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Application of Earthquake-Proof Design in Highway Bridge Design

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Abstract: Highway bridges are an important part of transportation infrastructure. With the rapid development of transportation, the design of bridge construction has received significant attention. The complex environment of some regions necessitates the selection of seismic design to improve the stability of the structure during the design phase of highway bridge construction. This article briefly discusses bridge structures that may be subject to seismic hazards and analyzes seismic design standards to explore their application in the design process of highway bridges, with the aim of providing support for bridge construction.

Keywords: Seismic design; Highway bridges; Design

Online publication: September 2, 2024

1. Introduction

Seismic design is very important during the construction of highway bridges. Since an earthquake will threaten the safety of the bridge structure, the seismic design should be considered to ensure the stability of the bridge structure in the earthquake environment. The safety of highway bridges in operation can be improved by reasonably selecting anti-seismic measures according to the requirements of bridge construction and the characteristics of the environment where the bridge is located [1].

2. Earthquake hazard of bridge structure

When an earthquake occurs, the bridge structure will be affected by seismic waves and there will be various damages. Simultaneously, under the influence of an earthquake, the sand of the bridge foundation may be liquefied, and the bearing capacity of the foundation is insufficient, causing the structure to sink, fracture, and even displacement in other directions. If the bridge foundation is damaged due to an earthquake, the damage is permanent and difficult to recover [2]. Among bridge structures, abutments and piers are important load-bearing structures, which can transfer the seismic load of the structure above the bridge to the foundation. If the bridge is located in a special terrain such as on a mountain, its abutment and pier elevation is relatively large.

Once an earthquake occurs, seismic waves will have a serious impact on abutments and piers, the components will be damaged under the influence of shear force and the plastic hinge will be destroyed. If the earthquake force is repeated, it will also cause serious damage to the abutments and piers and may lead to the collapse of the bridge. Under the influence of earthquake force, the bridge plate is subjected to shear failure, and relative displacement may occur, which will destroy the beam and plate members. If the width of the cover beam is not scientifically designed, the beam structure will collide with each other and the bridge will be damaged under the influence of the earthquake [3]. If it is an arch structure bridge, the earthquake acts on the arch and belly arch, and cracks appear at the arch foot and arch top. In the design stage of some bridges, the seismic performance of the bearing position is not taken into account, resulting in insufficient seismic capability. After the earthquake, the deformation and displacement of the support are relatively large, resulting in damage to the overall structure of the bridge and the gradual expansion of a large number of transverse and longitudinal cracks, which affect the safety of the bridge [4].

3. Analysis of seismic design standards for bridges

When the highway bridge is affected by an earthquake, the structure is seriously damaged, which may affect the safety of people's lives and property. Therefore, it is very important to adopt seismic design for highway bridges. The seismic design standards mainly include the following points.

The first is earthquake probability. According to the historical seismic activity data of the area where the bridge is located, the analysis of the probability that an earthquake may occur within a specific number of years can be designed according to the standards of once every 50 years, once every 100 years, and other intervals.

The second is the action frequency of earthquakes. Earthquake frequency will have an impact on the bridge structure. During the bridge design period, the natural frequency and seismic wave frequency of the structure should be taken into account to prevent resonance phenomena and damage to the structure.

The third is acceleration. Based on the characteristics of seismic wave intensity and frequency, the maximum horizontal acceleration of the bridge is determined when an earthquake occurs. The impact on the bridge structure is reflected through seismic acceleration, which lays the foundation for seismic design.

The fourth is the seismic targets. According to the purpose of the bridge, the performance objectives are determined, including safety limits, critical states, damage limits, and so on. These objectives comprehensively reflect the bridge's deformation and bearing capacity.

The fifth is materials and structure. Depending on the purpose and type of highway bridge, the construction mode and materials are selected. If necessary, reinforced concrete materials should be used for reinforcement structures, or the ductile design of bridge piers and columns should be implemented.

4. Application of earthquake-proof design in highway bridge design

4.1. Earthquake design principles and key points

With the rapid development of technology over time, the design technology of bridge structures is also constantly progressing. The seismic design principle is to consider the strength and stiffness of the bridge and adopt the seismic isolation design at the key position of the structure. This improves the seismic resistance of the bridge structure, ensures the aesthetics and economy of the structure, and meets the operation of the bridge. Based on general earthquake protection design, the following aspects should be adhered to.

Firstly, the reasonable selection of locations. Before highway bridge construction, site selection should be in good geological conditions, flat terrain, and high bearing capacity of the bridge. Before the design, technical personnel should conduct a reasonable analysis of the construction site, master the geological conditions of the site, and make an anti-earthquake design on the premise of clear seismic activity information to prevent the bridge structure from being affected by earthquakes [5].

Secondly, the design of the structural scheme. In terms of the selection of highway and bridge routes and control points, the areas with greater earthquake hazards or areas with relatively high earthquake intensity should be avoided. The design scheme should be determined by taking into account changes in site conditions to ensure the earthquake resistance level of the structure and maximize the control of earthquake hazards.

Thirdly, the analysis of the seismic performance of the structure and the strength of the seismic performance of the bridge structure should be considered from many aspects, including earthquake action and structural characteristics. Seismic wave amplitude, direction, and frequency are the key factors affecting the overall stress of bridge structure. Designers can record the seismic spectrum and analyze it to grasp the possible impact of earthquakes on bridge structures and provide data support for anti-earthquake design. To evaluate the seismic resistance of the bridge, it is important to consider various factors such as structural materials, types, and shapes. Designers can use mechanical analysis and structural simulation to conduct a comprehensive analysis of the stress and deformation of the bridge, and then evaluate its seismic resistance. Considering that the structure is not easy to be damaged under an earthquake attack, this is taken as the basis for anti-earthquake design [6]. For the existing bridge structure, the strength of its seismic performance can be completed through on-site investigation, monitoring, and other ways. After measurement and observation, the damage to the structure can be mastered, and its seismic resistance can be accurately analyzed to guide the subsequent maintenance and reinforcement work.

4.2. Master the main points of structural seismic design

4.2.1. Superstructure

In the process of highway bridge construction, the form and characteristics of the superstructure can have a direct impact on the normal use of the bridge. When designing the superstructure, it is necessary to consider the mechanical properties of the structure, the structure construction, late maintenance, and so on. If the superstructure of the bridge is cracked or worn, it will affect the structural characteristics. To prevent such problems, it is required to improve the performance of the upper structure through design. In the event of an earthquake, large displacements may occur above and below the bridge structure, resulting in structural damage or collapse in severe cases [7].

In this regard, the relative displacement of the upper and lower structures should be taken into account when designing the upper part of the bridge structure. It is necessary to identify common earthquake damage in different parts. For example, under the influence of an earthquake, collisions can occur between the joint of the cover beam and the adjacent beam, potentially damaging the main beam. The bridge joints are affected by earthquakes, with support and expansion joints likely to be damaged. The structure under the bridge can also be impacted, potentially damaging the pier. Additionally, the bridge foundation structure may experience soil slip or sand liquefaction. Therefore, in designing the superstructure, it is essential to ensure that relative displacement remains within a reasonable range to prevent common issues.

4.2.2. Support design

Bridge bearings, located at the upper and lower structural connection points, serve to transfer bridge loads and accommodate structural displacement caused by contraction, temperature changes, and other factors. During seismic events, they also help protect the bridge abutments. Typically, bearings are made from materials such as rubber or steel, which help mitigate lateral vibrations of the bridge structure during an earthquake. Bearings should be selected based on regional environment and bridge characteristics.

When setting bearing capacity, factors such as the number of bearings, bearing point reaction force, bridge constant load, and live load should be considered to calculate the bearing capacity. Generally, the ratio of the maximum reaction force of the bearing to its load capacity should be within 0.05, while the ratio of the minimum reaction force to its load capacity should be above 0.8. At the design stage, the minimum reaction force size is limited to ensure adequate slip capacity of the bearing. There is no need for redundant reserves in the bearing design. For example, if the maximum reaction force is 4,100 kN and the minimum reaction force is 3,700 kN, the bearing capacity should be selected as 4,100 kN [8].

4.2.3. Basic design

The bridge foundation structure design is very important and is relatively hidden. Research shows that more than 70% of the buildings damaged from an earthquake are related to the foundation design, especially since the bridge foundation is in a complex geological environment. Therefore, to control the liquefaction of bridge foundations during earthquakes, design methods are used to improve the bearing performance of the foundation structure and ensure the safety of the structure.

4.2.4. Pier column design

In the design of highway bridges, the pier column is also the focus of the design, which has the function of supporting bridge structure and anti-seismic. During the design of the pier column, the emphasis is on quality control, which can be started from the following aspects.

First, during the design phase, compare the strength of the pier column with the structural strength during an earthquake. This comparison is crucial for optimizing the design of the pier column to ensure adequate bearing capacity. Second, in the reinforcement design of the pier column, calculate the required reinforcement area first, then select the appropriate reinforcement type to ensure the flexural strength and bearing capacity of the structure. This approach improves the stability of the pier column and ensures its seismic performance.

4.3. Application of conventional anti-earthquake design measures

There are several conventional seismic design methods for bridges. Firstly, the strength design. In the initial phase of seismic design, design factors need to be taken into account. Since this design method only considers the seismic acceleration as a factor of bridge structure damage, and cannot consider the influence of the structure itself on the strength of the bridge, there are still limitations in this design method, which may result in the stiffness and strength of the bridge being difficult to meet the demand for earthquake protection.

