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Analysis of Highway Subgrade Slope Protection and Support Technologies

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Abstract: As an important transportation hub in China, the traffic volume and driving speed are important aspects of expressways. Therefore, the protection requirements for roadbed side slopes are higher, and it is necessary to resist rainwater erosion and other damages by protecting the side slopes. Therefore, it is necessary to adopt effective technical means of subgrade protection and support. This paper mainly summarizes the characteristics of highway subgrade slope protection construction and slope protection and support technologies.

Keywords: Expressway; Embankment slope; Protection; Support technology

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1. Introduction

The scale of expressway construction has been expanding continuously. China's expressway mileage has reached 169,100 kilometers by the end of 2021, which made travelling much more convenient. The main construction feature in expressway construction is that there are many sections of deep excavation and high filling. In order to ensure the quality of expressway construction and the stability of the roadbed and subgrade, it is necessary to strengthen the protection and support of the subgrade and slope. Suitable application of protection and support technology methods should be determined during the design stage while considering the condition of construction site to ensure the stability of the slope. Combined with the concept of green architecture, an ecological slope can be created.

2. Characteristic analysis of highway subgrade slope protection

Highway subgrade slope protection is a reinforcement for highway subgrades, and the foundation is stabilized through the construction of the side slope, so the requirements for it are relatively high. Therefore, it is necessary to summarize the construction characteristics in combination with the environment of the construction site and the technologies used, and to control the construction parameters.

(1) High requirements for construction coordination

The scope of expressway embankment slope construction is wide, the project volume is large, and the technical requirements for construction are high, which requires the cooperation and coordination of different construction personnel. Expressway construction projects are generally divided into different sections, which are constructed simultaneously. Moreover, the terrain conditions and geological structures of each section is different. Therefore, it is necessary to work together to ensure that the process of construction can be carried out smoothly. Special technical personnel should be employed to strengthen overall construction management and ensure the completion of the project by coordinating different parties.

(2) Susceptible to external influences

The construction of expressway embankment slope requires personnel of different professions, so it involves many departments. Besides, the construction of subgrade slopes require are many types and large quantities of equipment and materials, which means that they can be influenced by many external factors. If these factors are properly controlled, it will lead to construction quality problems[1]. The construction of a subgrade slope takes a long time. It usually takes several years to complete a project, and severe weathers during construction will be inevitable. At the same time, the skill level and quality of each construction personnel are different, which will also affect the construction quality of expressway embankment slope. Therefore, it is necessary to comprehensively consider various influencing factors and external conditions to ensure the smooth construction of embankment slope protection.

(3) Instability of expressway subgrade slope

On the one hand, the instability of expressway embankment slope is caused by damages like curved surface and plane damage of the slope surface, which typically occurs 2 meters under the slope surface. Because the sliding force is greater than the anti-sliding force, the slope surface is deformed, causing landslides. Due to its great hazards and serious consequences, landslides should be emphasized in the design and construction of embankment slopes. Slope collapse is also a major problem, which is usually caused by flood damage. In terms of the scope and factors of collapse, subgrade slope collapses can be divided into different states such as chipping, spalling, and collapsing. Rock-soil slopes are more prone to weathering and spalling under rain and shine. If the slope is not protected in time after excavation, the rock-soil composition will become granular and slide along the slope[2]. Collapses are prone to occur at steep slopes, causing rock blocks to topple along joints and layers, and collapse after losing their supporting force. When landslides occur, which lead to a large amount of alluvial deposits, those deposits would gather at the slope toe, which is also leads to a collapse.

3. Highway subgrade slope protection technologies

There are many types of expressway roadbed slope protection technologies. Each technology has its own advantages and disadvantages. Therefore, it is necessary to choose a reasonable construction method depending on the nature of the project, so that the slopes can be firmer and better protection can be provided. Besides, the construction costs should also be controlled. After comprehensive consideration of various factors, the slope protection can then be construction accordingly.

(1) Slope protection of expressways

Plastering is a relatively important means and method of slope protection, and it is mainly used in soft rock formations and rock formation slopes that are easily weathered. Generally, the thickness of the plastering surface is controlled at 3–7 cm, and it can last for 6 to 8 years. Soil compaction is also a relatively common protection method, which is generally used in the restoration of soil slopes. However, the slopes cannot be steeper than 1 : 0.5. Generally, the thickness of the compacted layer is controlled at 10–15 cm, which is thicker than plasters. The protection strength of a hammered surface is higher than that of the plastered surface, which can better resist the erosion of rainwater, and its general service life is 8–10 years. In addition, the spraying method can also be used to protect the slopes. The spraying method involves spraying concrete, mortar, etc., which is more suitable for joint cracks and slopes that are easily weathered. Although this method is convenient and provides good protection, it is costly and does not have a nice appearance.

(2) Vegetation method

Vegetation is a relatively common slope protection method, which is mainly used in low slopes and stable structures, with minor slope erosion. Generally, this method can only be applied for slopes of less than 6 m high, and there should not be heavy water flow at the slope. However, planting grass is not suitable for rock slopes. Instead, biological protection technology should be adopted for rock slopes[3]. Grass planting protection requires less labor and is conducive to highway landscape greening. Tree planting is also a relatively common protection method, mainly used in places with relatively gentle slopes, or on river bank slopes. Planting trees stabilizes the slope and reduces water erosion. Planting trees can prevent soil erosion due to their well-developed root-system, and growth rate can be increased through the combination of grassland and shrubs.

(3) Erosion protection technology

Expressway subgrades adjacent to the river are vulnerable to erosion. After erosion, the side slope may be damaged by embankment collapses or landslides, causing serious consequences. Therefore, in order to effectively prevent the erosion of the embankment slope and ensure the stability of the embankment structure proper erosion protection is necessary. Direct protection involves building retaining walls or any form of solid structures, whereas indirect protection involves adjusting the flow rate and flow direction of the waters through the setting of structures in a way that prevents roadbed erosion, such as dams and spur dikes.

4. Highway subgrade slope support technologies

Subgrade slope support technology can be used to improve the safety of expressway construction. The slope support technology used is determined based on the mechanical characteristics and structure of the highway itself. The most common method of roadbed slope support technology is by building retaining walls. There are many types of retaining walls: gravity retaining wall, anchor retaining wall, reinforced retaining wall and cantilever retaining wall, and many more.

(1) Gravity retaining wall

In general, gravity retaining wall is the most commonly used method in expressway subgrade slope support. Gravity retaining walls are heavy, which helps balance the pressure on the ground. Retaining walls are mostly made of mortar masonry or flake concrete depending on the site conditions. The material of the retaining wall must meet the relevant technical requirements, and the construction material can be reasonably selected in combination with the construction site environment[4]. Gravity retaining walls are generally used in road sections with rich stone materials and high foundation bearing capacity.

(2) Anchored retaining wall

Anchored retaining walls uses the original soil at the construction site as the basis, and the stability of the soil is strengthened by setting metal anchors and installing steel mesh and shotcrete on the excavation surface of the soil. The soil and the concrete structure should bind together to prevent the slope from collapsing[5]. Before excavation, the control wires should be checked first to ensure that the excavation is carried out in strict accordance with the drawings to prevent under-excavation or over-excavation. To ensure that the subgrade retaining wall is anchored, the materials used in the production of anchor rods must first undergo field tests and be approved by the supervisor before construction. The ratio of cement and accelerator must be suitable to ensure the stability of the slope structure[6].

(3) Reinforced retaining wall

Reinforced soil retaining wall refers to adding grids into soil, and stability of the retaining wall is maintained through the friction between the grids and the soil. The composition of reinforced retaining wall includes faceplates, tie bars, and fillers, and it is mainly used in filling road sections with relatively flat terrain. Reinforced retaining wall itself has better tensile effect and strong flexibility[7]. Therefore, it allows slight deformation of the foundation, so it is widely used in areas with low foundation bearing capacity and restricted areas.

