluation index system for the competitiveness of boutique homestays in Guangzhou, which is used to measure the overall competitiveness of boutique homestays in Guangzhou.

#### (2) Criterion layer B

By consulting the relevant literature, the we drew on the relatively influential competitiveness model of industrial clusters — factors of production, demand conditions, relevant supporting industries, corporate strategy and competition status, government policies and opportunities in Porter's diamond theoretical model. These main influencing factors were also proposed by combining the basic characteristics of the homestay tourism industry and the factors influencing the competitiveness of Guangzhou boutique homestays. After consulting experts repeatedly, we finally determined the five evaluation factor layers, which are environmental factors, operator factors, product characteristics, marketing strategies, and customer satisfaction as shown in **Figure 1**, which can comprehensively reflect the competitiveness of Guangzhou boutique homestays.



**Figure 1** Competitiveness evaluation index chart of Guangzhou boutique homestay

### (3) Evaluation factor layer C

According to the index of the criterion layer, the evaluation factor layer is selected in a targeted manner, and the index content of the criterion layer is further refined and improved comprehensively and systematically.

The indicators are shown in **Table 1**, which includes the following: the starting price of the guest room, the total construction area of the homestay, the number of homestay rooms, the number of beds in the homestay, the walking distance from the station, the number of core attractions within 1 km, the number of commercial points within 1 km, the number of homestay reviews, overall rating, user recommendation rate, location scores, facility scores, service scores, and hygiene scores, which were selected with reference to the index system established by Huang <sup>[10]</sup>; government support, related industry support, inter-enterprise cooperation, and inter-enterprise competition with reference to the index system established by Liu <sup>[29]</sup> and Li <sup>[30]</sup>; the level of education and management of employees with reference to the index system established by Ran <sup>[31]</sup> and Dong <sup>[32]</sup>; the number of A-level tourist scenic spots and the richness of rural tourism products with reference to the index system established by Qiao <sup>[33]</sup>; the investment of enterprises, the operator's sense of identity, the participation of the host, and the construction of personalized brands; several indicators were selected with reference to the indicator system established by Zhao <sup>[34]</sup>; the number of online platforms, the degree of publicization through WeChat short video platform and shooting of popular TV programs, and product preferential policies were selected with reference to Chen <sup>[18]</sup>; local culture, theme creativity, characteristic catering, and characteristic tourist souvenirs were selected with reference to the index system established by Fan <sup>[35]</sup>.

The selection of the above 34 evaluation indicators is explained as follows:

**Table 1.** Competitive index system of rural quality homestay

Hierarchy of objectives	Criterion layer	Subdivision criterion layer	Index level
A. Rural boutique homestay competitiveness	B1. Environmental factors	Natural environment	C1. Number of A-level scenic spots C2. Rural tourism products
		Basic information	C3. Starting price of rooms C4. Total construction area of the homestay C5. Number of rooms C6. Number of beds
		Locational conditions	C7. Distance to the station by foot C8. Number of core scenic spots within 1 kilometer C9. Number of commercial spots within 1 kilometer
		Social environment	C10. Government support C11. Relevant industry support C12. Degree of cooperation among enterprises C13. Degree of inter-enterprise competition

*(Continued on next page)*



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Hierarchy of objectives	Criterion layer	Subdivision criterion layer	Index level
A. Rural boutique homestay competitiveness	B2. Operator factors	Human resource	C14. Level of education of employees C15. Operators' sense of identity with local resources C16. Participation of the host in the reception
		Business management	C17. Capital invested by the enterprise C18. Quality of management
	B3. Product characteristics	Characteristic excavation	C19. Local history and culture C20. Characteristic catering C21. Characteristic tourism souvenir
		Personalized design	C22. Theme creativity C23. Personalized branding
	B4. Marketing strategy	Publicity	C24. Number of homestay marketing platforms C25. Degree of publicization on WeChat and short video platforms C26. Shooting of popular TV programs and movie
		Promotion strategy	C27. Product preferential policies
	B5. Customer satisfaction	Overall situation	C28. Number of reviews of homestay C29. Overall review score C30. Rate of recommendation of users
		Subitem situation	C31. Location score C32. Facility score C33. Service score C34. Hygiene score

### 5.3. Weight analysis result

The method of consulting relevant literature was used to determine the influencing factors. A total of 10 respondents were interviewed and consulted. The data obtained from 10 questionnaires were averaged for consistency analysis, and the weight of the index system was obtained, which is shown in **Table 2**.

**Table 2.** Weight analysis of target layer A

Criterion layer	Weighted value	Maximum eigenvalue	Consistency ratio
Environmental factors	13.435%	5.243	0.061
Operator factors	3.482%		
Product characteristics	50.282%		
Marketing strategy	6.778%		
Customer satisfaction	26.026%		

When the random consistency ratio is smaller than 0.1, the results of AHP are considered consistent, which means that the weight distribution is reasonable. It can be seen from **Table 2** that  $CR = 0.061$ , which is smaller than 0.1. After consistency test, the weight value of environmental factors, operator factors, product characteristics, marketing strategy, customer satisfaction are 13.435%, 3.482%, 50.282%, 6.778%, 26.026%, respectively.

According to the results in **Table 2**, the weight of product characteristics (B3) among the five first-order influencing factors was 50.282%, accounting for the highest proportion, making it a highly influential factor. This could be due to the increasing preference for personalized and characteristic homestay design in recent years. The weight of operator factors (B2) was 3.482%, accounting for the lowest proportion, which may be related to the impact of the business model of homestay chain brands on traditional family homestay.

**Table 3.** Weight analysis of evaluation factor layer C

Criterion layer	Subdivision criterion layer	Index level	Weight analysis of evaluation factor layer C
B1. Environmental factors (13.435%)	Natural environment (55.495%)	C1. Number of A-level scenic spots (75%)	5.592%
		C2. Rural tourism product richness (25%)	1.864%
	Basic information (9.670%)	C3. Starting price of rooms (64.268%)	0.835%
		C4. Total construction area of the homestay (10.104%)	0.131%
		C5. Number of rooms (20.827%)	0.271%
		C6. Number of beds (4.800%)	0.062%
	Locational conditions (9.670%)	C7. Distance to the station by foot (8.331%)	0.108%
		C8. Number of core scenic spots within 1 kilometer (72.351%)	0.940%
		C9. Number of commercial spots within 1 kilometer (19.319%)	0.251%
	Social environment (25.165%)	C10. Government support (26.335%)	0.890%
		C11. Relevant industry support (5.689%)	0.192%
		C12. Degree of cooperation among enterprises (55.789%)	1.886%
		C13. Degree of inter-enterprise competition (12.187%)	0.412%

*(Continued on next page)*

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Criterion layer	Subdivision criterion layer	Index level	Weight analysis of evaluation factor layer C
B2. Operator factors (3.482%)	Human resource (16.667%)	C14. Education level of employees (25.828%)	0.150%
		C15. Operators' sense of identity with local resources (10.473%)	0.061%
		C16. Participation of the host in the reception (63.699%)	0.370%
	Business management (83.333%)	C17. Capital invested by the enterprise (25%)	0.725%
		C18. Management level (75%)	2.176%
B3. Product characteristics (50.282%)	Characteristic excavation (16.667%)	C19. Local history and culture (63.699)	5.338%
		C20. Characteristic catering (25.828%)	2.165%
		C21. Characteristic tourism souvenir (10.473%)	0.878%
	Personalized design (83.333%)	C22. Theme creativity (50%)	20.951%
		C23. Personalized brand (50%)	20.951%
B4. Marketing strategy (6.778%)	Propaganda means (50%)	C24. Number of homestay platforms (10.473%)	0.355%
		C25. Number of publicities on WeChat and short video platforms (25.828%)	0.875%
		C26. Shooting location of popular TV and movie (63.699%)	2.160%
	Promotion strategy (50%)	C27. Product preferential policy (100%)	3.389%
B5. Customer satisfaction (26.023%)	Overall situation (83.333%)	C28. Number of reviews of homestay (8.096%)	1.756%
		C29. Overall score (73.064%)	15.844%
		C30. Recommendation rate of users (18.839%)	4.085%
	Subitem situation (16.667%)	C31. Location score (12.596%)	0.546%
		C32. Facility score (56.505%)	2.451%
		C33. Service score (26.964%)	1.169%
		C34. Hygiene score (3.935%)	0.171%

According to the results in **Table 3**, among the 34 second-level influencing factors, theme creativity (C22) and personalized brand (C23) accounted for 20.951%, accounting for the highest proportion. They were the most influential factors. The weight of second-level influencing factor, overall review (C29) of first-level influencing factor, customer satisfaction (B5), was 15.844%, accounting for a relatively high proportion, which was also a factor with a relatively large influence. The weight of operators' sense of identity with local resources (C15) of operator factors (B2) was 0.061%, accounting for the lowest

proportion. Among the first-order factors, environmental factors (B5), the weight of second-order factor, which was the number of beds (C6), was 0.062%, which was relatively low.