Secondly, the ductile design. When an earthquake occurs, the bridge structure may produce elastic-plastic damage, at this time we can use the ductile design method. The designer analyzes the characteristics of the bridge structure, taking into account the deformation conditions of the bridge such as plasticity and elasticity under the earthquake action environment, conducts in-depth research on different vibration curves, and accurately calculates the earthquake response force.

Thirdly, is the performance of anti-seismic. Designers carry out seismic design according to the performance of the bridge to ensure the stability of the structure during an earthquake. This design approach is more performance-oriented, close to the specific use of the bridge, and can improve structural safety to a certain extent. The prerequisite of performance design is to define the seismic design objectives, including seismic deformation, overturning, and displacement, and set the seismic performance objectives according to the purpose of the bridge, the use of the environment, and the safety requirements.

According to these specific objectives, we can determine the seismic loads, analyze the bridge structure, and evaluate the seismic performance of the structure according to the changes in displacement and bending produced by the structure under different seismic environments. During this period, designers can simulate the structural changes of the bridge seismic process with the help of numerical analysis. Finite element analysis is also a commonly used analysis method. According to the results of the analysis, the seismic structure is optimized, such as changing the materials, component sizes, structural arrangement, and so on to achieve the design objectives of the seismic performance of the bridge, and to improve the feasibility of the design scheme [9].

4.4. Reasonable selection of earthquake-proof design methods

Conventional seismic design methods are as follows. The first is foundation treatment. For highway bridges located in areas with poor geological conditions, it is necessary to improve the geology through design measures to restore the performance of the foundation and meet operational requirements. For instance, if the rock layer beneath the bridge foundation is shallow, the foundation can be expanded. In cases of uneven geological hardness and high-water tables, to prevent foundation liquefaction, the strength of the bridge can be increased by designing reasonable aperture sizes. This helps avoid geological instability and allows the bridge piles to penetrate deeper into the rock layer, enhancing foundation strength. Additionally, increasing the foundation area can improve seismic performance and ensure integrity during earthquakes.

The second is seismic isolation design. A vibration isolation device is placed between the foundation and the bridge structure to reduce earthquake-induced vibrations. Proper selection of the isolation device and its connection method helps control the bridge's deformation and displacement. Pipeline and accessory parts should be designed to adapt to the movements of the isolation system.

The third is abutment processing. During the design phase, choosing uniform-section piers and avoiding conical structures helps control longitudinal wave stress and maintain structural integrity. If the pier's diameter is large and experiences significant tensile forces, embedded steel bars can connect the pier and the bridge structure to prevent damage to the pier from the bridge deck during an earthquake. Additionally, buffer components like springs can be installed near supports to protect the pier from damage caused by the falling bridge floor [10].

4.5. The use of shock absorption and isolation measures

The design of highway bridges is characterized by its particularity and complexity. The structural height of some bridges may vary, which may increase the influence of earthquake impact. To ensure bridge safety, designers should conduct in-depth analyses of pier structures and incorporate damping and isolation components to strategically arrange the frame. This approach ensures sufficient deformation resistance during an earthquake, helping the structure withstand seismic forces and minimizing damage.

The stability of a highway bridge is closely related to shock absorption design. Designers can use isolation bearings or shock absorption bearings to enhance overall damping, optimize flexibility, and limit earthquake impact. Isolation and damping supports are typically installed at the connections between the abutments, piers, and bridges. Proper use of these supports ensures an effective connection between the abutment and beam, maximizes damping effects and improves overall structural stability.

During an earthquake, the bridge structure will shake due to seismic waves. Isolation or damping supports and dampers can mitigate the force of these waves, reducing their impact. At the design stage, designers should consider factors such as the maximum acceleration of the structure and support displacement to ensure the appropriate selection of isolation and shock absorption supports. The use of lead-core rubber bearings in bridge design can enhance overall seismic resistance. These bearings increase yield shear forces under seismic action, improve structural stiffness, and protect the bridge.

5. Conclusion

To sum up, in the design stage of highway bridges, no matter the selection of seismic design or the application of seismic isolation measures, the principle of local conditions should be upheld. Also, the damage caused by earthquakes to the bridge structure should be clearly defined, the seismic design points should be understood according to the seismic design standards, and the reasonable selection of seismic measures should be combined with seismic isolation and damping measures to ensure the seismic design effect of bridges and improve the effectiveness of structural seismic design.

Disclosure statement

The author declares no conflict of interest.

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Study on Bayu Vernacular Architecture and Culture—Baxian-Old-Courtyard

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Abstract: The vernacular architectural culture of the Bayu region is an important part of traditional Chinese architectural culture, of which the old courtyard in Baxian is a typical representative. The purpose of this paper is to explore the connotation and characteristics of Bayu vernacular architectural culture, and to take the old courtyard in Baxian as a specific research object, to analyze its architectural style, cultural connotation, and its value in contemporary society. The study of the old courtyard in Baxian can not only deepen the understanding of Bayu vernacular architectural culture but also provide a useful reference for the protection and inheritance of vernacular architecture. At the same time, this paper also calls for more people to pay attention to and participate in the protection of vernacular architectural culture, and jointly guard these precious historical and cultural heritages.

Keywords: Bayu culture; Vernacular architecture; Baxian-Old-Courtyard; Protection and utilization

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1. Introduction

Bayu region, a land located in the southwestern part of China, has nurtured a rich culture of vernacular architecture. Among them, the old courtyard in Baxian, with its unique architectural style and cultural connotation, has become a bright pearl of the vernacular architectural culture of Bayu. "Baxian-Old-Courtyard" refers to the traditional courtyards with high architectural, cultural and historical values in Chongqing Banan District, which have the characteristics of Bayu style, Baxian tradition and Banan characteristics, and are called Baxian-Old-Courtyard. These old courtyards, such as Peng's residence, Zhu's compound, Qin's compound, Liao's manor, etc., are not only the homes where the people of Bayu have lived for generations but also the witnesses of history and the carriers of culture. They have recorded the historical changes, social development, and cultural inheritance of the Bayu region, and are the crystallization of wisdom and emotional support of the Bayu people.

However, with the changes of the times and the advancement of modernization, the old courtyards in Bayu County are facing many challenges. How to protect and inherit these historical and cultural heritages while harmonizing them with modern life has become an urgent problem. Therefore, the study of the old courtyards in

Baxian has not only historical and cultural value but also practical significance and social significance.

2. Overview of Bayu vernacular architectural culture

2.1. The perfect fusion of natural environment and architectural art

Firstly, this integration is reflected in the Bayu vernacular architecture on the natural environment compliance and use. Bayu region has complex terrain, mountains, and water, vernacular architecture in the site selection, layout, form, and other aspects are fully considered the characteristics of the terrain and the natural environment. For example, the building is often built on the mountains and water, using the terrain of the height of the staggered, forming a rich spatial layout of the level. At the same time, the buildings also pay attention to the harmonious symbiosis with the surrounding environment, using vegetation, water systems, and other natural elements to create a natural, comfortable, and livable environment [1].

Secondly, the integration of Bayu vernacular architecture with the natural environment is also reflected in the choice of building materials. The vernacular architecture of the Bayu region mostly adopts locally produced timber, small green tiles, woolen stone walls, and other building materials, which not only have local characteristics but also coordinate with the natural environment, making the building more integrated into nature. Simultaneously, the use of these materials also reflects the wisdom and skills of the people of the Bayu region, since the art of architecture has achieved a perfect balance between practicality and aesthetics.

Thirdly, regarding the landscape pattern of the Bayu region and its relationship with traditional houses, we can elaborate on the following aspects. The landscape pattern of the Bayu region is unique, with longitudinal mountain ranges and dense rivers, and this topographical feature has had a far-reaching influence on the layout and form of traditional houses. From one perspective, traditional dwellings often follow the principle of “back of the mountain, face of the water” in choosing the site, i.e. there are mountains behind the houses as the reliance, and water in front as the prospect, which is not only conducive to ventilation and lighting but also implies stability and affluence in life. From another perspective, the shape of traditional houses is also influenced by the landscape pattern, for example, the contour lines of the buildings are often coordinated with those of the mountains, forming a harmonious and unified visual effect. This fusion not only demonstrates the unique natural features and humanistic characteristics of the Bayu region but also reflects the Bayu people’s reverence for the natural environment and their love of life.

2.2. Deep heritage of history and culture

The deep heritage of the history and culture of Bayu vernacular architecture is fully reflected in the old courtyard of Bayu County. As a representative of the traditional houses in the Bayu area, the old courtyard of Bayu County not only carries rich historical and cultural information but also shows the unique artistic charm of Bayu’s vernacular architecture.

The Baxian-Old-Courtyard reflect the diversity of Bayu culture in architectural style and decoration. These courtyards have the characteristics of traditional Bayu architecture and have absorbed elements of various architectural styles such as Huizhou architecture and piercing architecture. The architectural details, such as carvings and colored paintings, also show the unique flavor of Bayu culture. The fusion of these cultural elements makes the Baxian-Old-Courtyard both regionally distinctive and artistically valuable in terms of style.

Baxian-Old-Courtyard also carries rich historical and humanistic connotations. Most of these courtyards have a long historical background and are witnesses to the historical changes in the Bayu region. In the courtyards, we can feel the industriousness, wisdom, and resilience of the people of Bayu, as well as learn historical information about the social, economic, and cultural aspects of the Bayu region.

2.3. Flexible and changeable multicultural mingling and inheritance

Bayu architecture is flexible and versatile. Multicultural mingling and inheritance is an important manifestation of its unique charm. This integration is not only reflected in the diversity of architectural forms and styles but also lies in its deep historical and cultural heritage and inheritance of regional characteristics.