(4) Cantilever retaining wall

Cantilever retaining wall is one of the more commonly used methods in the protection and support of expressway subgrade slopes. Cantilever retaining walls are mostly made of reinforced concrete. The composition of the wall includes vertical wall, heel board, toe board, and other structures, and the cross-sectional area of the wall is small[8]. The gravity of the soil at the heel plate can effectively prevent and resist the overturning and sliding of the retaining wall. Cantilever retaining walls are generally used in areas where the height of the slope is less than 5 m and with low bearing capacity, and it occupies less land.

(5) Anti-slide piles

The anti-slide pile method is where anti-slide piles are embedded in the ground for the treatment of landslides or the pre-reinforcement of slopes. The principle of this method is to use the strong resistance of the anti-slide pile to resist the upper sliding force or earth pressure and transmit it to the lower stable stratum[10]. Anti-slide piles are a commonly used slope reinforcement method, which can not only effectively control slope slippage, but also form slope pre-reinforcement when used together with prestressed anchor cables. Anti-slide piles should be placed at appropriate positions of the sliding body to achieve effective reinforcement[10]. If the sliding force is relatively large, one or two rows of anti-slide piles can be considered.

(6) Buttressed retaining wall

A buttressed retaining wall involves placing a force arm along the cantilever retaining wall to serve as an auxiliary support, resulting in a buttress-style retaining wall formed by combining the heel plate and the force arm. The structure of a buttressed retaining wall is relatively simple, and it is thin, which makes it easy to build. The retaining wall is light-weight and has a small cross-sectional area, so it has high requirements for construction materials. Buttressed retaining wall can be used for expressway foundations with relatively low bearing capacity, such as expressways in earthquake-prone areas or areas where stones are scarce. Buttressed retaining walls can maintain the stability of the high-fill expressway section, reduce the amount of earth and stone used, and reduce the construction area.

The small section of the buttress retaining wall helps reduce the gravity of the heel plate, thereby avoiding potential risks like side shifting and overturning. Additionally, it enhances the force-bearing capacity of the retaining wall. Buttressed retaining walls can have pre-supported baffles welded to embedded parts in concrete, and soil poured into the retaining wall. This construction method occupies minimal space, has a short construction period, and meets environmental protection standards.

5. Conclusion

In summary, the application of expressway subgrade slope protection and support construction technology requires implementing targeted treatment measures that align with the characteristics of the expressway subgrade slope. This approach helps avoid potential engineering quality issues. Suitable support methods should be adopted depending on the construction site of the expressway and the structure of the surrounding buildings. By adopting these measures, subgrade slopes can be better protected, allowing for a comprehensive deployment of the construction site while ensuring the stability of the roadbed slope

Disclosure statement

The authors declare no conflicts of interest.

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Analysis of Interchange Exit Safety Technology

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Abstract: In order to improve the safety of the exit of expressway interchanges, the main problems and influencing factors of interchange exits are analyzed according to the number of traffic accidents at expressway interchange exits in China. Some suggestions and countermeasures are then put forward from the aspect of safety technology for future reference.
Keywords: Interchange; Exit safety; Safety guarantee

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1. Introduction

In view of urbanization, the construction of urban road network has been expanding in China. As an important part of the road network, interchanges are constantly increasing in scale and quantity. There are two types of interchanges: full interchange and semi-interchange, and the interchanges can be divided into three-level interchanges and five-level interchanges according to the traffic volume. However, there are still some problems in the design of the expressway interchange exits, such as the unreasonable design of the exit ramp and insufficient safety facilities. Accidents occur frequently at interchange exits. According to many statistics at home and abroad, accidents at the ramps of the expressway interchanges account for 30% of expressway traffic accidents. Among them, accidents on off-ramps are almost twice as high as on-ramps. Most of the research on the safety of interchange off-ramps at home and abroad discuss about different safety elements separately, failing to realize the synergy of multiple elements, and lacking the construction of the safety evaluation system and design method of interchange off-ramps[1-6]. Interchanges play an important role in the transportation system. However, with the continuous increase in the number and scale of interchanges, the problems in their safety and security technologies are also emerging.

2. Case study

A high-speed section with a total length of 552 km was constructed in four sections, forming a road network structure consisting of "two hubs and four interchanges." According to statistics, there were 4,495 traffic accidents in this section from 2012 to 2019, which caused 861 deaths and an economic loss of 290 million yuan. Among the traffic accidents, 97.9% of accidents caused human casualties; followed by mechanical damages such as motor vehicle collisions, tire blowouts, and vehicle rollovers, accounting for 32.3%, 13.2%, and 14.5%, respectively. There were many types of traffic accidents. Through the investigation and analysis of the accident scenes, it was found that the exit ramp of the expressway lacked safety facilities such as deceleration signs, speed limit signs and other warning signs, and these facilities were set up after traffic accidents occurred. Without proper facilities and signs, driver will not be able to brake in time. In addition, due to the improper design of the exit ramp, the failure to set up emergency lanes and diversion lines,, and insufficient speed control measures, drivers often speed. Because accidents were happening, the relevant departments renovated the interchange exits. According to renovation plan, the shape of the exit ramp will be changed from a "T" shape to an "L" shape. Vehicles turning left at the exit ramp of the interchange will directly enter the left-turn lane of the main line, and vehicles turning right will enter the right-turn lane of the main line. The linear design of the transformed interchange exit ramp is shown in Figure 1, which meets the requirements of the "Technical Standards for Highway Engineering" (JTGB01-2014)[7].

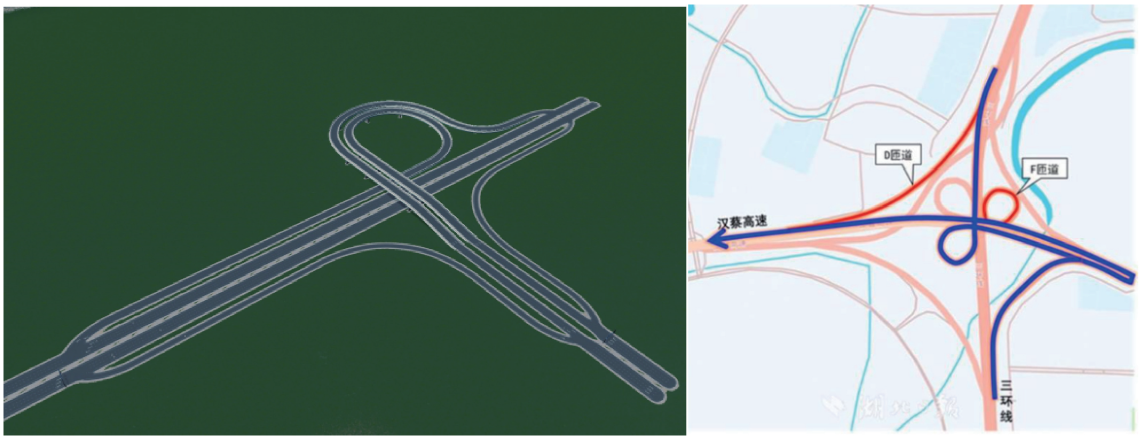

Figure 1　Exit ramps (left, "T" shape; right, "L" shape). Translation: (from left to right, top to bottom): Hancai Expressway, D ramp, F Ramp, Third-Ring Road

3. Problems and influencing factors in the safety design of interchange exits

3.1. Problems

Through the analysis of traffic accidents at interchange exits, several problems have been identified: First, the designed speed limit of the ramp does not match the actual operating speed. Taking this expressway as an example, the designed speed limit is 40 km/h, but the actual operating speed is about 70 km/h. Secondly, the horizontal and vertical alignment indicators of the entrance and exit are unreasonable. In cases where the angle is too small or too large, it becomes difficult for vehicles to make turns. Additionally, there are no warning signs when the ramp crosses the main road. The fourth problem is the improper design of emergency lanes. After analyzing the types and causes of expressway exit accidents in our country over the past ten years, it was found that the primary cause of such accidents is excessive speed when vehicles enter the ramp at the entrance and exit. This factor accounts for 81.0% of the total accidents at the entrance and exit points. The second leading cause is the improper operation of lane changes when vehicles enter the ramp, along with poor driving trajectories and the unreasonable placement of deceleration facilities. The road design (including alignment, line of sight, etc.) and condition of the driver (including fatigue driving, speeding, etc.) also contribute to traffic accidents.