## 6. Conclusion

Based on the combination of Porter's diamond model theory and the current situation of Guangzhou's rural homestay industry, this article reorganized the six influential factors of diamond model that affects the competitiveness of Guangzhou homestay through literature research, which includes the following: environmental factors, operator factors, product characteristics, marketing strategy, customer satisfaction, which was illustrated with an example. The factors were further subdivided into 34 second-level factors, forming the evaluation index system of homestay competitiveness. Based on this, combined with the survey opinions of experts, tourists, and homestays operators, the comprehensive weight of each factor index was analyzed through AHP. The results show that the most influential first-level factor affecting rural homestays in Guangzhou is product characteristics, while the secondary factors with great influence were theme creativity, personalized brand, and the overall score.

This research deeply analyzed the concept and characteristics of rural boutique homestay, through summarizing the research literature of domestic and foreign scholars and sorting out and determining the concept of rural boutique homestay. Strive to solve the current lack of boutique homestay's competitiveness evaluation model. In the process of studying the rural boutique homestay in Guangzhou, this research the indicators that affect the competitiveness evaluation of the boutique homestay in Guangzhou were analyzed based on from five influencing factors, which will be helpful and complementary to the competitiveness evaluation mechanism and model of the local rural boutique homestay.

## Disclosure statement

The authors declare no conflict of interest.

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# Load Test Analysis and Research on Long-Span Concrete Continuous Rigid Frame Bridge

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**Abstract:** Based on the as-built load test of a large bridge, this paper introduces the procedure of the prestressed concrete continuous rigid frame bridge load test. Numerical analysis of the bridge was carried out by simulating and establishing a finite element model, and comparative analysis was carried out with the measured values. The results show that the calculated values were basically consistent with the measured values, which showed that the establishment method of the model was reasonable, and the mechanical performance of the bridge met the service requirements of the designed live load.

**Keywords:** Bridge; Continuous rigid frame; Load test

**Online publication:** March 30, 2023

## 1. Introduction

As an artificial structure in the outdoor environment, bridges have a long service time, and they are subjected to harsh environmental conditions and heavy loads. In order to test the bridge design, construction quality, and the reliability of the project, a load test is usually carried out to understand the actual working state of the tested bridge span under the test load. After testing and analysis, the actual bearing capacity of the bridge is determined and its working performance under the designed load is evaluated. Based on the as-built load test of a bridge, the load test of continuous rigid frame bridge was studied in this paper. The test methods and results can be used as a reference for similar bridges <sup>[1-3]</sup>.

## 2. Project overview

The main part of the bridge was 267 m long, and the bridge span layout and structural form are (68.5 + 130 + 68.5)m three-span continuous rigid frame bridge, which was divided into left and right layouts. Each main girder was a box girder. The steepness of the horizontal slope of the top of the box girder was the same as the road arch, which is 1.5%. The top width of the box girder was 1520 cm, the bottom width was 700 cm, the center height of the root of the box girder was 780 cm, and the height of the midspan beam was 280 cm. The main pier adopted a double-leg thin-walled pier, and the pier body was consolidated with the superstructure box girder. Asphalt concrete bridge deck pavement was used for roadway bridge deck pavement.

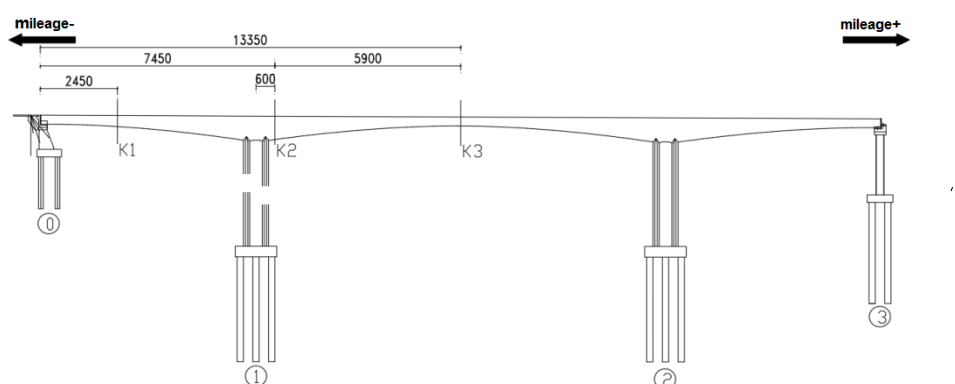
Design load = urban-level A + crowd load 3.0 kPa

Bridge design cross-section = 3 m (sidewalk) + 11.5 m (roadway) + 2.0 m (separation zone) +  
 11.5 m (roadway) + 3 m (sidewalk)  
 = total width 31 m

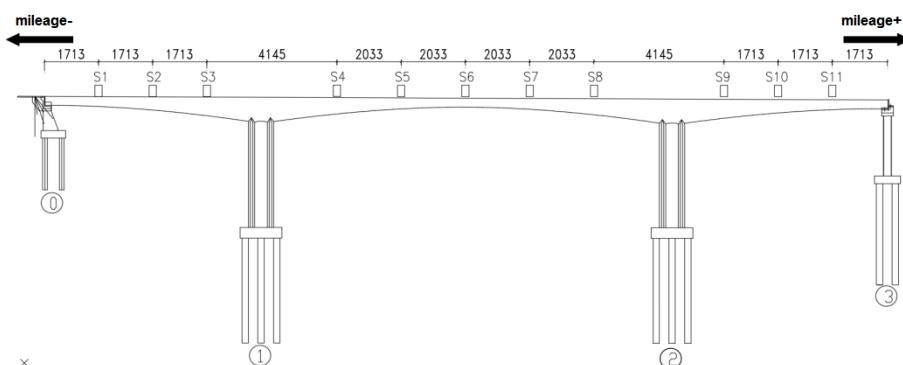
### 3. Test content

In order to determine the number of loading vehicles and the loading position of the load test, the corresponding finite element calculation and analysis of the bridge was carried out. The static load test of the bridge was mainly used to check the extent to which the displacement or stress of the main load-bearing member control section of the bridge span structure was in line with the design expectation under the most unfavorable live load. The test items included stress, displacement, and cracks. The dynamic test was performed to understand natural vibration characteristics of the bridge span structure and the dynamic response under the load, and to analyze its dynamic performance in the long-term. The test items included frequency, damping ratio, and response towards forced vibration under dynamic load, such as dynamic strain and impact coefficient [4-6].

According to the structural characteristics of the test bridge span, three sections were selected as control sections. The position of each control section is shown in **Figure 1**. The test section and measuring point layout of the structural modal parameters are shown in **Figure 2**. The test content is shown in **Table 1**.



**Figure 1.** Schematic diagram of control section layout (unit: cm)



**Figure 2.** Schematic diagram of the layout of the modal test measuring points (unit: cm)

**Table 1.** Test control section and test content

Section number	Control section	Test content
K1	The maximum positive bend of the main girder of the first span	Static strain, deflection, crack, dynamic strain
K2	The maximum negative bending of the main girder of No. 1 pier	Static strain, crack
K3	The maximum positive bend of the main girder of the second span	Static strain, deflection, crack, dynamic strain



## 4. Design of test scheme

### 4.1. Static load scheme

According to relevant specifications [7], the range of load efficiency in this static load test was  $0.85 < \eta \leq 1.05$ . A total of 6 loading conditions were designed in this test, numbered J1–J6. The loading vehicle was a 3-axle muck truck, the weight of a single vehicle was controlled at  $350 \text{ kN} \pm 10 \text{ kN}$ , the (middle) rear axle was controlled at 140 kN, and the front (middle) axle was controlled at 70kN. The maximum number of vehicles used in the test was 9, and the minimum was 6, which meant that the loading efficiency of each working condition met the specifications. The control section and vehicle consumption included in each working condition are shown in **Table 2**, and the control section numbers in the table correspond to **Table 1**.