Firstly, Bayu architecture is flexible in form thanks to its construction principle of adapting to the local conditions and mountainous terrain. Whether it is the twelve common methods of adapting to the terrain, such as platforms, hangings, slopes, and drags, or the unique architectural forms such as dry-rail buildings and palatial buildings, they all fully demonstrate the wisdom of Bayu's architecture in adapting to the nature and utilizing the space. This flexibility enables Bayu architecture to display a variety of styles in different terrains and forms a rich and three-dimensional architectural hierarchy.

Secondly, Bayu architecture is the style of the integration of a variety of cultural elements, showing the characteristics of multicultural mingling. On the one hand, Bayu architecture inherited the essence of traditional architecture in Sichuan, focusing on harmony and symbiosis with the natural environment, emphasizing the spatial enclosure and openness of the building, and displaying the aesthetic style of thinness, lightness, elegance, simplicity, and elegance. On the other hand, Bayu architecture has also absorbed the characteristics of foreign architectural styles such as Central Plains Architecture, Chu Architecture, Shu Architecture, etc. For example, the solemn and symmetrical layout of Central Plains Architecture, the dynamic and romantic flavor of Chu Architecture, and the delicate and detailed decoration of Shu Architecture are all embodied in Bayu architecture. Based on maintaining its characteristics, it has selectively absorbed and borrowed certain elements and techniques of Huizhou architecture. Huizhou architecture is based on mountains and water in the overall planning and design layout, which is cleverly conceived, and matches the concept of harmonious coexistence with the natural environment pursued by Bayu architecture. Thirdly, Huizhou architecture pays attention to the symmetrical layout, which is also reflected in some traditional houses of Bayu architecture. In addition, the characteristic elements of Huizhou architecture, such as horse-head walls, brick carvings, stone carvings, and wood carvings, are also used and reflected in Bayu architecture to some extent. This multicultural fusion makes Bayu architecture both regionally distinctive and contemporary in style [2].

Bayu architecture in the decorative techniques and detailing also reflects the multi-cultural integration and inheritance. Bayu architecture is good at using carving, painting, and other techniques to enrich the building's façade effect. These techniques not only reflect the mastery of the traditional craftsmanship of Sichuan but also a blend of foreign cultures and artistic styles. Concurrently, Bayu architecture uses materials from the combination of local characteristics and foreign elements, such as the use of local unique stone, wood, and other building materials, as well as using foreign building materials, forming a unique architectural style.

2.4. The embodiment of the concept of local materials and environmental protection

Bayu architecture emphasizes the use of local materials, making full use of the rich local natural resources. This practice not only reduces construction costs but also reduces the dependence on external resources, in line with the concept of environmental protection and sustainable development. In traditional Bayu villages, buildings are mostly sited on slopes facing the wind and are easy to drain. According to the topography, they are constructed as retreating elevated buildings or attached to cliffs and hanging feet facing the canals, which not only ensures ventilation and moisture-proofing of the buildings but also cleverly combines with the topography, embodying the respect for and use of the natural environment [3].

Typical timbers include pine wood. The Bayu region is mountainous, and pine grows widely, making it one of the most commonly used timbers for construction. Pine wood is light and soft, with straight grain, easy to process, and suitable for building structure and decoration. In addition, cypress is also common in the Bayu area. It is tough, corrosion-resistant, and is often used in load-bearing structures and parts of buildings that require high durability. Moreover, cedar has a special place in Bayu architecture. Because of its fast growth, good material, straight grain, not easy to deform, corrosion-resistant, and insect-resistant characteristics, it has become an important material for traditional Bayu architecture. The cedar bark produced during the processing of cedar is often used as a roofing material because of its superior toughness, more waterproof performance than thatch, and non-perishable characteristics.

Furthermore, typical stone materials used include limestone. The Bayu region is rich in limestone resources. This stone is hard, wear-resistant, and corrosion-resistant, and is often used in the foundation of the building, wall and floor paving. Additionally, granite is also more common in the Bayu area, with rich colors, unique textures, and high decorative qualities, often used in building facade decoration and carving. Beyond that, sandstone is also used. Sandstone has a loose texture, is easy to process, and is often used for carving and shaping architectural details, such as door and window casings, column heads, and other parts.

3. The cultural connotation and contemporary value of the Baxian-Old-Courtyard

3.1. The old courtyard in Baxian is rich in history and has a unique and diversified architectural style

The predecessor of Banan is the thousand-year-old historical county of Baxian, and there are many cultural relics such as ancient towns, ancient villages, and ancient buildings in the territory. These carry the humanistic spirit of resilience, boldness, openness, and tolerance of generations of Banan people and the strong nostalgia of the people of Bayu. Ancient towns and old courtyards are important carriers of cultural tours.

The architectural style of the Baxian-Old-Courtyard is unique. It combines various elements of Bayu and Huizhou architecture, with both the delicacy and subtlety of southern architecture and the simplicity and elegance of Huizhou architecture. This unique architectural style makes the Baxian-Old-Courtyard stand out among the many ancient buildings and become a unique landscape. The architectural style of the Baxian-Old-Courtyard embodies the characteristic of diversified integration. This is not only reflected in the integration of architectural elements but also the integration of architectural layout and function. Baxian-Old-Courtyard features a layout that serves both residential and commercial functions. The front shop of the street courtyard, along with the unique style of the footstools, embodies this multifaceted fusion of styles. Baxian-Old-Courtyard has a deep cultural connotation. Most of these old courtyards carry the long history and rich culture of the Bayu region and are important bearers of Bayu culture. By visiting these old courtyards, people can gain an in-depth understanding of the traditional culture and historical changes in the Bayu area, and feel the heavy historical atmosphere.

The old courtyards in Bayu County are rich in history. Most of these old courtyards have a history of several hundred years, witnessing the vicissitudes of the Bayu region. Each old courtyard contains rich historical stories and cultural connotations, allowing people to feel the weight of history and the charm of culture. For example, the famous Yang Cangbai's former residence, Peng's Residence, Huang's Compound, Bie Hua Shan Fang, Hua Fang Zhu-Ming Yuan, Xue Yuan Shuyuan, Wudou Qiu Xiaoyuan, Shiquan Hall, Hua Jing Yuan Zi and Qin's compound, among which Peng's Residence is a representative building among the old compounds in Baxian [4]. Peng's residence is located in South Hot Spring, Banan District, Chongqing, and is also commonly known as "Peng's Zhuangyuan" or "Peng's Compound," which was built in 1822 in the second year of the Qing Dynasty. With a history of 186 years, it is surrounded by a 5 to 7-metre-high wall, forming a courtyard with four corridors, and was originally the private residence of Peng, a salt merchant in the Qing Dynasty. With its unique architectural style, diversified and integrated features, deep cultural connotation, and rich historical background, the old courtyard in Baxian has become a unique cultural landscape in the Bayu region.

3.2. Inheritance value and protection significance of Baxian-Old-Courtyard

Baxian-Old-Courtyard carries rich historical and cultural connotations. As traditional courtyards with Bayu style, Baxian tradition, and Bannan characteristics in Chongqing, they have witnessed the historical changes and cultural development of the Bayu area. These old courtyards are not only material architectural heritage but also historical witnesses and cultural carriers, which are of great significance to the study and inheritance of Bayu culture.

The old courtyards in Bayu County embody unique architectural and artistic values. These old courtyards are unique in architectural style and diversified integration, both being the characteristics of Bayu architecture. However, the style also absorbed the architectural elements of other regions, forming a distinctive architectural style. Their architectural layouts, carving techniques, and use of materials reflect the wisdom and talent of ancient architects and are of great significance to the study of ancient architectural art and craftsmanship. The old courtyards in Baxian also have important social value. These old courtyards are valuable assets passed down from generation to generation by the people of the Bayu area, carrying the nostalgia and memory of the people of Bayu. They are not only a part of local residents' lives but also an important cultural resource to attract tourists. Protecting and inheriting the old courtyards in Baxian County helps promote the development of local cultural tourism and enhances the popularity and reputation of the region.

Nevertheless, with the acceleration of urbanization and modernization, the old courtyards in Baxian are facing more threats and challenges. Some of the old courtyards are gradually falling into disrepair or even being demolished due to age and lack of protection. Therefore, it is of great practical significance and urgency to protect the old courtyards in Baxian.

The inheritance value and protection significance of the old courtyards in Baxian lies in the fact that they carry rich historical and cultural connotations, embody unique architectural and artistic values, and have important social values. We should strengthen the protection and utilization of the old courtyards in Baxian so that they can continue to contribute to the inheritance and development of Bayu culture.

4. Strategies for architectural conservation and utilization of old courtyards in Baxian

4.1. Scientific utilization to make old courtyards come alive

Conducting in-depth survey mapping and assessment may help to conserve the old courtyards of Baxian. It is necessary to conduct a comprehensive resource survey to understand the historical background, cultural value, architectural features, etc. of each courtyard, to determine which courtyards have the value of development. Concurrently, the current situation of each courtyard should be assessed, and the focus and direction of protection and utilization should be clarified to formulate a scientific conservation plan. Conservation planning should take into account the historical, cultural, artistic, and scientific values of the old courtyards, and ensure that their original appearance and characteristics are not harmed in the process of conservation. The planning should clarify the objectives, principles, measures, and time sequence of protection, and guide subsequent utilization.

Moreover, diversified utilization and development can aid in conservation. The old courtyard of Baxian has rich cultural connotations and unique architectural styles, which can be activated to derive a variety of business forms, such as lodging, book gardens, cultural experience halls, and so on. Through the introduction of modern elements and design concepts, the old courtyard will become a cultural tourism destination integrating accommodation, leisure, entertainment, education, and other multi-functions. Strengthening publicity and promotion is also key. Through media publicity and cultural activities, the visibility and influence of the Baxian-Old-Courtyard will be increased to attract more tourists and investors. In parallel, strengthen cooperation with travel agencies, online travel platforms, etc., to include the old courtyard in Baxian into the tourism line and recommend products to expand its market share.