There are three typical characteristics of a major traffic accident: (1) The number of traffic accidents that occur each year is roughly the same; in 2018 and 2019, with the rapid development of expressway construction and with the continuous growth of traffic flow, the probability of a major traffic accident has increased. (2) The main cause of a major traffic accident is speeding. Besides, due to factors such as road construction and increase in traffic flow have also contributed to the increase of traffic accidents. (3) Under normal circumstances, it often takes a long time to resume normal driving after a major traffic accident.

3.2. Influencing factors

There are many factors affecting traffic accidents at interchange exits, including drivers, vehicles, road environment, traffic management, and other factors[8-11]. Among them, the driver's driving behavior is the most important factor. In addition, the road environment also contributes to the occurrence of accidents to a certain extent. As an important node between the interchange and the expressway, the interchange exit directly determines the traffic capacity and service level of the expressway. For ordinary roads, the traffic capacity of the interchange exit is low, but the probability of traffic accidents is high. In contrast, for expressways, the traffic capacity of the interchange exit is high, but the probability of traffic accidents is low. In addition, traffic management measures and traffic signs and markings also have a certain impact on the occurrence of traffic accidents. In short, there are many factors that affect the occurrence of accidents at interchange exits, which need to be considered comprehensively during the design stage.

4. Safety measures for interchange exits

In an interchange, the traffic flow from the main line and the ramp is heavily intertwined, and the exit experiences a relatively high volume of traffic. This complexity in traffic conditions contributes to an increased likelihood of traffic accidents. Therefore, the safety of exits is a very important issue in the design of interchanges. The exits should be designed according conditions like the speed and trajectory of the vehicles on the ramp, the traffic capacity and speed of the entrance and exit, the connection between the main line and the ramp, and the driver's behavior[12-13]. For locations prone to traffic accidents, corresponding measures should be taken to reduce their safety risks. Based on our analysis, the safety measures for the exit of the interchange include improving the traffic signs and markings at the entrance and exit, improving the setting of deceleration lanes at the exit, and improving the speed limit of the exit road.

4.1. Improve the exit deceleration lane setting

A deceleration lane should be set up before the exit ramp as the vehicle needs to decelerate before turning to enter the main line. At the same time, a lateral deceleration lane should be added before the ramp, and corresponding lateral deceleration lanes are set according to the vehicle speed. Due to the poor deceleration effect of the exit ramp, if raised pavement markers are set at appropriate positions (such as 20–90 m) from the ramp, with less distance between the markers, drivers will be able to feel the driving speed. Speeding up gradually and slowing down subconsciously is more beneficial to driving safety and can effectively reduce the accident rate. Longitudinal bumps can also be placed before the exit of the interchange to slow down the speed of vehicles and improve driving safety.

4.2. Strengthening the speed limit management of exit roads

Speed limit signs should be placed at the exit of interchanges, and the speed limit value should be determined according to the road grade and the specific conditions of that section. The drivers should drive according to the speed limit and should be fined or punished if they exceed the speed limit.

4.3. Strengthening the management of relevant units and personnel

Relevant units and personnel should place greater emphasis on and implement effective measures to ensure the traffic safety of the interchange exit. Corresponding safety measures should be taken according to the characteristics of the traffic accidents at the interchange exits to reduce the possibility of traffic accidents. In the design of exits, it is crucial to strengthen the management of facilities along the road, as well as signs and markings. Additionally, efforts should be made to enhance the capability to monitor and predict the traffic behavior and psychological state of drivers.

4.4. Improving the placement of traffic signs and markings so that drivers can identify the locations of the exit accurately

Proper signboards, deceleration signs, and other indicators should be strategically placed at interchange exits. Proper markings should be drawn on the exit section of the interchange and they should be adjusted accordingly. It is important to make sure that the markings are coordinated with the ground markings. The speed limit at ramp exits and the distance should be reduced to allow drivers to decelerate, brake, and stop in time, so that there is enough space between vehicles. This can be achieved by controlling the speed of the vehicles at the off-ramp or extending the length of the off-ramp. Early warning facilities such as variable speed limit signs and slow-down signs should be placed to remind drivers to slow-down or stop in time to avoid dangerous situations. It is important to use guidance signs, warning signs and other means to guide vehicles into the main lane. Traffic management facilities such as reversible lanes should be provided to ensure the orderly passage of vehicles.

4.5. Location of the exit

Incorrect judgment of the intersection´s direction by drivers can lead to vehicle collisions, which significantly disrupts the normal operation of the interchange exit. Especially for the continuous exits on the main line, because the signs are often complicated, so it is difficult for drivers to determine the direction that they want to go to in time. Therefore, it is best to not design multiple exits or intertwined entrances and exits on the main road. In view of the left and right turnings of the four road hubs, an exit in one direction should be formed on the main line, and the distance between exits in two directions should comply with the provisions of the "Design Rules for Highway Interchanges" (JTG/T D21-2014), so that drivers who need to turn can leave the main line from the exit in one direction after slowing down. After that, drivers can turn left or right in the ramp diversion in one direction. With this method, the driver can only make one decision at each exit or ramp intersection, and can only go one way, which gives them more time to think and react.

4.6. Traffic organization and management

(1) Vehicles in different directions should be strictly distinguished to avoid traffic accidents. The direction of the ramp exit should be clear to prevent traffic accidents. (2) A comprehensive assessment should be carried out on of the ramp's traffic capacity, operating speed, and plane alignment. Soft isolation should be used for ramps with small traffic capacity, high speed limit requirements, or poor alignment. (3) If the traffic flow on the main line is affected by vehicle lane changes, etc., hard isolation or soft isolation can be installed at the entrance of the exit ramp; (4) Traffic control should be done properly and some vehicles should be diverted to other roads. Stop and slow-down signs should be set up near the exit to ensure that there is enough space for vehicles to park safely on the road near the exit. (5) Toll plazas can be set up before the exit as needed. The toll plaza should be able to guide vehicles to enter and leave the auxiliary road, so as to reduce the interference of vehicles changing lanes on the traffic flow of the main line. (6) The signs and markings near the exit should be improved.

5. Conclusion

In terms of design, a comprehensive safety assurance system should be constructed with people, vehicles, roads, and the environment as the major elements. In terms of operation management, the active control of vehicles can be achieved by building a complete information system and early warning mechanism. From the perspective of road operation, the efficiency of road traffic can be improved by setting signs, lines, warnings and other facilities, and optimizing traffic conditions.

Unreasonable positions of interchange exits will cause drivers to change lanes frequently on the ramp, which leads to traffic accidents. (2) Unreasonable ramp alignment will cause the vehicle move slowly, and it might lead to vehicle collisions. (3) The safety facilities at the interchange exits are not ideal, so is the traffic organization and management system, which is also the reason for the traffic accidents. Therefore, in order to ensure the safety of vehicles at the exit of interchanges, safety facilities should be placed strategically. Besides, the research on the safety technology for interchange exits should be strengthened.

Disclosure statement

The authors declare no conflict of interest.

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Tunnel Support Structure System and Its Synergy

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Abstract: The tunnel support system is composed of lining, bolt, and steel frame. It is of great significance to effectively control the deformation of the surrounding rock of the tunnel, make full use of the characteristics of different support methods, and formulate an economical and effective support plan to ensure the safe operation of the tunnel structure. This paper clarifies the synergistic relationship between the support structure and the surrounding rock based on their fundamental characteristics and functions. Various support structures and components are also discussed in this paper. Additionally, the paper presents an optimized design of the tunnel support structure system.

Keywords: Tunnel engineering; Support structure system; Synergy; Support structure design

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1. Introduction

Based on the understanding of the surrounding rock structure and load effect, many scholars at home and abroad have expounded the basic functions of the support structure and formed various tunnel design theories and methods[1]. Tunnel design theory is out of touch with engineering practice, and the schemes and parameters of advance support, bolt support and initial support are mainly determined by engineering experience. Therefore, it is necessary and urgent to study the synergy between surrounding rock and supporting structures.