**Table 2.** Loading efficiency and vehicle consumption under each working condition

Case number	Loading method	Load feature	Loading efficiency	Vehicle use number
J1	Positive load	Positive bending moment (K1)	0.95	6
J2	To the right	Positive bending moment (K1)	0.95	6
J3	Positive load	Negative bending moment (K2)	0.91	9
J4	To the right	Negative bending moment (K2)	0.91	9
J5	Positive load	Positive bending moment (K3)	0.98	9
J6	To the right	Positive bending moment (K3)	0.98	9

The static load test strain measuring points were located inside the box girder. There were 13 measuring points in total on a single section, including 4 on the top plate, 5 on the bottom plate, and 2 on each of the left and right webs; the points were spread evenly on the bridge surface.

### 4.2. Dynamic load scheme

According to the relevant specifications and the actual situation of the site, the dynamic characteristic test was carried out by using the earth pulsation excitation method and the barrier-free driving test. In the barrier-free driving condition, a 350kN heavy vehicle was driven along the center line of the roadway. The specific content of the dynamic load test is shown in **Table 3**.

**Table 3.** Description of dynamic load test working condition

Case number	Working condition
D1	Pulsation
D2	1 vehicle crossing the bridge at a constant speed of 5 km/h on the center line
D3	1 vehicle crossing the bridge at a constant speed of 10 km/h on the center line
D4	1 vehicle crossing bridge at a constant speed of 20 km/h on the center line
D5	1 vehicle crossing the bridge at a constant speed of 30 km/h on the center line
D6	1 vehicle crossing the bridge at a constant speed of 40 km/h on the center line

A total of 11 modal measuring points were placed along the centerline of the bridge deck, and the longitudinal positions are shown in **Figure 3**; the positions and numbers of the dynamic strain measuring points were the same as those in the static load test, and two measuring points in the middle of the bottom plate of each section were selected.

## 5. Test results

### 5.1. Static load test results

#### 5.1.1. Strain test results

The strain observation results of each control section under the selected loading conditions J1–J6 are listed in **Table 4**. The elastic strain was the difference between the full load strain and the residual strain, and the theoretical value was the value calculated using the finite element model.

**Table 3.** Strain test results and calibration coefficients

Loading condition	Location of measuring point	Maximum elastic strain ( $\mu\epsilon$ )	Theoretical value ( $\mu\epsilon$ )	Calibration coefficient range	Relative residual range (%)
J1	K1	22	50	0.40–0.57	$\leq 9.1$
J2	K1	23	53	0.40–0.69	$\leq 5.3$
J3	K2	24	30	0.38–0.80	$\leq 11.1$
J4	K2	24	32	0.35–0.79	$\leq 6.3$
J5	K3	54	80	0.37–0.68	$\leq 8.5$
J6	K3	52	84	0.39–0.66	$\leq 5.6$

It can be seen from **Table 4** that the maximum strain values were generally smaller than the theoretical values, the calibration coefficient was between 0.35 and 0.80, and the relative residual was less than 20%, which indicated that the strength of the test bridge span met the design requirements.

#### 5.1.2. Deflection test results

The main control sections of the main girder deflection are K1 and K3, which were realized by loading conditions J1, J2, J5, and J6. The measured results are shown in **Table 5**. The elastic displacement was the difference between the full load displacement and the residual displacement, and the theoretical calculation value was calculated using the finite element model.

**Table 5.** The deflection observation results and calibration coefficients of the main control section of the main girder

Loading condition	Location of measuring point	Maximum elastic displacement (mm)	Theoretical value (mm)	Calibration coefficient range	Relative residual range (%)
J1	K1	3.7	6.8	0.49–0.54	$\leq 9.8$
J2	K1	3.9	7.1	0.49–0.55	$\leq 5.7$
J5	K3	14.4	24.3	0.53–0.59	$\leq 4.8$
J6	K3	14.0	25.5	0.54–0.57	$\leq 2.1$

Based on **Table 5**, the deflection of the control section under each working condition was smaller than the theoretical value, the calibration coefficient was between 0.49 and 0.59, and the relative residual was less than 20%, indicating that the stiffness of the bridge met the design requirements.

## 5.2. Dynamic load test results

### 5.2.1. Measurement results of modal parameters

The results of the modal parameters are shown in **Table 6**, where the theoretical frequency was calculated by the finite element model.

**Table 6.** Results of bridge model parameters

Number of executions	Measured frequency (Hz)	Damping ratio (%)	Theoretical frequency (Hz)	Mode shape
1	1.395	0.46	1.272	First-order vertical bending of main beam
2	2.620	0.93	2.476	Second-order vertical bending of main beam
3	3.250	1.92	2.833	Three-order vertical bending of the main beam

As shown in **Table 6**, under the corresponding model shapes, the measured frequency of the structure was greater than the theoretical frequency.

### 5.2.2. Dynamic response test results

According to relevant regulations <sup>[8]</sup>, when the measured vertical fundamental frequency of the bridge structure is  $f = 1.2719$  Hz, the calculated impact coefficient is  $\mu_c = 0.050$ . The results of the impact coefficient of the bridge structure are shown in **Table 7**.

**Table 7.** Results of impact coefficient of bridge structure

Location of measuring point	5 km/h driving speed	10 km/h driving speed	20 km/h driving speed	30 km/h driving speed	40 km/h driving speed
K1	0.072	0.055	0.098	0.075	0.096
K1	0.093	0.049	0.101	0.081	0.103
K3	0.028	0.020	0.022	0.020	0.036
K3	0.037	0.044	0.024	0.023	0.049

Based on **Table 7**, the measured impact coefficient of the K1 section of the main bridge was between 0.049 and 0.103, and the measured impact coefficient of the K3 section was between 0.020 and 0.049. The measured impact coefficient of the K3 section was smaller than the theoretical value, but the measured impact coefficient of the K1 section was slightly larger than the theoretical value. This can be due to the low efficiency of the dynamic load test, which was within the normal range compared with similar bridges.

## 6. Conclusion

The strain test values and girder displacement in the static load test of the continuous rigid frame bridge were all within a reasonable range, the calculated values were smaller than the theoretical values, and the calibration coefficient and relative residual all met the specifications <sup>[9]</sup>. In the dynamic load test, the measured values of the first three vertical vibration frequencies of the bridge structure were greater than the theoretical values, and the impact coefficients are all within the normal range.

- (1) The mechanical performance of the continuous rigid frame bridge met the normal use requirements of the urban-A level and the crowd load of 3.0 kPa.
- (2) The dynamic characteristics and dynamic response performance of the inspected span structure of the continuous rigid frame bridge were normal.
- (3) The finite element model was relatively accurate in simulating the actual stress state of the bridge, and the design of this test scheme was reasonable.

## Disclosure statement

The authors declare no conflict of interest.

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# Analysis of Building Construction Quality Control and Safety Management

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**Abstract:** Quality control and safety management are two very important contents in building construction project management. Once the construction quality is not up to standard or a safety accident occurs, the economic benefits of the project will be severely impacted. However, there are still some problems in the quality and safety management of the project. In this paper the problems in construction quality control and safety management are analyzed, and effective countermeasures are put forward, in hopes to help improve construction quality and safety.

**Keywords:** Building construction; Quality control; Construction safety

**Online publication:** March 30, 2023

## 1. Introduction

With the continuous development of society, the construction industry is also booming, and the scale of construction projects is also increasing. When quality issues or safety accidents occur in the construction on a building, not only will the progress of the project be affected, but also the image and development of the construction company. Especially in such a fiercely competitive market, it is all the more necessary to pay attention to the quality control and safety management of building construction.