Through in-depth investigation and mapping, scientific protection planning, diversified use, and development, strengthening publicity and promotion, as well as focusing on community participation and benefit sharing, the old courtyards in Baxian can be brought to life with new vitality and vigor.

4.2. Case study on the conservation and utilization of the old courtyard in Baxian

In recent years, Banan District has systematically developed the Baxian-Old-Courtyard cultural tourism brand. This includes the reservation of several Bayu style, Baxian traditional, and Banan characteristic traditional Chongqing architectures. The revitalization has led to the emergence of bed-and-breakfasts (B&B), bookstores, and other businesses, which have helped revive numerous scattered historical relics. This process, combined with the revitalization of the countryside, idle land, idle houses, and idle labor, paints a picture of livable and beautiful countryside [4].

As one of the important projects of the Baxian-Old-Courtyard cultural tourism brand, Biehua Mountain House has attracted a large number of tourists to experience its unique architectural style and cultural heritage. Through restoration and protection, Bihua Mountain House not only preserves the original historical style but also integrates modern design concepts to provide visitors with a comfortable accommodation environment full of historical atmosphere. Beihua Mountain House also actively promotes the culture of Bayu, so that tourists can enjoy a good accommodation experience, but also a deep understanding of the traditional culture and historical heritage of the Bayu region.

The “Hanafuzhu-Mingyuan” (Flower House Building-Mingyuan) is another representative of the B&B project. The project has transformed the building from an unused farmhouse, retaining original elements such as adobe walls and old wooden beams, while adding new modern accommodation facilities, achieving a perfect combination of tradition and modernity. The clever and ingenious design of Hanafuzhu-Mingyuan has won wide acclaim from visitors. Through the revitalization of idle assets, Hanafuzhu-Mingyuan not only creates employment opportunities for local villagers but also provides a unique rural accommodation experience for tourists.

In addition, B&B projects such as This Mountain Residence and Flower House Story also have their own special features. This Mountain Residence focuses on the integration of ecological protection and natural landscape, providing tourists with an excellent place to get close to nature and relax. Meanwhile, The Flower House Story tells a narrative about flowers, allowing tourists to enjoy the beauty of the scenery at the same time, but also to feel a strong cultural atmosphere.

The success of these B&B projects has not only enriched the connotation of the Baxian-Old-Courtyard cultural tourism brand but also injected new vitality into the development of the local rural economy. Through the effective use of idle land, idle houses, and idle labor in the countryside, these projects have driven local villagers to increase their income and promote the sustainable development of the rural economy. Simultaneously, these B&B projects also enhance the visibility and reputation of Banan District, attracting more tourists to come to sightseeing tours, and further promote the prosperous development of its culture and tourism industry.

Banan District has successfully revitalized some traditional buildings with historical value by creating the

Baxian-Old-Courtyard cultural tourism brand, which has given rise to a diversified range of lodging businesses. The implementation of these projects not only protects the historical and cultural heritage but also promotes the development of the rural economy and the villagers' income, making a positive contribution to the construction of a livable and beautiful countryside.

4.3. Protection and utilization strategies of Baxian-Old-Courtyard

With the acceleration of urbanization and modernization, the protection and utilization of the old courtyards in Baxian are facing many challenges. To protect these precious historical and cultural heritages, it is especially necessary to formulate scientific and reasonable conservation and utilization strategies. Firstly, strengthening laws and regulations is the basis for protecting the old courtyards in Baxian. Improve relevant laws and regulations, clarify the scope of protection and protection measures, and provide legal protection of the old courtyards. In parallel, increase the law enforcement efforts to crack down on the destruction of the old courtyard and ensure the effective implementation of the law. Secondly, exploring diversified ways of utilization is the key to maximizing the value of old courtyards. In addition to traditional cultural displays and tourism development, we can also consider using old courtyards for education, research, and other fields. For example, it can be made into an educational base to carry out historical and cultural education or as a research institution to attract experts and scholars to conduct in-depth research. These ways of utilization not only give full play to the value of old courtyards but also promote the development of related industries. Finally, strengthening public education and publicity is an effective way to enhance the awareness of the protection of old courtyards in Baxian. Through various channels and methods, popularize the historical value and cultural connotation of the old courtyards to the public, and raise the public's awareness and attention to them. Concurrently, encourage and support all walks of life to participate in the protection and utilization of the old courtyards to form a good atmosphere of common participation of the whole society [5,6].

5. Conclusion

In the process of exploring the contemporary value, conservation, and utilization of the old courtyards in Baxian, we are deeply aware that these old courtyards not only carry rich historical and cultural information but also are the vivid embodiment of the unique culture of the Bayu region. With their simple and elegant architectural style and deep cultural connotations, they have become a bridge connecting the past and present, inheritance and development. We should also be aware that the protection and utilization of the old courtyards in Bayu County is a long-term and arduous task. In our future work, we need to constantly innovate ideas and methods, and strengthen interdisciplinary cooperation and exchange, to promote the conservation and utilization of the old courtyard in Baxian County to move forward.

Facing the impact of urbanization and the challenges of modernization, the conservation and utilization of old courtyards in Baxian are particularly important. By strengthening laws and regulations, exploring diversified ways of utilization, and enhancing public education and publicity, we can effectively protect these precious historical and cultural heritages and give full play to their contemporary value.

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Construction Cost Control Strategy of Finished House Based on BIM-5D

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Abstract: Building Information Modeling (BIM) technology can not only achieve project refinement management of the construction process based on a 3D model but also form a BIM-5D model based on the fusion of progress data and cost data to achieve the dynamic control of the whole process of project cost. This paper discusses the application of BIM-5D in the cost control of finished house construction, aiming to provide technical reference for China's finished house project units, so that they can master how to realize the construction of cost control system based on BIM, the monitoring of the key coefficients of the cost, corrective action, to ensure that the project cost deviation is within the controllable range, and to make an effective guarantee for the economic benefits of the project construction.

Keywords: BIM-5D; Finished house project; Cost control system; Cost corrective deviation

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1. Introduction

In recent years, due to economic fluctuations, prices of bulk building materials and equipment in China have become more volatile. This has increased the uncertainty and difficulty of cost control in finished house construction. Additionally, the low degree of industrialization in China's residential decoration sector means that most finished house projects use a menu-type decoration approach, with varying standards, further complicating cost control. Consequently, many housing projects face high input and construction but low output and efficiency. BIM technology, as a widely used digital tool in construction engineering, can establish a 5D cost control model for dynamic cost management in finished housing construction. Therefore, exploring how to achieve cost control of finished house construction based on BIM-5D is essential for the sustainable development of China's architectural and construction enterprises.

2. Connotation of BIM-5D

BIM-5D builds upon traditional three-dimensional spatial information by incorporating the time dimension (4D) and the cost dimension (5D). This integration enables managers to achieve comprehensive and precise project management. The core of BIM-5D lies in realizing full life cycle cost control and management for the project. On the one hand, the 5D multi-dimensional data model constructed with BIM technology allows the project team to intuitively view and analyze detailed data and information from the design to the construction stages. This transparent information-sharing mechanism ensures scientific decision-making and efficiency, reducing cost wastage due to information asymmetry and miscommunication. On the other hand, BIM-5D integrates time and cost management functions, allowing real-time control of the project schedule and budget, visual display of the construction process, and resource allocation, thereby identifying and addressing cost deviations [1].

3. Finished house construction cost control requirements and the application value of BIM technology

3.1. Finished house construction cost control requirements

Firstly, it is necessary to achieve detailed budgeting for controlling the construction costs of the finished houses. In the early stages of the project, a comprehensive and detailed cost estimation should be carried out, and it should cover the full range of materials, labor, machinery, and other costs to ensure budget accuracy and reasonableness.

Secondly, establishing a systematic control system enables multi-dimensional cost control and monitoring, ensuring continuous oversight of budget implementation and timely identification of cost overruns in specific construction stages. Additionally, effective cost control for finished houses requires digital early warning systems. When a cost overrun occurs, digital technology should be used to trigger alarms and early warnings. This approach addresses the shortcomings of traditional manual management, allowing the project team to identify the root causes of cost deviations and take dynamic corrective measures to prevent issues related to price fluctuations, construction changes, and other budgetary challenges.

3.2. Application value of BIM technology in construction cost control

Firstly, based on the BIM-5D model, budget refinement can be achieved. BIM technology, through its digital and visual 5D model, integrates three-dimensional spatial information and cost data, making the budgeting process more accurate and comprehensive. The project team can use the model to detail and quantify the work involved at each stage and link, resulting in precise and comprehensive accounting. This refined budgeting approach will significantly enhance budget accuracy and provide solid data support for subsequent cost control.

Secondly, BIM technology facilitates systematic multi-dimensional cost management. BIM software offers an integrated platform covering design, construction, procurement, operation, and other project life cycle costs. This platform centralizes, manages, and analyzes all project-related cost information, allowing the project team to fully understand and control cost changes across different segments, ensuring that construction stays within budget. Additionally, this systematic approach covers not only direct costs like materials, labor, and machinery but also indirect costs such as management and operating expenses, supporting investment decisions, and business management.

Finally, BIM enables dynamic cost monitoring and early warning for the project, demonstrating strong dynamic management and real-time alert capabilities. During construction, the BIM model records and updates cost data in real-time, allowing the project management team to monitor and analyze cost deviations and potential risks promptly. The BIM system also provides early warning notifications and corrective suggestions, helping the team take effective measures to prevent cost overruns and schedule delays through digital means [2].