2. Analysis of supporting structure

2. 1. Tunnel support structure system

It is the basic problem of tunnel engineering design to make the surrounding rock form a new stable state as soon as possible without instability and damage. Support structures such as advance support, primary support and secondary lining should be adopted.

2. 2. Lining support

Domestic and foreign experts generally regard the tunnel surrounding rock as a continuum, and the study the tunnel support system is usually studied using the elastoplasticity theory. So far, great progress has been made in the research of stress field, displacement field, and constitutive equation. The basic assumptions of this study are described below.

(i) The surface of the surrounding rock is flat

(ii) The rock fragmentation structure is rigid

(iii) The strength or damage of the rock mass itself is not considered

(iv) The movement of the surrounding rock along the structural plane of the stratum is referred to as the instability of the surrounding rock.

According to the key block theory (as shown in Figure 1), the surrounding rock is categorized into different types of blocks based on the spatial structure plane under normal conditions. After the excavation and unloading of the tunnel, some blocks lose their natural balance, resulting in the instability of the surrounding rock and even partial collapse.

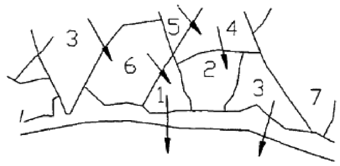

Figure 1 Conceptual diagram of "key block"

During this process, the first block that breaks the balance is the critical block, while the others are divided into stable blocks, static blocks, and potentially critical blocks. The reinforcement position of the key block is determined by analyzing the stability of the tunnel´s surrounding rock, thus effectively controlling the displacement of the entire slack zone of the tunnel[2].

The model is shown in Figure 2. Under the action of *in-situ* stress load q (MPa), the lining thickness t (mm) and inner diameter r (mm). As the thickness of the lining increases, the stress on it decreases, and the safety factor increases, resulting in better support under the action of ground stress.

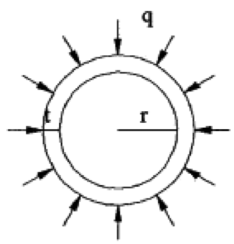

Figure 2 Circular lining model

The maximum thickness of the lining support can be set to t_g(mm), regardless of its own weight. The conditions for the lining under this model to produce non-destructive support effects are as follows:

Arrangement based on stress inequality:

$$(\sigma_s - 2q)t^2 + 2r(\sigma_s - 2q)t - 2r2q > 0$$

The discriminant of the quadratic equation $(\sigma_s - 2q)t^2 + 2r(\sigma_s - 2q)t - 2r2q = 0$ about t is $\triangle = 4r^2 \sigma_s (\sigma_s - 2q)$.

When $\triangle > 0$, that is, when $\sigma_s > 2q$, the equation has two roots set as t_1 and t_2, and $t_1 < t_2$. Assumming that $(\sigma_s - 2q)t^2 + 2r(\sigma_s - 2q)t - 2r^2 q$, then the approximate image is shown in Figure 3.

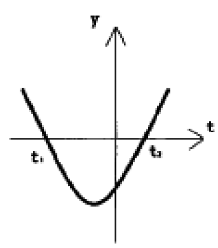

Figure 3 Discriminative image

When △ ⩽ 0, the stress inequality has no solution.

Under the assumption that the lining's thickness is not affected by its own weight, the study examines the relationship between the stress in the safety zone and the lining thickness under the joint action of internal force and gravity. The lining arc illustrated in Figure 2 is divided into four parts.

As shown in Figure 4, the self-weight direction is vertically downward. In the simplified model, it is assumed that the self-weight direction of the overlying arch is the same as the direction of the ground stress, and the direction is located at the center of the circle.

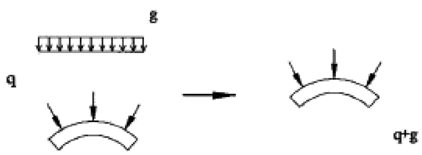

Figure 4 Upper lining arc

As depicted in Figure 5, the self-weight direction is vertically downward. The simplified model assumes that the self-weight directions of the left and right lining arches are perpendicular to the direction of φσ and have no impact on it.

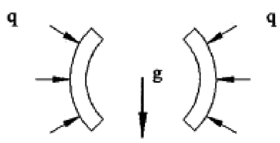

Figure 5 The central lining arc

As shown in Figure 6, the self-weight direction is vertically downward. According to the simplified model, the previous conclusions still apply to the case where the self-weight of the arch bottom lining is opposite to the direction of the ground stress. In this scenario, relative to the previous load (q), it becomes q-g, pointing to the center of the circle.

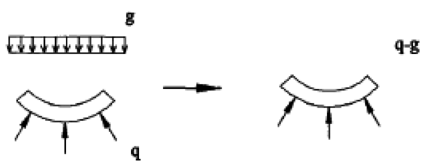

Figure 6 The lower part of the lining through the arc

2. 3. Bolt support

The classic anchor theory has gone through three stages of development.

(i) Suspension theory

The bolt works by compressing the loose rock mass at the top of the tunnel wall against the dense surrounding rock above. This prevents the loose surrounding rock from falling off, thereby preventing layer separation at the tunnel' s roof.

(ii) Composite beam theory

Similar to the suspension theory, the composite beam theory also believes that the surrounding rock of the tunnel roof is a layered rock formation. The difference is that the composite beam theory regards the junction point between the side wall and the top of the tunnel as the fulcrum, and the rock load on its upper part us supported by the rock beam. Each rock formation in the composite beam maintains coordinated deformation through the connection of anchor rods, which improves the bending resistance and reduces the deflection[3].

(iii) Reinforced arch theory

The reinforced arch theory holds that the anchor rod has a radial extrusion effect on the rock mass. After the internal stress of the top rock formation is stabilized, a fan-shaped compressed anchorage area will be formed on both sides of the anchor rod. With a suitable distance between adjacent anchor rods, the anchorage areas of a single bolt can be superimposed on each other, forming a compression zone with uniform thickness in the loose area, improving the stress state of the rock formation and effectively controlling its displacement.

2. 4. Steel frame

From a construction standpoint, it is crucial to promptly install the steel frame and maximize the contact area between the steel frame and the tunnel; the gap between the steel frame and the tunnel wall rock mass should be filled and wrapped to create an integrated force-bearing system between the steel frame and the lining[1].

3. Support structure synergy

3. 1. Mechanism of supporting structure synergy

Support structures that are highly rigid can bear a relatively large pressure without deforming severely. When the lining and the bolt are supported at the same time, the bolt stiffness (K_m) is greater than the lining stiffness (K_c), and combined stiffness K_z is greater than or equal to any one of K_c and K_m. When relying on a single structure, in terms of the deformation of the loose surrounding rock when the supporting structure yields, the deformation of the surrounding rock in the loose area when the anchor rod is bent is u_1, and the deformation of the surrounding rock in the loose area when the lining reaches its yield point is u_2, with $u_2 > u_1$.

3. 2. Theoretical analysis of synergy mechanism

The stiffness of the bolt in the loose area is greater than that of the lining, so the bolt plays its role first in the shotcrete + bolt combined support system, and the initial support plays a leading role in controlling the deformation of the rock mass. When the bolt cannot completely restrain the displacement of the rock mass, the lining plays a leading role in controlling the deformation of the surrounding rock[2].

3. 3. Numerical analysis of synergy mechanism

After two composite bolts were installed in the horseshoe-shaped tunnel, the numerical calculation was carried out. A monitoring point was set up on the tunnel wall every 2000 steps. The stress value of the anchor bolt and the lining were measured, and the synergistic effect of the lining support, prestressed anchor bolt, and non-prestressed anchor bolt support (alternate arrangement) was observed[5]. The numerical simulation parameters are shown in Table 1.

(i) The constitutive model of the tunnel surrounding rock adopted the Drucker-Prager (D-P) criterion; the tunnel lining structure was simulated using elastic isotropic materials[3].

(ii) The bolt was simulated by the rod unit, and the advanced support (pipe shed, small conduit, grouting, etc.) was simulated by increasing the stiffness of the iso-layer around the tunnel[4].

(iii) The house was simulated with linear elastic material and solid elements.