## 2. Problems in quality control and construction safety management of building construction

### 2.1. Lack of management from construction companies

Many construction companies do not pay enough attention to quality control and safety management during the construction process, so the management system is flawed and does not take basic characteristics of building construction into consideration, leading to the failure of controlling dangerous segments of building construction. Moreover, some management personnel lack sense of responsibility, thus they fail to perform their tasks and investigate safety hazards in the construction of the project, and fail to correctly deal with problems that arises, which leads to quality and safety issues.

### 2.2. Factors affecting construction quality and construction safety

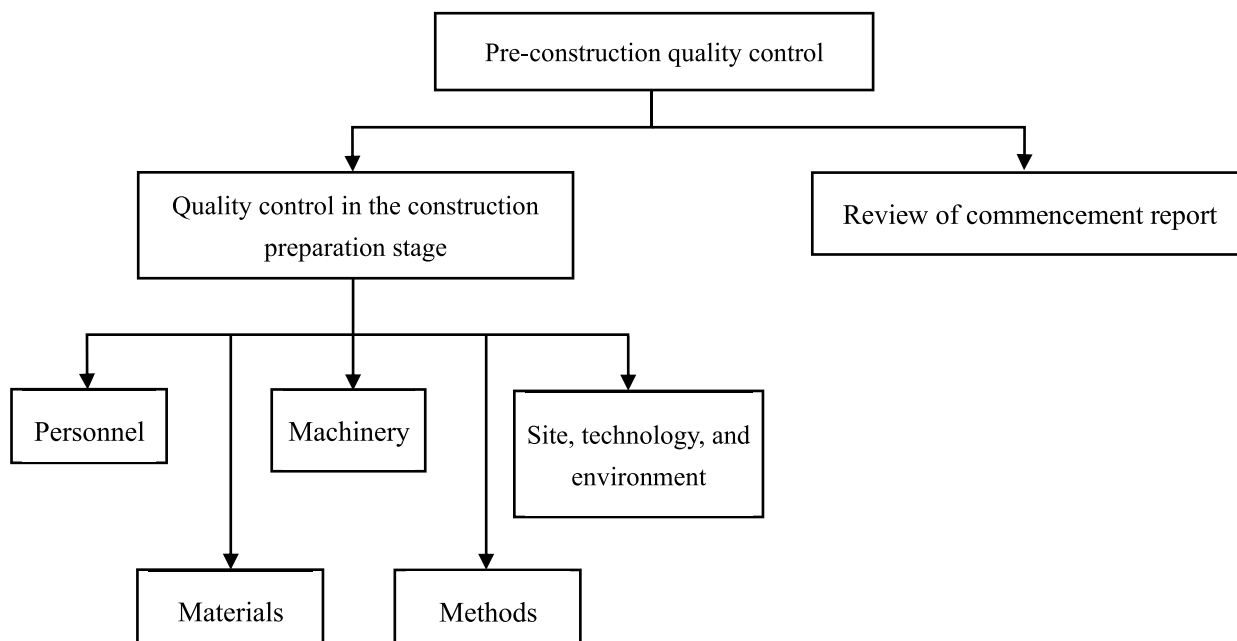
The construction period of most projects is relatively long, and the construction process is relatively complicated, and there are many factors that may affect the construction quality and safety. Generally, construction materials occupy a relatively large proportion of the construction costs. Therefore, some construction companies will try to cut costs by purchasing subpar materials, which will not only affect the construction quality, but also increase hidden dangers of the project. Nowadays, many large-scale machinery and equipment are used in the construction of a building, which poses certain risks. Safety

accidents are prone to occur if the management or maintenance of construction machinery and equipment is neglected in order to complete the project in time. In addition, some companies employ migrant workers to save labor costs and maximize economic benefits. However, most migrant workers lack professional knowledge and skills, and safety awareness, which will in turn affect the construction quality and construction of a project.

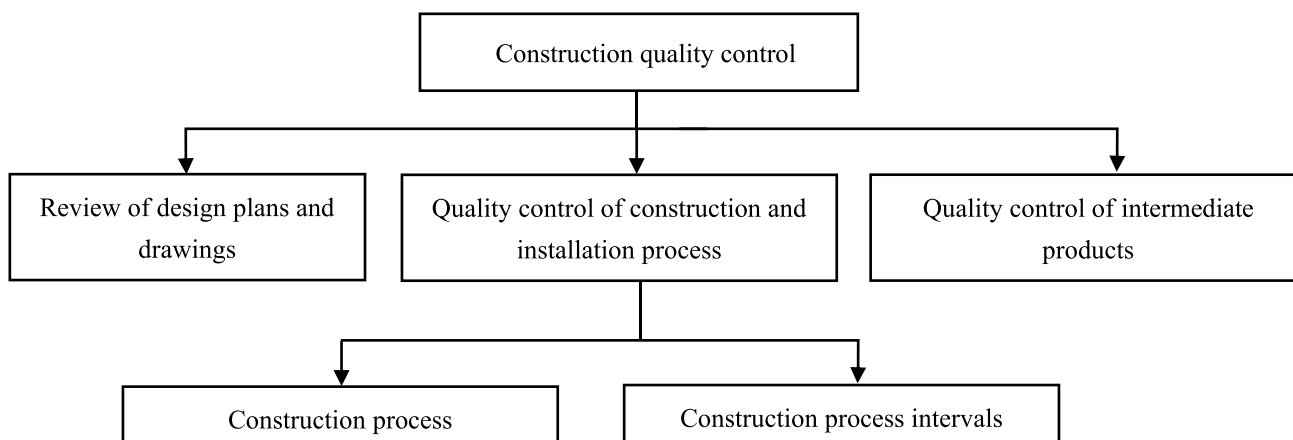
### 3. Effective strategies for quality control and safety management in building construction

#### 3.1. Outlining the content of quality control

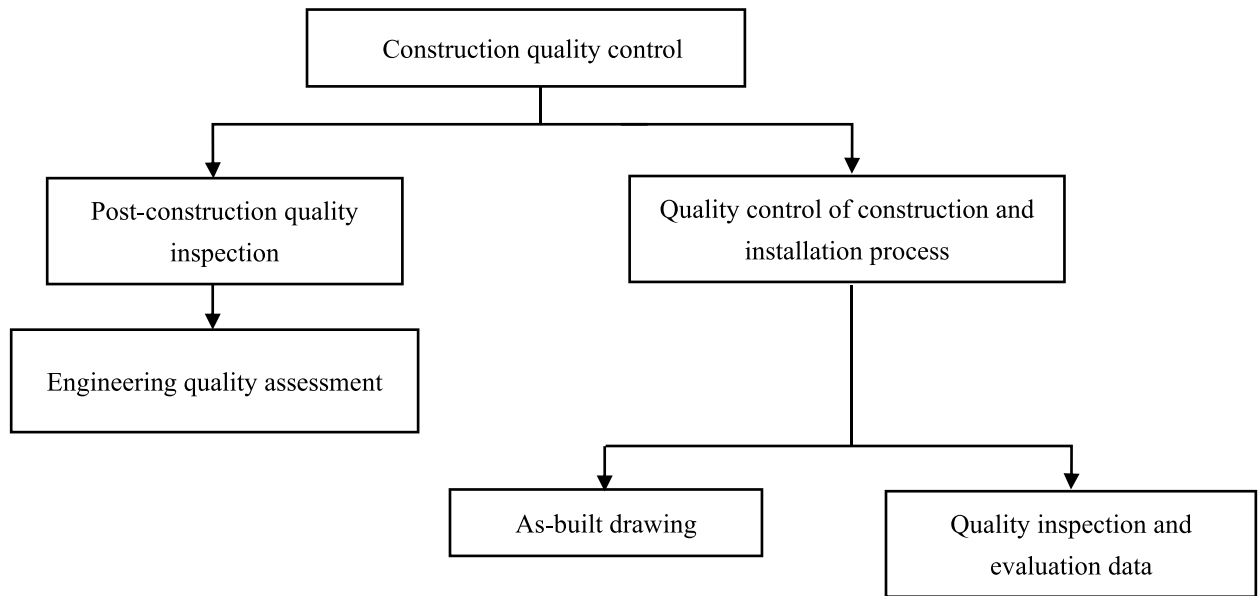
To prevent quality issues and fully execute construction quality control, it is necessary to formulate a clear quality control system in the pre-construction, construction, and post-construction periods, as shown in **Figures 1, 2, and 3**, and strictly implement them.