4. Construction cost control strategy based on BIM-5D in finished house project

4.1. Background of finished house project

Changchun Surgical – Golden Mansion is located at the interchange of Longhu Road and Beiwan East Street in Changchun City, Jilin Province. This project features small high-rise and high-rise slab floor finished houses with decorative delivery. The Golden Mansion project covers an area of 48,091 m^2, with a construction area of 131,580 m^2. It is adjacent to the large-scale commercial center Beihu Wuyue Plaza and near the Light Rail Line 8. The development includes 30% internal greening, complete supporting facilities, and a 24-hour security system. The buildings adhere to modern aesthetic concepts, blending traditional and contemporary elements to create a comfortable and safe living environment for residents.

4.2. Establishment of 5D construction cost control model based on BIM

In Vanke – Golden Mansion finished house project, under the construction cost control strategy based on the BIM-5D model begins with establishing a 3D model from Computer-Aided Design (CAD) drawings. This model is then enhanced by adding a time dimension and a cost dimension, using Revit software to build the complete BIM-5D model, as shown in **Figure 1**.

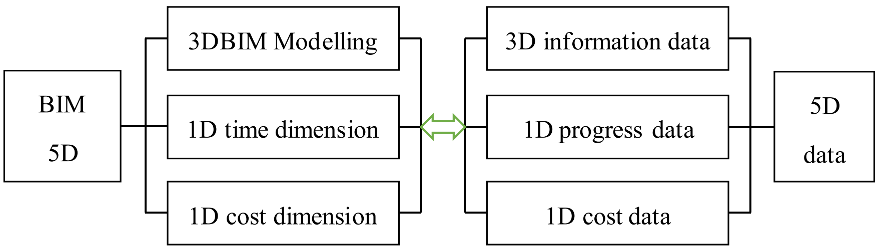

Figure 1. Schematic diagram of BIM-5D model

In the first step, the BIM-3D model is created based on CAD drawings, using Revit software to convert 2D design drawings into 3D models. The model must include all professional information, such as architecture, structure, and electromechanical details, to form a comprehensive 3D model.

In the second step, schedule information is added to create the BIM-4D model. This involves using the Work Breakdown Structure (WBS) to detail project tasks, with each sub-task having a clear time plan [3]. Microsoft Project is used to develop the schedule, and the time data is exported and imported into Revit, linking model elements with time nodes to dynamically reflect construction progress.

In the third step, cost information is integrated into the BIM-4D model. During the operation stage, cost accounting is performed for each WBS sub-task using Navisworks cost estimation software, detailing each cost. This cost data is then imported into Revit and linked with the schedule information, so each model element has actual cost attributes, achieving multi-dimensional integration of time and cost.

In the above BIM-5D model establishment, task decomposition and data integration are the keys to establishing the BIM-5D model. In the operation phase, the project should be decomposed into multiple sub-tasks using WBS, covering the whole construction life cycle from foundation works to house decoration. The actual operation stage requires highly accurate progress information and cost information.

4.3. Establishment of 5D construction cost control system based on BIM

Based on establishing the BIM-5D model, the 5D construction cost control system is constructed, aiming at realizing the comprehensive management and monitoring of the project budget and actual cost data, which covers the four main management functions of the progress plan, budget cost, actual progress and actual cost [4].

The first step involves designing the schedule module. Using the BIM-5D model, the project's building and foundation works are refined to the work package level in phases using WBS, ensuring each work package includes a specific time plan. These plans are then associated with the corresponding components in the BIM model. In Revit, the time plan for each process is imported into the BIM-4D model, achieving dynamic visualization and management of the schedule.

The budget cost module, responsible for managing estimated project costs, integrates quantity data, standard quotas, and market prices in the BIM-5D model to generate the total budget for each WBS task [5]. Navisworks automatically generates a detailed list of material, manpower, and equipment costs which is correlated with each structural part in the 5D model, assigning budget cost attributes to each model component. For the actual schedule module, a detailed schedule is created in Microsoft Project, and the 5D model data is updated based on schedule adjustments and actual data [6]. For actual cost management, detailed records of completed work estimates, actual material, and labor costs are recorded and compared with budget data in real time. By regularly updating the 5D model with actual cost data, the construction unit allows to accurately monitor the actual cost expenditure at each stage, resulting in a "Completed Actual Cost Summary Table."

In the second step, based on the design of these basic functions, the BIM system performs cost deviation and performance analysis using cross-calculation methods with the input data. It regularly calculates completed actual costs, completed budget costs, and planned work costs. This analysis provides cost performance and schedule performance indicators, helping the project team quickly identify cost deviations and their metrics. When deviations are detected, the system triggers a cost early warning mechanism, generates a deviation report, and prompts the project team to analyze and address the deviations [7].

4.4. Confirmation of cost monitoring parameters

After completing the construction of the 5D cost monitoring system, the project construction stage cost monitoring parameters were confirmed. For the Vanke-Golden Mansion finished house project, the project team establishes the monitoring parameters as Budgeted Cost of Completed Work (BCWP), Budgeted Cost of Planned Work (BCWS), and Actual Cost of Completed Work (ACWP) [8]. BCWP represents the amount of work completed (WP) multiplied by the Budgeted Unit Price (BC), reflecting the final cost of completed work for a specific period. BCWS is the amount of work planned (WS) multiplied by the BC, indicating the future cost of planned work. ACWP is the amount of work performed (WS) multiplied by BC, showing the actual cost of work performed up to a certain point in time. It is calculated as the amount of work completed (WP) multiplied by the Actual Unit Price (AC) to determine the actual cost incurred [9]. The Earned Value Method is used to calculate four basic parameters: Cost Variance (CV), Schedule Variance (SV), Cost Performance Index (CPI), and Schedule Performance Index (SPI):

$$CV = BCWP - ACWP$$

$$SV = BCWP - BCWS$$

$$CPI = \frac{BCWP}{ACWP}$$

$$SPI = \frac{BCWP}{BCWS}$$

4.5. Cost monitoring and deviation warning

The above CV, SV, CPI, and SPI are monitored in real-time, and the BIM system automatically carries out deviation analysis and monitoring based on the actual situation calculated from the adopted numbers. Taking the CPI value as an example, during the monitoring of CPI parameters, the CPI warning value is set to five levels, i.e., the deviation level is very high, the deviation level is high, the deviation level is medium, the deviation level is low, and the deviation level is very low. The corresponding CPI values are 0 to 0.6, 0.6 to 0.75, 0.75 to 0.78, 0.85 to 0.95, and above 0.95, respectively. The deviation warning values specifically for CPI thresholds are shown in **Table 1**.

Table 1. Cost bias warning for CPI parameters

CPI value	Deviation level	Hierarchy	Early warning signal
0–0.6	Very high deviation level	I	Red signal
0.6–0.75	High deviation level	II	Orange signal
0.75–0.85	Medium deviation level	III	Yellow signal
0.85–0.95	Low deviation level	IV	Blue signal
$>$ 0.95	Very low deviation	V	Green signal

4.6. Cost Correction

For different types of cost deviation, the Vanke - Golden Mansion finished house project team, combined with different basic parameter relationships, formed different types of deviation and formulated targeted solutions [10]. Specific reference can be made to **Table 2**.

Table 2. Cost deviation parameter relationships and solutions for Vanke - Golden Mansion finished house

Parameter relationships	Classification of deviations	Evaluation indicators	Solutions
	Inputs ahead of schedule, fast and efficient	$SV > 0, CV > 0$ $CPI > 1, SPI > 1$	Downsize crews, slow down construction tempo
	Faster and more efficient but lagging behind in inputs	$SV > 0, CV > 0$ $SPI > 1, CPI > 1$	Adjust for deviations, or maintain the status quo if deviations are small
	Highly efficient, but behind schedule and behind inputs	$SV < 0, CV > 0$ $SPI < 1, CPI > 1$	Increase crew inputs
$BCWS > ACWP > BCWP$	Behind schedule, behind inputs and inefficient	$SV < 0, CV < 0$ $SPI < 1, CPI < 1$	Increase crew inputs to improve efficiency
$ACWP > BCWS > BCWP$	Behind schedule, inefficient but ahead of inputs	$SV < 0, CV < 0$ $SPI < 1, CPI < 1$	Replace highly efficient machinery and crews
$ACWP > BCWP > BCWS$	Inputs ahead of schedule but inefficient	$SV > 0, CV < 0$ $SPI > 1, CPI < 1$	Reduce crew inputs, promote resource balance

5. Conclusion

As analyzed above, this paper researches the application of BIM-5D in the construction cost control of the finished house project, takes Vanke-Golden Mansion project as an example, and explores the establishment process of BIM-5D model, along with the establishment and application strategy of the cost control system based on 5D model. The construction team of the finished house project can learn from this paper to carry out the establishment of the cost control program, give full play to the advantages of BIM technology, effectively control the cost parameter deviation during the project construction process, ensure that the cost deviation is always within the acceptable range of the project, and achieve dynamic cost management based on the perfect model to provide technical guarantee for the implementation of the project construction goals.

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Structural Design of Roadbed and Pavement in Transition Section of Roads and Bridges

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Abstract: As the lifeline of social development, road and bridge projects are the main channel to realize resource transportation and economic circulation. Ensuring the quality of road and bridge project construction is crucial for the development of society, the economy, and people's livelihoods. This paper studies the design of roadbed pavement structures in road and bridge transition sections. It aims to provide technical references and significance for China's road and bridge engineering design and construction units, promoting scientific and standardized design in these actions. This will contribute to the safety and stable operation of road and bridge projects, offering effective technical support. Furthermore, it seeks to foster the sustainable and healthy development of China's road and bridge engineering on a macro level.