Table 1 Numerical simulation of synergy between lining support and bolt support

Step	2000	4000	6000	8000	16000	24000	32000	40000	44000	48000	Convergence
Axial force of anchor rod 1/KN	263. 3	397. 9	571. 2	520							
Lining 1 stress/Mpa	2. 311	2. 285	2. 279	2. 485	2. 589	2. 643	2. 711	2. 744	2. 747	2. 953	2. 982
Anchor 2 axial force/KN	54. 94	55. 38	79. 18	173. 7	274. 6	293. 9	323. 4	351. 8	354. 3	341. 4	
Lining 2 stress/Mpa	1. 274	2. 018	2. 041	2. 439	2. 446	2. 588	2. 618	2. 666	2. 661	2. 897	2. 925

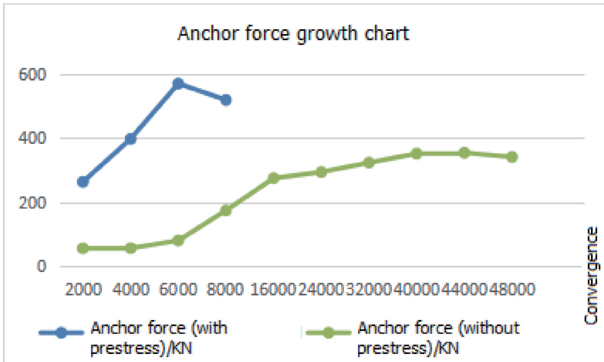

Figure 7 Anchor force growth chart

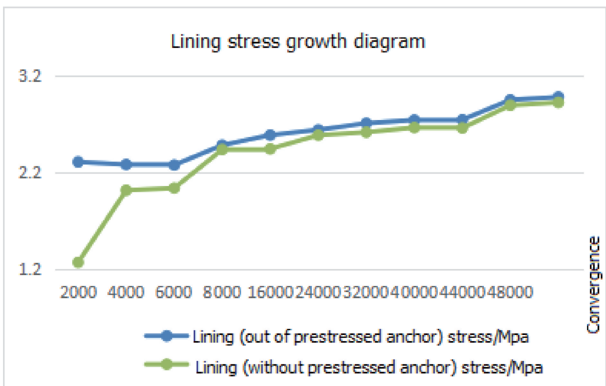

Figure 8 Lining stress growth diagram

Through an analysis of the data in Figures 7 and 8, it was found that the overall trend of the synergy between the lining and the anchor remained unchanged, and the anchor played a major role before the lining[6], but the prestressed anchor fails to yield before the ordinary anchor that is passively stressed due to active stress. The axial force of the plain anchor (without prestress) increased significantly when it failed. After all the anchors failed, the lining stress at the corresponding position increased[7].

4. Conclusion

In this paper, the new Austrian method was used to simulate the excavation process, and the supporting mechanism of the lining, bolt and steel frame was theoretically analyzed. Based on the numerical simulation and calculation, the characteristics of the interaction between the surrounding rock deformation and the supporting structure were analyzed, and the conclusions are as follows:

(i) If the support is not applied in time during the excavation process, the tunnel deformation becomes significant, and numerical simulation indicated that the calculation failed to converge. Excavation or distributed excavation with insufficient support will cause the tunnel to collapse.

(ii) The basic function of bolt anchorage is to limit the displacement of the rock layer by stimulating the self-stability of the rock mass. The bolts should be installed in time during the excavation of the tunnel, so that the horizontal displacement can be better controlled.

(iii) There is a synergistic effect after the lining support and bolt support are applied together. The stiffness of the bolt support structure is greater than that of the lining support structure. In the initial stage, the bolt plays the main supporting role before the lining, but when the bolts fail, the role of the lining supporting structure increases.

(iv) When the vertical displacement of the lining support is not ideal and the lining and bolts fail to limit the deformation of the surrounding rock, steel frame can be installed.

(v) Steel frames demonstrate better displacement control in the horizontal direction compared to the vertical direction. Moreover, a steel frame is more efficient in providing rapid stabilization compared to the lining and anchors. The steel frame support can rapidly improve the tunnel displacement. Therefore, steel frame support works well with lining and bolt support to improve the rigidity of the support system.

Disclosure statement

The authors declare no conflict of interest.

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Well-Drilling and Groundwater Monitoring Network Construction: Taking Changde City as an Example

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Abstract: Entrusted by the Environmental Protection Bureau of Changde City, we conducted drilling, sampling survey and constructed a monitoring network for groundwater in several counties and districts of Changde City. This article introduces the drilling technology, detection method and detection network layout plan adopted in the project, and expounds the problems that occurred while executing the project, in order to provide reference for similar groundwater capacity supervision and construction projects.

Keywords: Groundwater; Well-drilling; Monitoring network; Changde City

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1. Introduction

From the 1950 s to the 1980 s, China embarked on a gradual process of groundwater monitoring and control. However, the phenomenon of imprudent development and utilization of groundwater in various regions of the country has resulted in frequent geological disasters[1]. Since the beginning of this century, the Ministry of Land & Water Resources has deployed over 20,000 groundwater monitoring points throughout the nation, contributing to the establishment of our country's groundwater monitoring network. However, due to the different conditions in various provinces and cities, the progress of groundwater monitoring network deployment is also inconsistent. Guangxi Province started groundwater monitoring in 1981, and a total of 431 third-level groundwater monitoring stations have been built by 2017[2]. As one of the provinces with the most water shortage in China, more than 1,200 groundwater monitoring stations have been built in Shanxi Province[3].

Shandong Province was among the earliest regions in China to initiate the establishment of groundwater monitoring networks[4]. By the end of 2017, the Provincial Land and Resources Department had amassed a total of over 2,200 groundwater monitoring points[5] in order to control their groundwater resources. Compared with provinces that implemented groundwater control earlier, Hunan Province first started groundwater monitoring in Shaoshan City in the 1970 s, and it spread throughout the province. Until now, the Ministry of Natural Resources of Hunan Province possess only more than 300 groundwater monitoring stations, which is only half of the average number of monitoring stations among all provinces in China. The comprehensive deployment of monitoring stations across most areas of the province has not been achieved. Therefore, the national requirements for management and control for groundwater resources have not been met. Therefore, this makes the construction of groundwater monitoring stations in Hunan

Province a crucial issue[6]. Changde City is located in the northwest of Hunan Province, with 2 districts, 6 counties and 1 city under its jurisdiction. The Changde City Ecological Environment Bureau actively carried out the construction of groundwater supervision capacity, and compiled the "Changde City Groundwater Supervision Capacity Building Project Plan." On one hand, this plan was initiated in response to the Ministry of Ecology and Environment's "Notice on the Construction of the Central Environmental Protection Investment Project Reserve Bank in 2019 (Huan Ban Ke Cai Han [2019] No. 474)." On the other hand, the plan serves to increase the number of monitoring stations in the region to form a more comprehensive environment and a complete monitoring network.

2. Drilling technology

In order to have a clearer understanding of the overall groundwater pollution in Changde City, several counties and districts have built new monitoring wells for the basic environmental conditions of groundwater and groundwater monitoring wells to detect pollution sources. Many infill wells have been built in large-scale industrial parks or landfills that produce pollutants, which are mainly used for single sampling to detect the quality of groundwater, and the wells will be backfilled and sealed after the sampling is completed. Groundwater quality monitoring wells are constructed at pollution sources in full compliance with national standards, and are used as permanent facilities to monitor groundwater quality in the area in real time.