**Figure 1.** Prior control process of project construction quality



**Figure 2.** In-process control of project construction quality



**Figure 3.** Process of quality control after completion

### 3.2. Strengthening the management of construction materials

The quality of the materials should be properly managed and controlled to ensure the quality of the final product and safety in building construction. The qualifications of material suppliers should be carefully reviewed in the selection of suppliers to ensure the quality of the construction materials. It is necessary to re-inspect and re-test the materials before using them. The inspection content includes but not limited to the quantity, specification, performance, and quality of the construction materials. The materials can only be used after passing the inspection <sup>[1]</sup>. When the construction materials are transported to the site, it is important to store them in strict accordance with the corresponding regulations. Besides, protective measures should be taken to prevent the materials from being damp, damaged, and deteriorated during storage. Therefore, only through proper management and quality control of construction materials can the advantages of materials be maximized.

### 3.3. Strengthening the management of construction machinery and equipment

Construction technology is advancing with the continuous development of the construction industry, and the degree of mechanization of engineering construction is increasing. Many procedures that were previously done manually are currently done with machines and equipment. Although construction efficiency and quality have been significantly improved, there are still some hidden dangers. To maximize the advantages of construction machinery and equipment, we must pay attention to the management of machinery and equipment. The equipment should be regularly inspected and old equipment that have deteriorated should be replaced. Besides, the equipment should be repaired and maintained regularly, so as to ensure normal and stable operation during building construction and prevent safety accidents caused by malfunctioning machinery.

### 3.4. Improving the comprehensive qualities of construction workers

The technical skills, comprehensive qualities, and safety awareness of construction personnel are directly related to the quality and safety of the construction process. Therefore, construction companies should strengthen the training of construction personnel. All construction personnel should undergo a pre-job training and proper technical briefing before construction to ensure that all construction personnel are

qualified for their roles, especially welders, electricians, and tower cranes <sup>[2]</sup>. In addition, construction companies also need to realize that it is difficult to ensure that all construction personnel have a strong safety awareness through a few training sessions before construction. Therefore, construction companies should also increase the intensity of publicity on construction safety, set reasonable specifications on construction safety, and increase the enforcement efforts. For example, construction companies can put up posters and specifications related to construction safety at the construction site, so as to subtly strengthen the safety awareness of construction workers. In addition, construction companies can also encourage construction workers to prioritize construction safety by regularly providing lectures on construction safety.

### **3.5. Standardize construction procedures**

In order to ensure the quality and the safety of construction, it is necessary to formulate standardized construction procedures. The construction company is the main body responsible for the construction of the project, so the company should carry out on-site supervision and inspection. It is necessary to pay attention to the quality control and safety management at every stage of a project from construction drawings, technical briefing, to the construction and completion of the project. Every little detail cannot be ignored. In order to ensure the orderly progress of engineering construction, it is necessary to formulate standardized construction procedures <sup>[3]</sup>. First of all, before the official construction, it is necessary to review of the construction drawings, so as to discover the problems in the design drawings and rectify them in time. After the review stage, it is necessary to brief the construction workers involved on the construction drawings so that they are familiar with the design intent, operation process, and important and difficult points in the construction of the project. Subsequently, the construction of the building should be carried out in strict accordance with the plan. For sections that need to be intersected, it is important to ensure that the construction of intersecting parts does not affect the sections involved. After each section is completed, the construction quality needs to be strictly inspected to ensure that it is up to standard before proceeding to the next step. Once any quality issues are found, the part needs to be reconstructed, and the next step can only be carried out after the reconstructed part meets the required standards.

### **3.6. Comprehensive implementation of construction safety management**

In order to ensure that the construction of each section of the project fulfills the safety requirements, the previous concept of construction safety management should be renewed <sup>[4]</sup>. A team should be created specially for construction safety management, in which the team will be responsible for evaluating and analyzing potential safety hazards in project construction. The team should also be responsible for predicting the safety risks and the possible losses caused by safety risks of the project. A construction safety risk library should be created, which includes relevant uncertainties in the construction process that may cause safety issues, and practical emergency plans should be formulated based on these risks. In addition, construction companies should also appropriately increase investment in construction safety management according to the characteristics of the project and provide sufficient protective equipment and facilities for project construction. An ideal construction safety management system should also be created, and the responsibilities of each safety management personnel should be clearly defined, so as to ensure the effective development of safety management.

### **3.7. Maximizing the role of supervisory units**

To ensure the construction quality and safety of a building, construction companies usually hire a supervisory unit to track, supervise, manage, and control the entire construction process of the project. However, in some cases, the supervision units did not perform their roles. Nowadays, despite the rapid development of the market economy, various industries are becoming increasingly competitive, and the



same is true for the supervision industry <sup>[5]</sup>. Therefore, when selecting supervisory unit through bidding, the focus should not only be on the price quotation, but also the qualifications of the supervisory unit and the comprehensive qualities of the staff. Besides, in the process of signing the contract with the supervision unit, the construction company must clearly state the rights and interests of both parties in the contract, and put forward clear requirements for the supervisors, requiring the supervision unit to be equipped with a full range of staff, which will be responsible for the supervision of the entire construction process. Clear requirements regarding the professional qualifications required for the supervision unit staff should also be stated, so that the supervision can be carried out with due diligence. The construction company should also grant the supervision unit some authority in terms of site management, so that when there are quality or safety issues, the team can then solve the problems in time, which will in turn prevent serious damage to the construction quality and safety.

#### 4. Conclusion

In conclusion, to maximize the economic benefits of a building project, it is necessary to emphasize strengthening construction quality control and safety management, so that construction companies can have a competitive advantage. Therefore, construction companies must be aware of the impact of factors like construction materials, construction personnel, and construction machinery and equipment on construction quality and safety, and thus improve on these factors. Besides, construction companies should also formulate standardized construction procedures according to the characteristics of the project, and at the same time implement proper safety management, and form a special supervision team, so as to provide the necessary support for the development of the project. Sufficient financial support can effectively improve the quality and safety of project construction, thereby creating greater value for the companies.

#### Disclosure statement

The author declares no conflict of interest.

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# Steady-State Analysis of Grid-Connected New Energy Power Plants

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**Abstract:** In order to ease the fossil energy crunch, new energy sources need to be fully utilized. Clean energy sources such as wind, light, and nuclear energy are important tools to solve environmental and energy problems. However, in the process of researching new energy farms, there are some problems when they are integrated into the power system. In order to ensure the stability of new energy power plants, it is necessary to conduct an in-depth analysis of the grid connection technology of new energy farms. In the study, it is necessary to learn about the specific problems of the stability of the grid connection of new energy power plants, and to clarify the specific application of the grid connection technology of new energy power plants from the application principle and advantages of the grid connection technology of new energy power plants. Through simulation experiments, the positive effect of grid connection technology of new energy power plants in improving the stability of power systems was determined.

**Keywords:** New energy power plant; Grid connection technology

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## 1. Introduction

In light of China's rapid economic development, the level of industrialization is improving continually, and the current production and life demand for electric energy is increasing. If we simply rely on traditional thermal power generation, it cannot meet the demand for electric energy for social development, and it may cause serious environmental and energy problems. Therefore, it is necessary to pay attention to the promotion and application of new energy generation technology. The application of new energy generation technology in power systems is becoming more and more common. Compared to traditional power generation technology, new energy generation technology is cleaner, more environmentally friendly, and has a positive effect on promoting the sustainable development of the power industry. However, there are some problems in the integration of new energy power farms with the existing power system for grid integration, which leads to the stability of the power system being affected. Therefore, it is necessary to control the light intensity and inverter and filter of the grid-connected system to enhance the stability of power system and play a positive role of new energy power field.

## 2. Transient stability analysis of grid-connected new energy power plants

In this study, we mainly discuss the transient stability of new energy sources after they are connected to the grid. The specific requirement of transient stability is that after the new energy sources are connected to the grid, the generators are to operate synchronously, and at the same time, new energy should be spent or returned to the original operating state. When the new energy power plant is connected to the grid, there

will be a large disturbance. The main part of an actual transient function curve is mainly the first or second pendulum being able to keep up with the control speed. The main perspective in the analysis of the stability requirements of the grid-connected transients of new energy farms is explained below.