Keywords: Road and bridge transition section; Roadbed pavement structure design; Lap plate; Easing transition section; Drainage system

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1. Introduction

As society develops, the demand for road and bridge infrastructure is becoming increasingly diversified. Road and bridge engineering needs to be highly adaptable and functional to meet the multifaceted requirements of economic development and the improvement of people's livelihoods. Therefore, it is crucial to focus on enhancing the quality of design during the planning stage of road and bridge engineering. Meeting the demands of social development depends significantly on the design quality, particularly in the transition sections of roadbeds and pavements. The design of these sections directly impacts the overall construction quality of road and bridge projects. Only through a reasonable and refined design of roadbed pavement structures in transition sections can road and bridge engineering projects meet the quality requirements necessary for social development, effectively ensuring their success.

2. Importance of road and bridge transition section roadbed pavement design

The road and bridge transition section is an important part of connecting the roadbed and bridge section, and its design quality occupies a vital position in the overall project.

Firstly, the rationality of road and bridge transition section design directly affects the stability and applicability of the overall structure of the project. In the road traffic operation stage, the transition section between the roadbed and the bridge junction must ensure a smooth transition due to the differing structural forms. This is necessary to avoid issues such as road surface unevenness and settlement problems caused by structural differences.

Secondly, the design of the road and bridge transition section significantly impacts road comfort and safety. An inappropriate design may cause vehicles to experience jumping and vibrations, increasing driving safety risks, particularly for high-speed vehicles on highways. Therefore, the transition section design must consider vehicle response to ensure a smooth driving surface.

Finally, the design should also account for economic and sustainability factors. The costs of construction and maintenance for the transition section should not be overlooked. A well-designed section can reduce material and labor costs, extend the service life of road and bridge projects, and lower long-term maintenance costs [1].

3. Road and bridge transition section of the roadbed pavement common issues

3.1. Uneven settlement produces steps

The transition section between the roadbed and bridge, as a structural connection node, often experiences uneven settlement due to its unique structural characteristics. This uneven settlement is a common issue in road and bridge engineering. It not only affects driving comfort and safety but also negatively impacts the long-term performance of the roadbed and bridge. Typically, uneven settlement results from differences in stiffness between the roadbed and bridge foundation. The roadbed soil is usually softer compared to the bridge foundation, which is relatively rigid. Vehicle loads and highway gravity can cause significant settlement in the roadbed, while the bridge foundation experiences minimal settlement. This discrepancy creates a noticeable height difference at the junction, leading to the formation of "steps." Such discontinuities can cause driving vibrations, reduce comfort, and even lead to traffic accidents.

3.2. Depreciation problems lead to road and bridge issues

The road and bridge transition section of the roadbed pavement inevitably experiences depreciation over time and with frequent vehicle passage. This is a significant cause of road and bridge damage. Depreciation not only reduces the functionality of the transition section but may also seriously shorten its service life and increase maintenance costs. Depreciation problems typically manifest as material aging and wear. Transition sections are subjected to repetitive stresses from the vehicle wheel loads, causing material performance to gradually weaken. Asphalt pavements may develop cracks and potholes, while concrete pavements may experience spalling and cracking. In regions affected by climate change, high temperatures, low temperatures, and humidity variations further accelerate material aging and exacerbate depreciation issues, particularly when combined with uneven vehicle load distribution.

3.3. Excessive structures causing inconsistent bridge head step heights

In the transition section of road and bridge projects, an excessive number of structures such as bridge culverts and channels can lead to inconsistencies in the bridgehead step height. This phenomenon not only affects driving comfort and safety but may also result in more serious roadbed issues, impacting the service life of the road and bridge project. On one hand, as previously discussed, differences in structural stiffness between rigid elements like bridges, culverts, and passages, and the relatively softer roadbed can cause uneven settlement, leading to noticeable steps. On the other hand, projects with numerous structures often involve complex hydrological environments. Bridges, culverts, and passages are typically located in areas where water flows converge, making them susceptible to water erosion, flood scouring, and changes in water level. If the drainage system is not properly designed, water accumulation during the rainy season can lead to roadbed settlement, further exacerbating the issue of varying bridge head step heights [2].

4. Road and bridge transition section roadbed pavement structure design points

4.1. Lap plate and non-lap plate design considerations

4.1.1. Lap plate design

In the road and bridge transition section roadbed pavement structure design, lap plate design is a key element. A well-designed lap plate not only addresses the issue of bridge bumpiness but also ensures driving comfort and safety. Firstly, the appropriate form of lap plate must be selected, which serves as the foundation for the design. Common forms of lap plates include single-sloping, double-sloping, and flat lap plates. Single-sloping lap plates are suitable for transition sections with significant settlement differences, as they help mitigate unevenness caused by settlement. Double-sloping lap plates are typically used in transition sections where settlement differences are minimal and provide more stability than single-sloping plates. Flat lap plates are appropriate for cases with minimal settlement and favorable foundation conditions but are less commonly used in practice.

Secondly, the length and width of the lap plate design should be determined based on specific engineering conditions. During the design stage, the length of the lap plate must account for the length of the gap reserved before placing the soil. The lap plate needs to span this gap to ensure that the filler settles properly and the plate effectively crosses the settlement zone, maintaining a smooth road surface. However, if the span length is too large, it may damage the original roadbed structure and prism. Typically, the length of the transition section for large bridges should be controlled between 8 to 12 meters, while for medium and small bridges, it should be set between 6 to 8 meters. Additionally, controlling the longitudinal slope change value of the lap plate is crucial in the transition section. The longitudinal slope change must meet the maximum allowable capacity value to ensure smooth and safe traffic flow. To ensure smoothness after settlement, the effective length of the lap plate must be adequately designed, considering all types of loads, including vehicle loads and its own weight, while leaving sufficient safety margins.

Finally, in the design of the lap plate width, it should be consistent with the width of the road surface to ensure continuity and safety. The design should ensure that the ratio of the short to long sides is greater than 2. Additionally, to facilitate road construction and subsequent maintenance, the edge of the lap plate should maintain a 0.5 m interval from the edge of the stone during the design phase. The design should also comply with the relevant technical parameters outlined in **Table 1**.

Table 1. Road and bridge transition section lap plate design technical parameters requirements

Parameters	Requirement	Parameter	Requirement
Length of large bridge overlap plate	8 m ~ 12 m	Length of bridge decks for small and medium-sized bridges	6 m ~ 8 m
Change in longitudinal slope after settlement	< Set maximum capacity value	Load considered at design stage	Vehicle Load, self-weight, safety margin
Slab width	The ratio of short and long sides ＞ 2	Edge to edge of curb spacing	0.5 m

4.1.2. Non-lap plate design

While the use of lap plates in transition sections offers significant advantages, there are also disadvantages. If a lap plate becomes damaged, it can lead to serious losses and require extensive, difficult maintenance. The root cause of bridge deck bumping issues lies in the rigidity differences between the bridge deck and the approach road. For transition sections without lap plates, it is crucial to ensure a proper rigid-to-flexible transition by using semi-rigid building materials. This approach has been widely practiced in road and bridge projects in Shaanxi Province, where practical results have demonstrated that this strategy effectively reduces the likelihood of settlement differences.

When applying a non-plate design, it is essential to enhance the drainage setup behind the platform and ensure that the compaction meets the prescribed standards. If the compaction base is inadequate, the soil's compression modulus has certain limitations. Even if soil compaction reaches 95%, its settlement may still exceed that of lime-stabilized soil. Therefore, the amount of soil used in the roadbed design should be carefully controlled [3].

4.2. Design points for gentle transition sections

The design of the gentle transition section of road and bridge transition section roadbed pavement focuses on several keys, subgrade treatment, filler section, structural layer design, and pavement elevation design [4].

Firstly, subgrade treatment is the primary concern in the design of gentle transition sections. The subgrade must be adequately compacted and stabilized to ensure its bearing capacity and stability meet the requirements. Typically, foundation reinforcement can be achieved through methods such as strong tamping, replacement, or mixing piles to minimize settlement and displacement.

Secondly, the selection of fillers for the gentle transition section significantly impacts the performance of the road base [5]. During the design phase, fillers with good gradation and superior compaction properties, such as crushed stone and gravel, should be chosen to ensure that the durability and bearing capacity of the roadbed. Therefore, during the construction design phase, it is crucial for the construction unit to strictly control the quality of the filler and the paving thickness, ensuring that compaction is performed in layers and that each layer's thickness aligns with design specifications.

Thirdly, in the structural layer design phase, it is essential to account for stress changes in the gentle transitions section and to adopt a reasonable combination of different materials and structural levels to facilitate a smooth transition between the bridge deck and the roadbed. During implementation, a high-strength semi-rigid base layer, such as cement-stabilized crushed stone combined with an asphalt layer, should be used to form a composite structure. This approach not only effectively disperses vehicular loads but also reduces the impact of settlement differences and enhances the overall stability of the gentle transition section.

Finally, pavement elevation design is a critical technical aspect of the gentle transition section. The road surface elevation must be carefully adjusted to ensure a smooth transition between the road and the bridge, avoiding the risk of vehicles "jumping" at the bridgehead due to sudden elevation changes. During the design phase, designers should carefully consider the elevation changes across different road sections and implement a gradual transition to ensure a smooth connection [6].