Due to the different specifications of the two types of wells, the drilling techniques and materials used are also different. The pores of infill wells have a single-tube single-layer structure, and the depth of the pores depends on the water-bearing depth of the groundwater. The diameter of the well was 110 mm, and the diameter of the pore was 50 mm. The pipe material is polyvinyl chloride (PVC), the water supply pipes were also made of PVC. The method used for drilling into the quaternary loose layer involved dry drilling with a Φ127 mm drill bit. Rotary drilling with casing follow-up was used for the gravel layer; after reaching the bedrock layer, a Φ108 mm diamond drill bit was used to drill to the design depth through normal-circulation rotary drilling. After the coring was completed, the Φ220 mm tri-cone bit was used instead of the anti-deviation drilling tool to pressurize and anti-deviation drilling process for reaming. The monitoring well also had a single-pipe and single-layer structure, and the depth of the hole depended on the depth of the groundwater. The diameter of the well was 358 mm and the diameter of the hole was 146 mm. The well pipe consisted of three parts: the well wall pipe, the filter pipe, and the sedimentation pipe. The well pipe was made of stainless-steel with a thickness of not less than 4.5 mm. The length of the sedimentation pipe was not less than 3 m, the length of the filter pipe was the same as the thickness of the aquifer, and the wall pipe extended more than 50 cm from the wellhead. In terms of drilling methods, the quaternary loose layer was drilled using the dry-drilling method with a Φ127 mm drill bit. For the gravel layer, the rotary drilling method was used followed by casing follow-up. After reaching the bedrock layer, a Φ108 mm diamond bit was used. The normal-circulation rotary drilling is used drill to the designed depth. After the coring was completed, the quaternary loose layer was reamed using a Φ350 mm tri-cone bit biased anti-deviation drilling tool pressurization and anti-deviation drilling technology. The bedrock section was drilled with a diamond bit and normal-circulation rotary drilling, and the final hole diameter of the bedrock section was not less than Φ110 mm.

The construction of monitoring wells is more complex in terms of materials and procedures compared to infill wells, and it requires the construction team to make correct judgments on-site based on field conditions. During the construction of the monitoring wells of this project, PVC-U was originally selected as the material of the monitoring wells, which was consistent with the survey wells, and the selection of such materials is also in full compliance with the "Code for Construction of Groundwater Monitoring Wells"

(DT/Z 0270−2014) requirements. However, during the actual construction process, the first monitoring well had a cross-hole after the final hole was drilled, and the PVC-U pipe could not bear the pressure of the surrounding soil layer and was distorted and deformed. Through multiple discussions among experts, it was proposed that the reason for this phenomenon should be that there are many thick underground sand and gravel layers in many areas of Changde. This is also consistent with the conditions of the cores taken out, and the pressure on the pipes is relatively high, resulting in engineering problems. Therefore, the material for the monitoring well pipe was changed to stainless steel. This incident provided very valuable experience for the construction of monitoring well in Changde City.

3. Sampling and detection

In the groundwater supervision and capacity building project in Changde City, to fully understand the groundwater pollution in the monitored area, a comprehensive detection of the pollution factors of each block was carried out based on the "Investigation Information and Risk Screening Report of Enterprises in Key Industries in Hunan Province" in addition to the routine quality indicators of groundwater stated in the "National Groundwater Quality Standards" (GB/T14848−2017).

The sampling mode and frequency of all newly-built monitoring wells were sampled once, and the wells were sealed right after the sampling is completed. 18 monitoring wells needed to be regularly sampled and maintained. The monitoring wells are sampled once a quarter manually to form a quarterly inspection report, and four times throughout the year to form an annual inspection report. Through the comparative analysis of the four quarterly reports, we can have a clearer understanding of the migration and transformation of groundwater pollution factors in each monitoring block.

In terms of groundwater quality sampling methods, the water samples used are grab samples. Before each sampling, on-site swabbing is carried out through a Baylor tube. The amount of swabbed water must be twice the volume of the accumulated water in the well, and the sampling depth should be below 0. 5 m of the groundwater surface to ensure that the water samples taken reflects the groundwater quality in the area. In addition, some indicators are measured on-site. For −indicators that cannot be measured on-site, the samples will be stored in strict accordance with the national sampling and testing standards and sent to a laboratory for testing within a specific period[7].

The national or industry standard method always come first in groundwater quality detection and analysis. For indexes without a standard analysis method, a unified industry analysis method can be used. When other equivalent analytical methods for other bodies like the International Organization for Standardization (ISO), the United States Environmental Protection Agency (EPA), and the Japanese Industrial Standards (JIS) are used, method confirmation and verification must be carried out in accordance with the provisions of GB/T 27417. In addition, the detection limit, accuracy, and precision should meet the requirements for groundwater testing.

4. Monitoring network construction

One of the goals of this project was to have a comprehensive understanding of the groundwater pollution in the counties and districts under the jurisdiction of Changde City. Another goal is to form a more unified and dense monitoring network with the existing five national-level well resources in Changde City.

The five existing well resources in Changde City are groundwater pollution tracking and monitoring wells, groundwater-type drinking water wells, soil pollution monitoring wells, groundwater environmental status monitoring wells, and pollution source groundwater quality monitoring wells[8]. In order to save national funds as much as possible and at the same time ensure the accuracy of groundwater pollution trend prediction, the existing data of five types of wells were collected and sorted out, and the available well points were surveyed and analyzed on site. After unified numbering, selective sampling and testing were carried out according to the regional distribution. Through actual field investigation, there were 20 monitoring wells for groundwater quality in Changde City, all of which are national-level monitoring points, with one well and one pipe, with automatic monitoring technology. Therefore, while building 18 new monitoring wells for groundwater quality at pollution sources, the existing monitoring wells should also be repaired and maintained to ensure that a unified monitoring network can be formed after the project is completed.

The newly built upgraded monitoring wells are mainly designed for key industrial enterprises, polluted irrigation areas, and informal landfills near drinking water sources, so as to ensure the safety of drinking groundwater and improve the layout of groundwater monitoring networks. According to the monitoring point layout principles in the "Guidelines for Investigation and Evaluation of Groundwater Environmental Conditions" (2019), there are 7 monitoring points in each informal landfill block, industrial enterprise, general monitoring point, and agricultural area with reclaimed water. A total of 124 upgraded monitoring wells would be built through this project. The site selection of the 18 monitoring wells would also based on the existing 20 monitoring wells, that is, the original monitoring network, which will be in large and medium-sized industrial parks and informal landfills near groundwater drinking water sources. A total of 9 plots without groundwater monitoring wells were selected, and together with the original 20 monitoring wells, a relatively complete groundwater environment monitoring network that span across different areas, pollution sources, and drinking water sources was formed.

In addition to the construction of the monitoring network, an online monitoring platform was also built to further classify and analyze data[9] that is obtained through groundwater monitoring. The data is first uploaded to the monitoring platform, the water quality information of well points in the groundwater monitoring network are then recorded and updated. In this way, the groundwater quality can be understood clearly and intuitively in a timely manner. The monitoring platform can be used to display and analyze Changde City overall groundwater status. A new early warning interface will be developed in the monitoring platform in the future. By referring to the five types of groundwater quality requirements in the "Groundwater Quality Standard" (GB/T 14848-2017), the thresholds for each monitoring factor will be set. When the groundwater quality reaches a certain concentration, an early warning will be issued to report the abnormal situation, and corresponding countermeasures will be taken.

5. Conclusion

The successful implementation of this project yields the following suggestions and prospects for the development of the national groundwater monitoring network:

(1) During the drilling stage of groundwater projects, a more reliable and accurate judgment should have been made on the pipe material and pipe diameter to ensure the smooth progress of the construction.

(2) The project has improved the coverage groundwater networks in urban and rural areas. Through this project, new automatic monitoring wells were built, and the old and damaged monitoring wells in some areas were repaired, the outdated testing equipment was updated, and the original testing data in the area were sorted out and compared with the latest testing data. Comparing the data is beneficial to the overall management of groundwater in this area[10].

(3) The "Regulations on Groundwater Management" was passed at the 149th executive meeting of the State Council on September 15, 2021, and was officially promulgated on November 9, 2021 in Order No. 748 of the State Council of the People's Republic of China. The regulations clearly stipulate that environmental department of the State Council is responsible for the supervision and management of groundwater pollution prevention and control nationwide. Besides, it is also stated that the local

governments are responsible for the management of groundwater within their administrative regions, and relevant environmental departments are responsible for groundwater inspection, monitoring and other related work within their administrative regions. It can be seen that in the future, all provinces and cities across the country will fully develop and expand the construction of groundwater monitoring networks. This paper was written in hopes of providing valuable reference for similar projects in the future.

Disclosure statement

The authors declare no conflict of interest.