- (1) If the disturbance of the system itself is a common fault, its impact on the stability of the grid connection is relatively small, and the requirements for transient stability are relatively high. After the disturbance, it is necessary to ensure a continuous and stable power supply to users, and at the same time to maintain the stability of the power supply system. For example, in a 220 kV system, if it is a multi-line circuit, a single-phase permanent fault occurs in one return, and the circuit breaker will trip forever after reclosing starts <sup>[1]</sup>.
- (2) In the process of connecting new energy plants to the grid in disturbed areas, the main requirement for transient stability in weak areas of the grid, such as when a single contact line fails, is to allow for partial and load loss while ensuring system stability.
- (3) If faults occurring in the network are more serious, larger disturbances will be produced, which will have a great impact on the stability of the power supply system. Therefore, it is necessary to ensure that various feasible measures, such as three-phase short circuits, are applied on the basis of the system being able to keep up with the control speed, thus ensuring the transient stability of new energy farms connected to the grid. According to the relevant power system safety guidelines in China, if the fault is a single-phase ground fault on the busbar, it can be regarded as a transient stability problem that occurs at the disturbance site in the weak area of the network. An in-depth analysis of the problem of increasing base work angle triggered by each larger disturbance suffered by the system is required. After the first swing, decaying oscillations occur and the pivot voltage continues to recover slowly. Large disturbances are usually caused by the removal of line or unit reclosing faults and short circuits.

### **3. Influence mechanism of photovoltaic grid connection on transient stability of power grid**

In the process of grid connection of photovoltaic power farms, the specific impact on the stability of the grid state is the system voltage dip in which photovoltaic power supply variable speed constant velocity (VSCV) has the characteristics of low voltage and high current. The high current injected into the supply line will lead to transient reactive load at the bus, and the voltage of the system cannot be recovered quickly. In this case, the system will experience a long period of low voltage state. In terms of energy conservation, the output power of the inverter side of the photovoltaic power will also be reduced after the system voltage drops. However, because of the U-I characteristics of the photovoltaic power cell itself, the power is prompted to remain unchanged. At this time, the energy is stored in the direct current capacitor, and the voltage of the direct current capacitor rises rapidly, along with the photovoltaic power array output voltage. Because the Voltage Source Converter controller has a certain direct current voltage difference, it will cause the output current to rise to boost the output power, so that the direct current capacitor voltage drops until the steady state, and the reactive power on the line rises as the output alternating current continues to increase. As a result, the voltage of the converging bus will gradually decrease, and the characteristics of transient reactive load will appear <sup>[2]</sup>.

After the photovoltaic power plant is connected to the distribution network, it will also have a great impact on the stability of the state power angle of the unit, which is mainly manifested in the aspects below.

#### **(1) Inertia coefficient (H)**

In the case of the same disturbance, the larger the inertia coefficient (H), the more the peak power angle of the unit will decrease, and the trend of this change will gradually slow down, and the risk of power angle instability is relatively small. However, the smaller the H value, the peak power angle of the unit will increase further, and this change will not slow down with time, but become faster and faster, leading to a higher risk of power angle instability.

(2) The specific scale of photovoltaic grid connected

The scale of photovoltaic grid connected is mainly evaluated through the penetration rate. The higher the penetration rate, the more obvious the characteristics of low voltage and high current in transient state. As a result, the duration of transient low voltage at the bus of grid-connected system will be prolonged. On the other hand, the smaller the output electromagnetic power of the unit, the more the increase of accelerated energy in the characteristic curve of transient work angle, and the risk of instability will be increased.

(3) Photovoltaic control mode

The Voltage Source Converter, as an important element of the photovoltaic power generation unit, controls the active and reactive power exchange of the alternating current grid and can realize the transition from direct current to alternating current power. The controller is generally designed using a two-loop control structure with direct-quadrature-zero (dq0) coordinates. The outer-loop control allows effective control of direct current voltage reactive power or alternating current voltage and is able to obtain the current value of the inner-loop current access controller. The direct current side voltage controlled by the inverter can ensure the tracking effect of the photovoltaic control power at the maximum operating power point. If the system is disturbed by disturbances affecting light intensity or ambient temperature, the control system can adjust the output alternating current voltage phase shift angle according to the deviation of the direct current voltage to ensure that the direct current voltage is dynamically balanced between the battery input power at the target setting and the inverter output power [3].

## **4. Application analysis of transient stability of grid connection technology for new energy power plants**

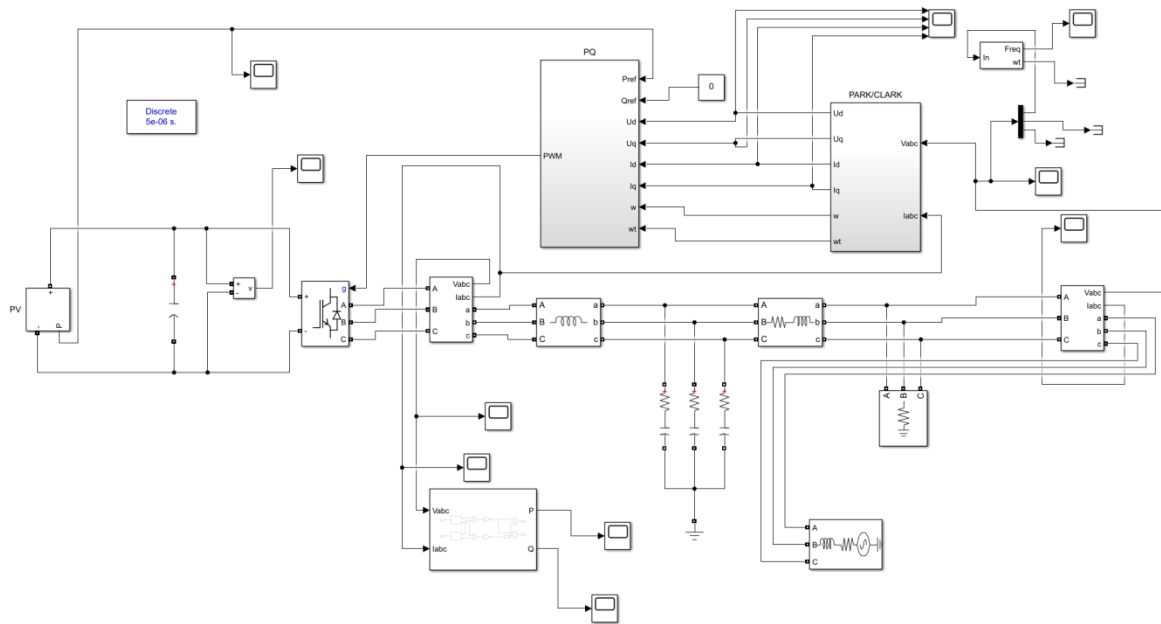
### **4.1. Experimental design and analysis**

In this study, experimental analysis of the stability of new energy generation fields was carried out with solar photovoltaic arrays. Photovoltaic arrays have non-linear characteristics, and parallel circuits can be designed according to the power. Photovoltaic cells include diodes, parallel resistors, and other components. The photovoltaic cell's light energy is more closely linked to the light intensity and time. When the current passes through the diode, there is little resistance, but the characteristics of photovoltaic cell cannot be manifested. When designing the photovoltaic array model, the power under different light intensity and time needs to be calculated to obtain the maximum power value. For the maximum power when the photovoltaic array is grid-connected, the reference voltage of the photovoltaic array in operation was analyzed comprehensively to form a three-phase photovoltaic grid-connected system with direct current voltage feedback control. The grid-connected stability of the photovoltaic array was controlled through closed-loop control system. When calculating the maximum power of the photovoltaic array, it is necessary to analyze the initial current value of the photovoltaic array and obtain the light intensity and time under the maximum power to design the reference current value under maximum power. Simulation analysis was also performed on the main points of inverter and harmonizer improvement for direct current voltage feedback grid-connected technology in packaged photovoltaic module control system. Lastly, the application value of direct current voltage feedback control technology was verified using experimental validation to provide a reference for steady-state research under stability construction in the process of grid connection of new energy power farms.