4.3. Key points of bridge abutment back design

Typically, the back of the bridge abutment primarily employs geotechnical barrier technology. During the design stage, the first key point is the selection and arrangement of geogrid. The design team should choose the appropriate geogrid materials, such as plastic, glass fiber, or polyester grating, based on specific engineering needs. It is essential to ensure that the geogrid possesses high strength and durability. The laying direction and the number of geogrid layers should be determined according to the actual conditions. Horizontal laying is generally effective in improving the stability of the fill and shear strength. During installation, the construction team must ensure that the geotechnical barrier is smooth and tau to avoid wrinkles and slack.

Secondly, the selection of backfill material is crucial [7]. Quality, well-graded fillers such as medium-coarse sand, gravel, and well-graded aggregate should be used. Backfill compaction must meet the design standard, and the construction unit should fill in layers, with each layer's thickness not exceeding 20 cm to 30 cm. Layer-by-layer should be employed to ensure compaction and uniformity, with a compaction rate of ≥ 95%.

Thirdly, during the bearing capacity design stage, the design team must thoroughly consider the load distribution characteristics of the abutment back area to ensure that the bearing capacity meets the design requirements. Geocells within the backfill primarily enhance the tensile strength of the filler and help distribute the load. Therefore, during the design phase, the tensile strength and ductility of the geogrid should be taken into account to improve the overall structural stability.

Finally, for the interface processing design, the joints between the bridge deck and the roadbed should use flexible transition buttresses to mitigate the stiffness differences between materials. The combined effect of the geogrid and filler should effectively alleviate stress concentration issues caused by load changes and foundation deformation [8].

4.4. Road and bridge drainage system design points

The road and bridge transition section, which connects the bridge and the roadbed, is a critical area where the drainage system's design plays a vital role in ensuring long-term stability and performance.

Firstly, the overall layout of the transition section's drainage system should be scientific and reasonable. The design team needs to consider both horizontal and vertical drainage effectiveness while ensuring the smooth flow and capacity of the drainage pipes. The longitudinal drainage system is typically arranged along the center and sides of the roadbed, with drainage gradients set to effectively reduce water accumulation. The horizontal drainage system, which includes side ditches, drainage blind ditches, and horizontal drainage pipes, must ensure that water is quickly discharged during the rainy season [9].

Secondly, the design of the drainage system should include a reasonable road cross slope and longitudinal slope to ensure that surface water is quickly discharged into the side ditches and longitudinal drainage facilities. Typically, the cross slope of the road surface in the transition section should be set between 1.5% and 2.5% to allow surface water to flow quickly into the shoulder and side ditch. Additionally, the selection of drainage facility materials should prioritize high-strength, corrosion-resistant, and water-permeable materials. For instance, permeable concrete blocks are recommended for drainage blind ditches, and polyethylene or polyvinyl chloride (PVC) pipes are preferred for drain pipes to prevent damage and corrosion over long-term use.

Finally, the arrangement of drainage facilities should be meticulously planned according to the actual terrain and hydrological conditions. Side ditches should be placed on both sides of the roadbed, with a width of 0.5 m to 1.0 m, and the depth can be increased according to the bridge's scale to enhance drainage capacity. During the design of drainage blind ditches, they should be placed at the bottom of the side ditches, and maintenance wells should be installed at the connections between the blind ditches and drainage pipes to facilitate later maintenance work [10].

5. Conclusion

In summary, this paper presents research on the structural design of roadbed pavement in the road and bridge transition section. After analyzing the importance of roadbed pavement structural design and exploring common issues in the transition section, the research delves into four key areas: the design of lap plate and non-lap plate extradition sections, easing transition section design, abutment back design, and the design of road and bridge drainage systems. This comprehensive approach aims to form a well-rounded design system for roadbed pavement.

The progress of society is closely linked to the construction of road and bridge projects, and the quality of these projects has a significant impact on social and economic development. Therefore, road and bridge design and construction enterprises should draw lessons from this paper, strengthen research on roadbed pavement design in transition sections, and master scientific design approaches and technologies to ensure the overall quality of road and bridge projects.

Disclosure statement

The author declares no conflict of interest.

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Overall Selection Design Based on the Mega Highway Bridge Project

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Abstract: In the continuous development of the modern highway and bridge engineering industry, the reasonable selection of mega highway bridges and their design is crucial. Based on this, this paper takes the actual bridge project as an example, and analyses the overall selection design of such highway bridges, including the basic overview of the project, the basic selection principle of mega highway bridge project structure and its design strategy, etc., to provide scientific reference for its selection design.

Keywords: Mega highway bridge; Selection principle; Selection design for railway crossing; Selection design for road crossing

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1. Introduction

In the process of selecting and designing the structure of the mega highway bridge project, the staff should first clarify the basic project situation. Then, based on this, the selection principles of such structures should be analyzed scientifically. Finally, taking into account the actual situation, reasonable measures should be taken to carry out the overall structure of the selection and design. So that the structure can be designed reasonably to meet the actual construction and application needs.

2. Project overview

The study is about the selection and design of the structure of a highway mega bridge project. The bridge is located on the highway in a standard two-way six-lane form, and its design speed is 120 km. the overall length of the mega highway bridge is about 3.4 km, and its line needs to cross the city main road, city and township river, embankment highway, West-East Gas Pipeline, township river, waterway, city railway, and so on. **Table 1** shows the cross-angle design of the mega highway bridge project and its crossroads and rivers along the route.

Table 1. The design of the mega highway bridge project and its crossing roads and rivers along the route

Serial number	Crossing roads/rivers	Designing cross angles
1	City Trunk Road No. 1	42°
2	City Trunk Road No. 2	134°
3	Urban Trunk Road No. 3	27°
4	Urban and Rural Level River	142°
5	Top of Dike Road	138°
6	West-East Gas Pipeline	38°
7	Township River	42°
8	Waterways	145°
9	Urban Railway	50°

This paper mainly analyzes the overall selection design of the mega highway bridge structure.

3. The basic selection principle of mega highway bridge engineering structure

In the process of selecting and designing the structure of the mega highway bridge project, the designer should combine the construction and application requirements of the actual project, and determine the basic structural selection principles through the comprehensive consideration, analysis, and evaluation of various factors according to the actual situation on the site.

According to the actual situation of the mega highway bridge project and its specific construction and application needs, when the structure is selected and designed, the basic selection principles include the following.

(1) The selection technology of the mega bridge structure should be sufficiently advanced, and the overall structure needs to be safe, reliable, durable, practical, and economically reasonable.

(2) Specific selection: The designer needs to be on the route of the linear index, smoothness, hydrogeological conditions, road traffic requirements, etc. to do a comprehensive consideration so that it is sufficient to have the conditions of adaptability [1].

(3) The upper part of the mainline bridge should use an assembly prefabricated structure with a standard span. For spans below 20 m, a prestressed hollow plate should be selected, while spans between 20 m to 40 m should be determined based on a variety of designs.

(4) When designing for crossings over highways, rivers, and waterways, designers should comprehensively consider the impact of the substructure on traffic, navigation, flooding, etc., and strive to align it with the direction of crossroads and rivers to minimize pier turbulence, cross-flow, and the effects of water barriers.

Adhering strictly to these design principles ensures that the overall design, construction, and application of the mega highway bridge structure are optimally protected and effectively minimize adverse impacts on surrounding infrastructure, achieving the most scientific and reasonable design outcome.

4. Overall selection and design strategy of mega highway bridge structure project

In the overall selection and design of a mega highway bridge structure project, the designer must create a reasonable design for each key bridge section based on the specific design and construction requirements, while considering the actual conditions of the project site. The bridge structure design focuses on three key areas: crossing railways, crossing rivers and waterways, and crossing roads. For these key areas, the designer should develop a variety of design options, conduct a comprehensive comparison and evaluation of these options, and scientifically determine the best choice. This approach ensures the quality of design selection for each critical point in the bridge project, thereby providing robust support for the overall design quality. The following is an analysis of the practical application of the overall selection and design strategy for the mega highway bridge project.

4.1. Selection and design scheme of the bridge across the railway

Site investigations reveal that the bridge crosses the railway at a roadbed height of approximately 7 m, with a crossing angle of 40° between the bridge line and the railway line. According to the overall design principles, the upper span and abutment arrangement must comply with the railway's clearance standards. Specifically, the clearance height of the upper span should not be less than 7.96 m, and the clearance at the top of the railway electrification pole should exceed 20 cm. For the underpass design, the clearance height should be at least 5.5 m. Considering various aspects such as bridge construction, pipeline integration, drainage, and future maintenance, the designer compared three options: a transverse upper span, a small box girder upper span, and an underpass railway [2].

Further analysis of the site conditions indicates that an underpass design would require a split-width passage, occupy significant space, and involve complex jacking construction due to the large crossing angle between the box structure and the railway. This would pose considerable construction challenges and risks, potentially disturbing the railway's roadbed and negatively affecting its quality and traffic flow. Additionally, the underpass would require a dedicated pumping station for rainwater, increasing long-term operation and maintenance costs. Therefore, the underpass option is not suitable for this bridge design.

If a small box girder upper span were used, the piers would need to be placed on the railway slope, increasing construction risks. The construction of the banner plate would also need to occur near the contact network, further elevating the overall construction risk. As a result, the small box girder upper span is also not suitable for this project.

A transverse T-beam structure, on the other hand, would have a smaller footprint, requiring construction only within the railway blockade area, thus minimizing disruption to railway traffic and ensuring higher construction safety. After considering all these factors, the designer decided to adopt a transverse T-beam structure with a 2 × 80 m specification, featuring staggered holes and split widths to span the railway. This design meets the required principles and accommodates the actual construction and operational needs.