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Overview of Urban Landscape Rewilding Research

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Abstract: Urban wildscape refers to landscape units within or surrounding urban areas that are primarily shaped by natural processes, exhibiting high ecological value and diversity. Due to urbanization, urban wildscapes are at risk of disappearing or degrading, but they also present opportunities for the protection and restoration of urban ecosystems. The purpose of this article is to systematically review and analyze the concepts, classifications, values, threats, and conservation strategies of urban wildscapes, in order to provide references for urban planning and wildscape design.
Keywords: Wildscapes; Landscape rewilding; Urban renewal; Rewilding

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1. Concept of urban wildscapes

Urban wildscapes are a unique type of urban space characterized by being primarily shaped by natural processes and possessing wild characteristics and functions similar to natural wilderness[1]. The concept and development of urban wildscapes are closely related to processes such as urban expansion, transformation, and contraction. It is based on the continuous expansion and in-depth exploration of the concept of wilderness, and has gained attention and recognition from multiple disciplines. It reflects changes in urban structure, such as the relocation of industries, decentralization, and the development of new areas. Additionally, it is also influenced by factors like social culture, economic policies, and environmental awareness, exhibiting varying degrees of "wildness." This concept also reflects people´s increasing demands for urban ecosystems and prompts a reevaluation of the relationship between nature and humans[2].

According to different perspectives and purposes, urban wildscapes are named and defined in various ways, such as urban nature, urban wilderness, urban and wildness[3]. The development of urban wildscapes can be divided into three stages: exclusion, acceptance, and utilization. In the exclusion stage, wilderness is seen as an uninhabited and inaccessible place, standing in contrast to human society. In the acceptance stage, wilderness is recognized as an important and endangered natural resource with ecosystem services and aesthetic value, requiring protection and respect. In the utilization stage, wilderness is seen as a landscape type that can provide habitat resources for cities, support human habitats, and ensure the health and stability of ecosystems, requiring rational planning and design[4-7].

At the 11th Global Wilderness Congress held in 2020, the "Global Charter for Rewilding the Earth" was introduced for the first time. The most notable principle of this charter is "rewilding means helping nature heal." Everything we do is to assist in the healing of nature, rather than expecting nature to heal itself although nature inherently possesses the ability and potential for self-restoration.

Urban wildscape is not only a natural phenomenon but also a cultural phenomenon, reflecting the changing awareness and attitudes towards nature[8]. It is also a design phenomenon that presents new challenges and opportunities for landscape theory and practice. This article proposes a comprehensive and systematic definition by integrating various theories and practices, stating that urban wildscape refers to urban spaces where ecological processes are primarily guided by nature and exhibit characteristics and functional types similar to natural wilderness.

2. Classification of urban wildscapes

Urban wildscapes are mainly categorized based on their forms and spatial scales. Diemer *et al.* divided them into five levels based on the area of urban wildscapes[9]. Kovári divided urban wildscapes into ancient wildscapes and newly formed wildscapes according to their timeline of formation[10]. Wang *et al.* classified urban wildscapes into primary-, secondary-, gap-, and pseudo-wilderness types based on their space and distinct features[11]. In this article, urban wildscapes are comprehensively classified into four categories based on their mechanism of formation, spatial distribution, species composition, and structural characteristics.

2. 1. Human-abandoned type

The human-abandoned type of urban wildscapes is a space of natural recovery resulting from the interruption or abandonment of human activities. These spaces are typically found at the edges or centers of cities, such as abandoned factories, warehouses, railways, docks, etc[12]. They bear significant human traces but also exhibit natural vitality and diversity. These spaces not only provide ecological services to the city, such as air purification, climate regulation, and water protection but also offer opportunities for leisure, education, and exploration for urban residents. For example, Beijing' s 798 Art District is a typical human-abandoned urban wildscape. It was once a military factory area but later occupied by artists and cultural institutions, forming a unique combination of industrial heritage and artistic creativity. This landscape preserves the historical imprint of the industrial era while showcasing the vibrancy and innovation of contemporary culture.

2. 2. Natural-degradation type

The natural-degradation type of urban wildscapes is formed due to natural factors such as geology, climate, and hydrology, resulting in land degradation or desertification, such as exposed slopes, riverbanks, and sand dunes. These landscapes typically exhibit lower biodiversity and ecological functions, often appearing incongruous within the urban context and contrasting sharply with the surrounding architecture and human environment. However, they also possess a certain natural beauty and sense of intrigue. They reflect the power and changes of nature and can inspire awe and a sense of conservation. For example, the Binjiang Park in Shanghai is a typical natural- degradation type urban wildscape. Located along the Huangpu River, it was originally a beach and salt field. It was later developed into a park, preserving some of the characteristics of sand dunes and salt fields, creating a leisure space with a desert-like ambiance.

2. 3. Natural-preservation type

The natural-preservation type of urban wildscapes is characterized by a higher degree of naturalness and is formed with minimal human interference or conservatory efforts. Examples include forests, wetlands, grasslands, and so on. These landscapes typically exhibit higher biodiversity and ecological functions, as well as aesthetic appeal. For instance, Baiyun Mountain in Guangzhou is a typical example of a natural-preservation type of urban wildscape. It serves as an important recreational, fitness, and viewing area for the citizens of Guangzhou, while also functioning as an ecological barrier and climate regulator for the city. When planning and designing natural-preservation type urban wildscapes, priority should be given to the protection and restoration of nature. This involves minimizing human disturbance and destruction, while also providing suitable facilities and services to fulfill people' s needs and enhance their appreciation of nature.

2.4. Man-made type

Man-made type of urban wildscapes is formed through human activities, either by creation or imitation. Examples include artificial lakes, wetland parks, theme parks, and so on. These landscapes typically exhibit a strong artificial character in terms of design forms, functions, materials, etc., while also incorporating certain elements of nature, such as vegetation and water circulation. For instance, the Shanghai Native Ecological Science Popularization Demonstration Base is an artificially created urban rewilding project with the goal of biodiversity restoration. The project is divided into seven different ecological functional zones, utilizing native species to construct a balanced biological community that can undergo spontaneous succession and gradually become wilder. This project not only enriches the biodiversity within the city but also provides the public with a science popularization platform to get closer to nature and understand native ecosystems.

3. Value and functions of urban wildscapes

3.1. Ecological dimension

Urban wildscapes are an important means of urban greening, providing diverse habitats for organisms, protecting urban biodiversity, and maintaining the stability and health of ecosystems. These organisms not only promote soil fertility and water conservation but also control the spread of pests and diseases[13]. Urban wildscapes can also regulate urban climate, reduce the urban heat island effect, improve urban air quality, reduce noise pollution, increase green space in cities, and enhance the quality of life for urban residents. Urban wildscapes are beneficial not only for environmental protection but also for social and economic development. They enhance the aesthetics and attractiveness of cities, provide places for recreation and education, and promote the physical and mental well-being of urban residents and social cohesion.

3.2. Social dimension

Urban wildscapes offer ample opportunities for recreation and education. They enhance environmental awareness and a sense of responsibility among urban residents, while also promoting their physical and mental well-being and fostering social cohesion. Urban wildscapes also contribute to the aesthetics and attractiveness of cities, elevating their image and prestige, and fostering a sense of belonging and pride among urban residents. These positive contributions of urban wildscapes to social development warrant our utmost attention and protection. To better utilize and manage urban wildscapes, it is necessary to strengthen relevant planning and policies, encourage public participation and support, establish effective monitoring and evaluation mechanisms, and promote the sustainable development of urban wildscapes.

3.3. Cultural dimension

Urban wildscapes represent a distinctive form of urban landscape that preserves the pristine state of nature while embodying traces of human history, holding significant meaning and value. Firstly, urban wildscapes can preserve and inherit the historical and cultural heritage of cities, such as ancient sites, industrial remnants, folk customs, etc. These serve as carriers of urban memory and symbols of urban identity. Secondly, urban wildscapes can reflect the characteristics and style of cities, such as landscapes, vegetation, architecture, etc. These embody the uniqueness of cities and serve as sources of urban charm. Furthermore, urban wildscapes can inspire the creativity and imagination of urban residents, such as in the fields of art, design, education, etc. These drive urban innovation and represent the potential for urban development. Lastly, urban wildscapes can foster communication and mutual understanding among individuals from diverse cultures and backgrounds, primarily through avenues like tourism, communal activities, and shared communities. These aspects showcase the diversity and inclusivity of cities, while also enriching the cultural significance and value of urban environments.