### **4.2. Simulated analysis**

The power system simulation software Simulink was used for this research and to build a simulation model as shown in **Figure 1**. In the simulation process, the specific impact of the new energy side fluctuations

was not analyzed. In order to improve the reliability of the simulation results, the new energy was controlled using the photovoltaic module control system and direct current voltage feedback.



**Figure 1.** Simulation model

A photovoltaic array consists of several photovoltaic modules and panels. The relationship between the output voltage,  $V$ , and the output current,  $I$ , of the photovoltaic cell can be expressed through the equation below.

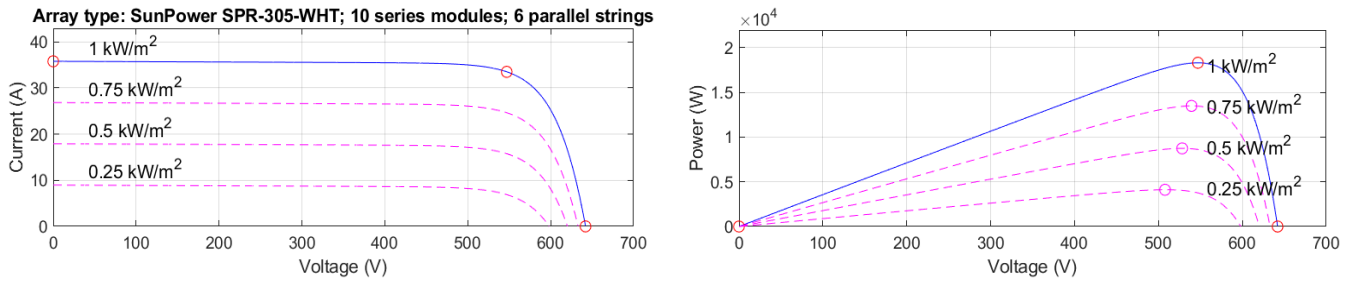
$$I = I_{ph} - I_o \left\{ \exp \left[ \frac{q(V + IR_s)}{AKT_\theta} \right] - 1 \right\} - \frac{V + IR_s}{R_{sh}}$$

To determine the specific influence of illumination intensity, inverter, and filter on the transient characteristics of the new energy when the synchronous motor is applied to the grid connection technology, the effective value of phase voltage of the grid was set to 220 V and 50 Hz in the simulation design. In this condition, the following conclusions were obtained through simulation analysis:

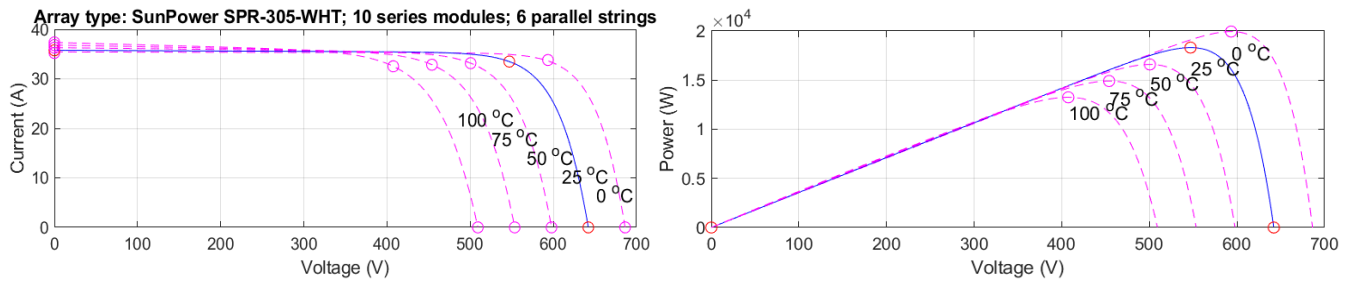
#### (1) Light intensity changes

In the simulation experiment, the  $H$  value was set at  $50e-7s$  and the damping coefficient at 0.001. A total of 4 simulation experiments were completed, and the results are shown in **Figures 2** and **3**.

The output current, voltage and power of the photovoltaic cell model were different at different light intensities and temperatures. At the same temperature, as the light intensity increased, the output current of the cell model increased and the maximum output power increased, as shown in Figure 2. Under the same light intensity, the output voltage and the maximum output power decreased with the increase of temperature. This indicates that reasonable control of light time helps in improving the transient stability of synchronous motors of new energy farms to the grid [4].



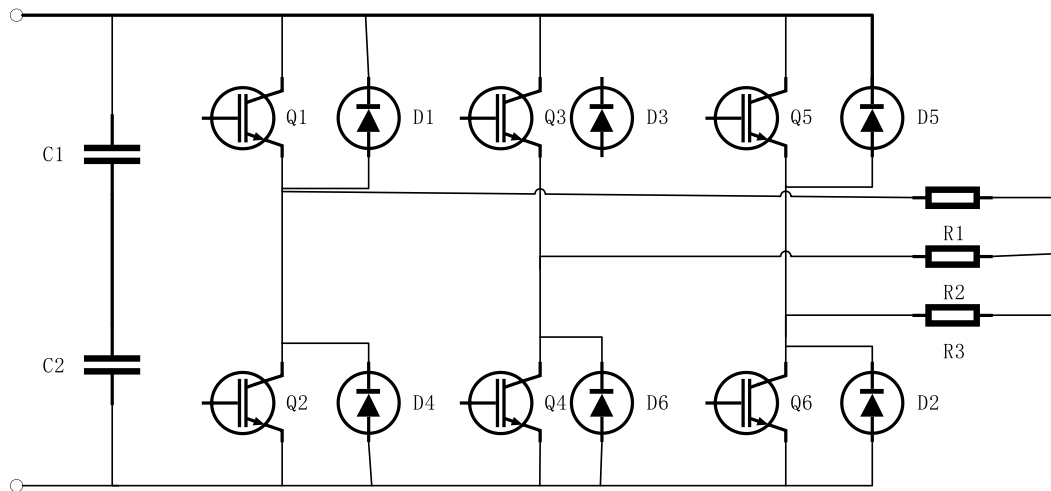
**Figure 2.** Output current and power under different light intensities



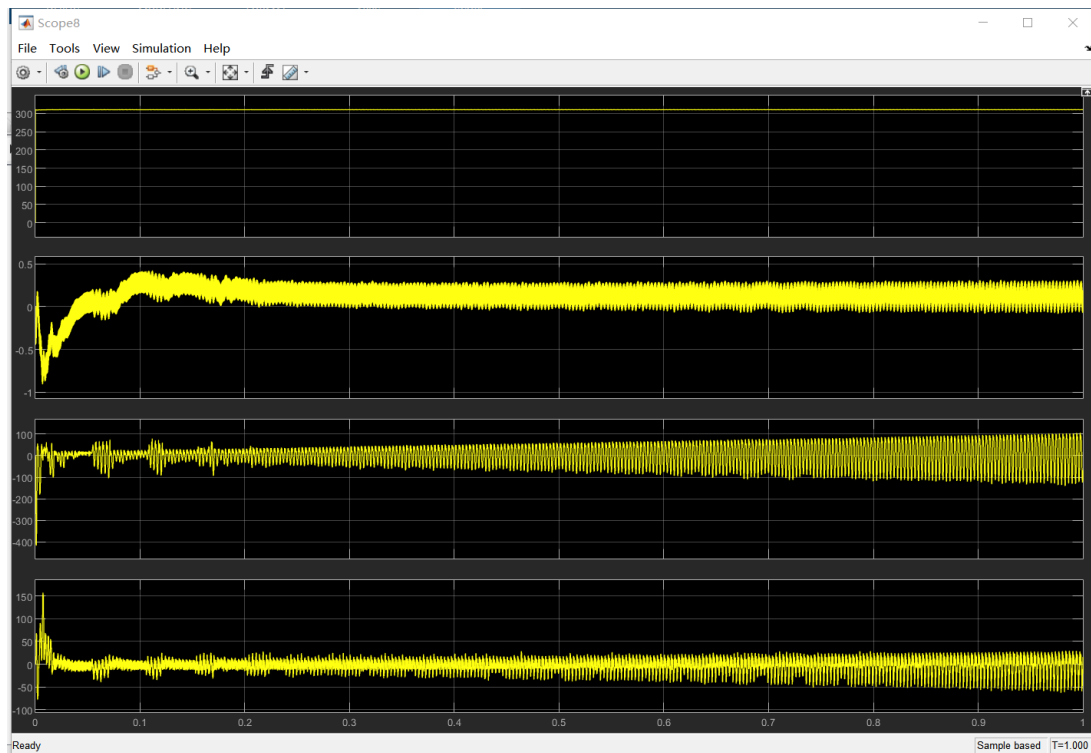
**Figure 3.** Output current and power at different temperatures

## (2) Inverter

A three-phase full-bridge inverter was designed in this study. This is because compared to a half-bridge inverter, a full-bridge inverter has higher output power and smaller switching losses. Its structure is shown in **Figure 4**. A total of four simulation experiments were completed and the results are shown in **Figure 5**.