4.2. Cross-river and cross-channel bridge selection design program

Site visits for the mega highway bridge construction revealed that the bridge structure needs to cross three consecutive urban main roads, a river, and a waterway. The crossing angles between the bridge and the roads and waterways are relatively small, with significant changes before and after the crossings. The river's width at the site is approximately 120 m. During the specific design process, the designer must thoroughly collect all relevant information and coordinate with local water conservancy, and water and land transport departments during the pre-design phase. This coordination is crucial for making a scientific determination of various boundary conditions, including road clearance, water level design, embankment requirements, water obstruction rate, berm section, waterway clearance, flooding compensation, and collision avoidance requirements. Based on these considerations, the bridge structure selection and design program can be scientifically determined [3].

Since the bridge project crosses a Class VII channel, with a wide estuary and a small crossing angle with the river, the impact on water conservancy and flood control has become the primary constraint in the design selection process. Given this, the designer must first fully consider the requirements of the Class VII channel. Following field inspections and coordination with relevant authorities, the clearance requirement was determined to be 18 by 3.5 m. Considering the site conditions and various factors, the initial design proposed a structure comprising a combination of four 50 m T-beams and two 40 m assembled prestressed concrete box girders, with six spans to successfully cross the river and its embankments.

During the design process, after consulting with flood assessment experts, the designer increased the bridge span to accommodate flood discharge needs, as the river is a key channel for local flood relief. With significant elevation on both sides of the river and minimal embankment, placing bridge abutments within the river was deemed unsuitable, and the water resistance ratio of the abutments was controlled within a range of 5% to 7%. Based on these considerations, the designer, following expert recommendations, proposed two design options: a variable cross-section suspended prestressed concrete box girder and a steel box girder, tailored to the specific structural requirements of the bridge's superstructure and substructure.

For the variable cross-section suspended prestressed concrete box girder, the designer, following expert recommendations, placed the piers at the normal water level line. The span of the main bridge was designed to be 115 m, and the main piers were designed as solid piers [4]. For the steel box girder, the designer reduced the weight of the superstructure based on the actual conditions and designed the substructure with elliptical variable cross-section abutments oriented in the direction of the water flow. The span of the main bridge was designed to be 55 m, with the projected width of the abutment in the direction of the water flow set at 2.1 m. After comprehensive consideration of factors such as cycle time, maintenance difficulty, and the entire lifecycle, the designer decided to adopt the steel box girder design scheme, incorporating special water compensation measures based on flood and navigation assessments.

Additionally, two options were proposed for the steel box girder structure: one with a lower part designed as a double-column pier structure and the other with an elliptical variable cross-section pier structure in the downstream direction. Upon evaluating construction difficulty, structural stress, economy, aesthetics, and other factors, the designer found that the elliptical variable cross-section pier structure offered simpler construction, better structural performance, lower costs, and superior aesthetic integration. Therefore, the designer chose the elliptical pier design scheme [5].

4.3. Across-the-road bridge selection design program

Since the mega highway bridge needs to cross multiple city main roads at small crossing angles, the designer must carefully analyze and design the crossing road scheme. Field investigations reveal that the crossing angles are as follows: approximately 42° with City Trunk Road No. 1, 135° with the river at pile number 443.7 m, 38° with the West-East Gas Pipeline at pile number 132.1 m, and around 145° with the navigation channel and embankment road at pile number 427.8 m. This indicates significant variation in crossing angles along the bridge [6]. Given these conditions, the designer developed three options for crossing the roads: a positive incline bridge design, an oblique incline bridge design, and a reverse incline bridge design [7]. After evaluating construction difficulty, impact on the surroundings, economic factors, and aesthetics, the diagonal bridge option (i.e., split-width staggered holes) was selected as the recommended design.

Additionally, the designer considered the impact of the West-East Gas Pipeline (WEP). To accommodate operational and maintenance needs, the design ensures a minimum horizontal clearance of 5 m or more between the bridge abutments and the pipeline [8].

4.4. Overall bridge selection design program

After developing, selecting, and determining the design schemes of each bridge section, the designer has formulated a comprehensive design for the key nodes of the mega highway bridge project. The overall design scheme is as follows.

(1) For bridge sections without major control factors but with secondary control factors, the designer has opted for a combined box girder structure with a 30 m specification. A single diagonal connection will facilitate the transition of the box girder, forming the foundation of the mega highway bridge project. This selection represents the optimal design scheme for the bridge.

(2) The total length of the bridge structure is approximately 3.4 km. The superstructure primarily consists of transverse T-girder structures, steel box girder structures, prestressed assembled concrete continuous box girder structures, and prestressed cast-in-place continuous concrete box girder structures [9].

(3) The lower abutment structure includes solid abutments, elliptical variable section abutments, gantry abutments, and column abutments.

(4) The bridge abutment utilizes ribbed plate platforms and seat plate platforms, with drilled piles serving as the foundation [10].

5. Conclusion

In summary, when selecting and designing a mega bridge structure in highway engineering, the designer must first clarify the basic project profile, including the design and application requirements of the mega bridge and the actual conditions of the construction site. This helps in identifying key factors and establishing fundamental selection and design principles. Based on this foundation, the designer can then perform a comprehensive selection and design process for the mega bridge structure, ensuring it aligns with site conditions and meets the project's design, construction, and application needs. This approach effectively ensures the rationality of the overall structural design, maximizes structural advantages, minimizes adverse impacts on surrounding infrastructure, and supports the successful construction, application, and development of the mega bridge project.

Disclosure statement

The author declares no conflict of interest.

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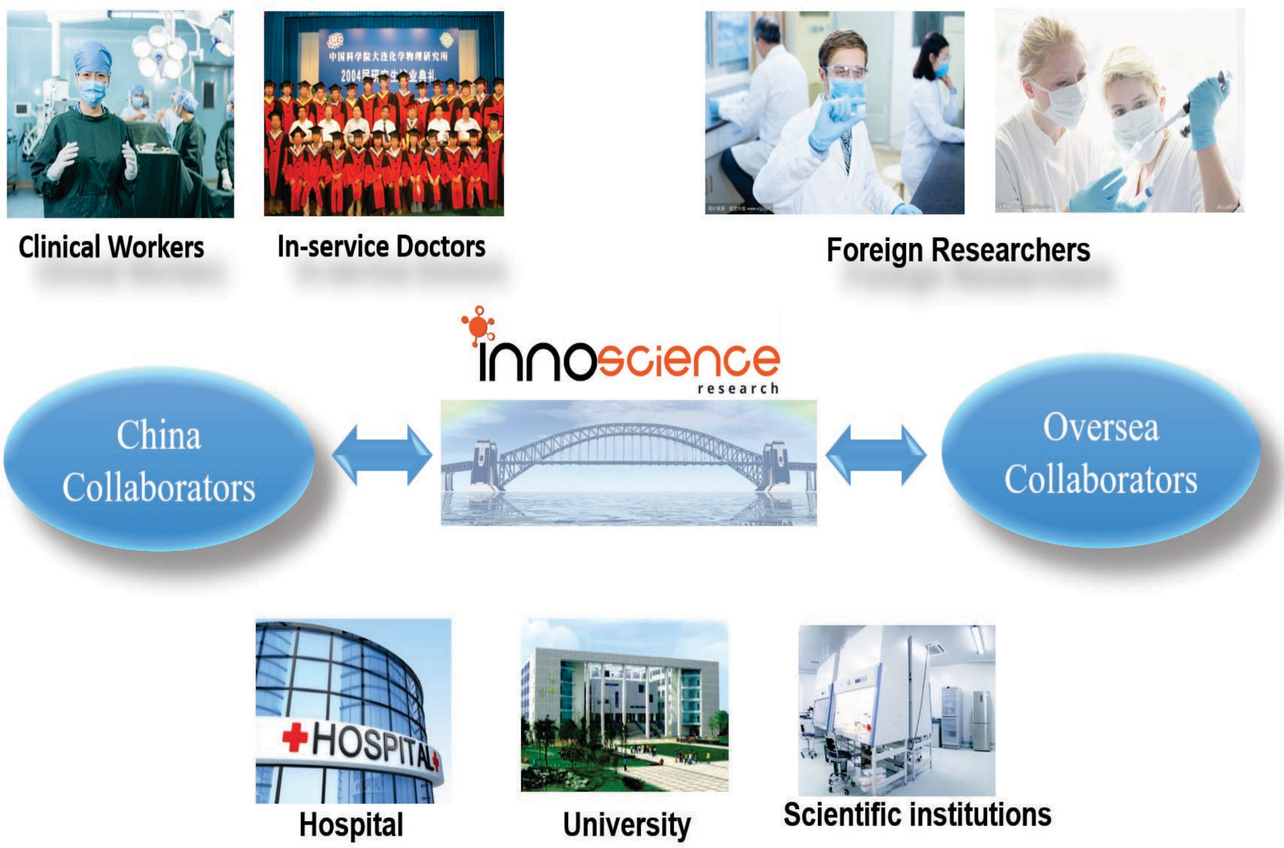

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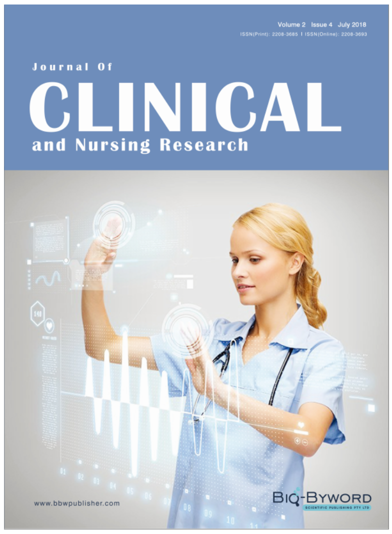

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