**Figure 4.** Full bridge inverter



**Figure 5.** Output power

The analysis of the simulation experiment results can be determined in the case that the light intensity changes. In using the three-phase full-bridge inverter circuit, insulated-gate bipolar transistor (IGBT) was selected as the switching device, and the driving signal provided by the Pulse Width Modulation (PWM) drove the switching of the IGBT transistor to finally convert the direct current to alternating current, and the specific amplitude of the light intensity was reasonably controlled in the actual operation to ensure the stability of the power system.

### (3) Filters

The high harmonic distortion rate during the experiment was mainly due to the nonlinear access of devices such as inverters. These power electronic devices generate high amplitude, short pulse currents that cause severe distortion in various waveforms of the line. In the photovoltaic grid modeling, LCL filters were selected to filter high harmonics, but the current filtering effect was not ideal because grid parameters and control parameters also had an impact on the harmonic characteristics of distributed photovoltaic power generation. Hence, the simulation could have been improved in several ways. The first point is to add a tripping signal on the direct current supply to simulate the environmental changes of distributed power generation in actual operation. The second point is to change the parameters of the line and electronic blocks, such as the PID block, to reduce the distortion of the system. The third point is to increase the power factor by increasing the capacitance value or reactive power compensation block to compensate the large amount of reactive power absorbed by the components. The fourth point is to add energy storage devices to make up for the shortcomings of photovoltaic power generation due to environmental constraints that lead to unstable power generation to ensure the stability of power generation.

### 4.3. Experimental verification

In order to verify and analyze the stability characteristics of the new energy grid connection, a photovoltaic-driven grid connection system was constructed. Besides, in order to determine the transient characteristics

of grid-connected photovoltaic power plants, the application effects of photovoltaic grid-connected and direct current voltage feedback control grid-connection was compared and studied. The transient stability of the grid-connected system under load variation was compared in the experiments. Two experiments with different loads were carried out in the experimental platform built. The load conditions of the grid-connected system in the experiments were the same. The experimental results were as follows: the direct current voltage feedback-controlled grid-connected inverter was a three-phase full-bridge inverter. In the grid-connected, the harmonizer set in the grid-stabilized system designed in this paper enhanced the power factor through the reactive power compensation block to avoid the rapid increase of reactive power from negatively affecting the transient stability of the grid-connected system. The maximum offset of the operating frequency of the grid-connected photovoltaic power plant with direct current voltage feedback control was one-third of that when the photovoltaic is directly connected to the grid. The overall operating frequency of the grid was relatively stable in direct current voltage feedback-controlled grid connection, and the inertial response and damping level of the grid connection were improved, which ensured the transient stability of the grid connection of the new energy farm.

## **5. Measures to improve the transient stability of grid-connected new energy power plants**

In the process of connecting a new energy power plant to the distribution network, measures should be taken to ensure the grid-connected transient stability.

### **(1) Effective control of power quality**

At present, new energy farms mainly consist of wind and solar energy power plants, and there are a few disadvantages in using these two new energy sources. Firstly, the power output of the power generation system at different times is differ greatly, which will directly affect the safe operation of the power grid. In order to reduce the probability of power system failure, the installation of real-time power quality monitoring devices when the new energy is connected to the grid can provide comprehensive monitoring of voltage fluctuations, voltage deviations, harmonic changes, and other conditions in the power system. If it does not meet the usage requirements, active voltage filters and reactive power compensators can be installed to improve the power quality <sup>[4]</sup>.

### **(2) The need to promote the effective application of advanced technologies**

In the process of development of new energy industry in China, the corresponding power generation and transmission technologies are still immature, and relevant researchers need to strengthen the in-depth study of new energy generation technologies. We can use advanced technologies to improve the quality of power generation in new energy farms. For example, in the development of photovoltaic power generation technology, mechanical automatic control devices can be used to adjust the working point of solar panels to ensure that the power generation is in a relatively constant state. In addition, energy storage devices can be used to control the output power, so as to achieve the goal of power regulation. The requirements for batteries in for energy storage devices are relatively high, and the topology of the common distribution network can be improved according to the scale of new energy devices connected to the grid, to ensure that the power system can quickly make the correct response after a fault occurs when the new energy power plant is connected to the grid, and to improve the stability and safety of the supply and distribution system.

### **(3) Strengthen the management of grid connection**

There are some differences in the way new energy power plants are connected to the grid, which makes it difficult to manage new energy power plants after they are connected to the grid. In order to improve the stability and safety of the power system, technicians can build an information management platform to supervise the specific situation of new energy farms after they are connected to the grid, strengthen the data collection and analysis of the power grid, and set up a special supervisory team to carry out



large-scale monitoring of the power grid, so as to timely discover any problems during the operation of the power grid to ensure the safety and stability of the power grid.

## 6. Conclusion

In conclusion, through the analysis of the stability of new energy grid-connection, it is clear that the application of synchronous motor to grid-connection technology in the process of grid-connection of new energy power plants can greatly improve the frequency stability of new energy power grid and play a positive role in ensuring the reliability and safety level of the power system. However, further research should be carried out on the advantages and disadvantages of synchronous motor on grid-connected technology in different scenarios using different new energy power plants, so as to improve the application level of synchronous motor on power grid technology.

## Disclosure statement

The author declares no conflict of interest.

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Tables, lists and equations must be submitted together with the manuscript. Likewise, lists and equations should be properly aligned and its meaning clear to readers. Tables created using Microsoft Word table function are preferred. Place each table in your manuscript file right after the paragraph in which it is first cited. Do not submit your tables in separate files. The tables should include a concise but sufficiently explanatory title at the top. Vertical lines should not be used to separate columns. Leave some extra space between the columns instead. All tables should be based on three horizontal lines to separate the caption, header and body. A few additional horizontal lines MAY be included as needed (example below). Any explanations essential to the understanding of the table should be given in footnotes at the bottom of the table. SI units should be used.

## Supplementary information

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Reference citations in the text should be numbered consecutively in superscript square brackets. Some examples:

1. Negotiation research spans many disciplines <sup>[3, 4]</sup>.
2. This result was later contradicted by Becker and Seligman <sup>[5]</sup>.
3. This effect has been widely studied <sup>[1–3, 7]</sup>.

Personal communications and unpublished works can only be used in the main text of the submission and are not to be placed in the Reference section. Authors are advised to limit such usage to the minimum. They should also be easily identifiable by stating the authors and year of such unpublished works or personal communications and the word 'Unpublished' in parenthesis.

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## Journal

*Journal article (print) with one to three authors*

[1] Yao Y., Xia B. Application of Phase Frequency Feature Group Delay Algorithm in Database Differential Access. *Computer Simulation*, 2014, 31(12): 238-241.

*Journal article (print) with more than three authors*

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## **Book**

### *Book with one to three authors*

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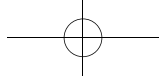
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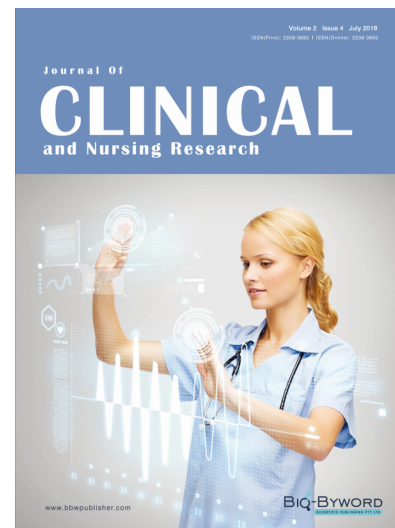
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