3. 4. Economic dimension

Urban wildscapes can enhance the ecological service value of cities, providing more natural resources and ecosystem services, which helps cities conserve resource consumption and reduce cost expenditures, thereby increasing economic benefits and competitiveness. Wildscapes have a certain therapeutic effect on the physical and mental well-being of the public, especially in the post-pandemic era. Healing landscapes are increasingly applied in the field of medicine to address social health issues among sub-healthy populations[14]. Additionally, urban wildscapes can promote the development of the tourism industry and related sectors. They offer unique tourist destinations, attracting more visitors and stimulating the growth of local tourism and associated industries. This creates more job opportunities and sources of income, enhancing the economic vitality and sustainability of the city.

4. Challenges in conserving urban wildscapes

4. 1. Urban expansion

Urban expansion leads to the reduction and fragmentation of urban wildscapes. The rapid growth of urban construction land results in the continuous encroachment, filling, and development of existing natural spaces, significantly decreasing the area and quantity of urban wildscapes. Additionally, urban expansion reduces the connectivity of urban wildscapes, creating phenomena such as isolation, marginalization, and segregation, which affect biodiversity and ecosystem functions. Urban expansion also results in the decline of quality and functionality of urban wildscapes. For example, it increases the urban heat island effect, causing issues such as elevated temperatures, reduced water availability, and vegetation degradation.

4. 2. Change of land use

The change of land use is one of the most significant impacts of human activities on the natural environment. It alters the type, structures, and functions of urban wildscapes, posing threats and influences on the stability and sustainability of urban ecosystems. The diverse land use patterns in cities, including residential, commercial, industrial, transportation, and public facilities, have varying degrees of impact on urban wildscapes. On one hand, the change of land use modifies the physical conditions of urban wildscapes, such as temperature, humidity, light, and wind speed, affecting plant growth and animal distribution. On the other hand, it also alters the chemical conditions of urban wildscapes, such as soil fertility, pH value, and organic matter content, which affects plant nutrition and animal food sources.

4. 3. Human disturbance

Humans are the most active factor in urban wildscapes, directly or indirectly disturbing these landscapes through their activities. Direct disturbances include logging, excavation, landfilling, burning, hunting, grazing, and many more. These disturbances disrupt the structure and functionality of urban wildscapes, leading to species loss or the invasion of alien species. Indirect disturbances include the introduction of foreign substances, alteration of hydrological conditions, and modification of climate conditions. These disturbances change the environmental quality and stability of urban wildscapes, causing species adaptation or migration.

4. 4. Introduction of invasive species

Invasive species refer to species that enter non-native areas due to human or natural reasons, and these species can establish populations and negatively impact local ecosystems. Invasive species often possess strong competitive advantages and adaptability in urban wildscapes, allowing them to reproduce rapidly, occupy resources, and displace or hybridize with native species, disrupting the existing ecological balance and evolutionary processes.

5. Strategies and recommendations for urban wildscape conservation

5. 1. Identifying and assessing urban wildscape resources

By using multiple data sources and methods, urban wildscapes can be systematically identified and classified, including assessing their ecological functions, service values, and conservation status, and establishing a database of urban wildscape resources. This information will provide a scientific basis for conservation planning and management, assisting decision-makers in formulating appropriate conservation measures and promoting the sustainable development of urban wildscapes.

5. 2. Establishing a network for urban wildscape conservation

Based on the distribution characteristics and ecological connections of urban wildscapes, reasonable zoning and connectivity can be designed to establish a network for urban wildscape conservation. This will enhance the integrity and connectivity of urban wildscapes, improving their ability to resist disturbances and adapt to changes. By establishing a network for urban wildscape conservation, urban wildscapes can be better protected, promoting their sustainable development.

5. 3. Developing effective management measures and standards

According to the characteristics and requirements of different types and grades of urban wildscapes, corresponding management objectives, measures, and standards should be formulated. This may include limiting or prohibiting unsuitable development activities, controlling human disturbances, restoring damaged ecosystems, preventing or eliminating invasive species, ensuring the ecological integrity and functional completeness of urban wildscapes. Besides, the monitoring and evaluation of urban wildscapes should also be strengthened. A scientific data management system that regularly analyzes trends and influencing factors of urban wildscapes should be established, and management measures and standards should be modified accoding to different situations to improve the effectiveness and quality of management.

5. 4. Enhancing public participation and education

By conducting various forms of promotion, education, volunteer activities, community involvement, and other initiatives, public awareness and attention towards urban wildscapes can be increased. This will cultivate respect and care for urban wildscapes among the public, creating a social atmosphere of collective participation in conservation. This approach not only enhances the ecological and aesthetic values of urban wildscapes but also strengthens public environmental awareness and a sense of responsibility, driving the sustainable development of cities.

6. Conclusion

Urban wildscapes are natural landscapes that exist within urban environments. They possess nativeness, diversity, openness, and unpredictability, beyond human control and constraints. Urban wildscapes not only hold significant ecological value, such as biodiversity conservation and the provision of ecosystem services but also possess social, economic, and aesthetic value. They contribute to the well-being, happiness, and cultural identity of urban residents. Therefore, urban wildscapes should receive more attention and protection in current urban development and planning.

Disclosure statement

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Discussion on the Status Quo of Non-Destructive Testing Technology in Highway Engineering and Strategies of Improving the Quality of Testing

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Abstract: Highway test and detection technology play a very important role in controlling the quality of road and bridge engineering and improving the maintenance of roads and bridges. The study of highway bridge test detection technology is both theoretically and practically useful. Road and bridge test and detection is a complicated task. With the development of science and technology, highway and bridge engineering test and detection technology has also made great progress. The continuous improvement of test and detection technology has brought good social benefits to road and bridge construction. This article discusses the problems in test and detection technology of highway bridges and how to improve the quality of test and detection.
Keywords: Highway engineering; Non-destructive testing; Testing technology; Quality improvement

Online publication: August 29, 2023

1. Introduction

Highway and bridges are important structures that should be tested by unique test and detection technology. Highway bridge test and detection technology is key ensure the quality of the road and bridge. Therefore, the study of road and bridge test and detection technology is not only theoretically useful, but also practically useful. The development of automation technology, computer technology, and high-precision micro-measurement has greatly advanced the test and detection techniques in highway bridge engineering. This progress is particularly evident in the direction of non-destructive, intelligent, automated, and precise methods. In this paper, we will analyze the test and detection technology of highway bridge engineering.

Non-destructive testing refers to the use of changes in thermal, sound, light, electricity, magnetization, and other reactions caused by abnormalities in the structure or defects of materials without damaging or affecting the performance and the internal organization of the tested object of the tested object[1]. It is crucial for the development of the road inspection industry, including radiographic inspection, ultrasonic inspection, magnetic particle inspection, and image inspection.

Non-destructive testing technology is a testing technology for engineering structures. It is an intuitive, fast, and effective testing method that can display the internal conditions of structural components. This testing technology can avoid damaging the structure of the tested object. Therefore, it is of great significance to establish a scientific inspection system to improve the quality of roads and bridges. Several common non-destructive inspection techniques are introduced below.

2. Common non-destructive detection technology in highway engineering

2. 1. Ultrasonic testing

Ultrasonic testing involves high-frequency sound waves and utilizes the medium' s ability to emit ultrasonic waves. It analyzes the reflected waves received from roads and bridges, thereby providing insights into the condition of the road or bridge[2]. Its working principle involves studying how ultrasonic waves interact with a test piece through reflected, transmitted, and scattered waves. This is used to detect macroscopic defects, measure geometric characteristics, assess changes in structural organization and mechanical properties of the test piece. For highway and bridges, ultrasonic testing technology is mainly used in the detection of internal defects of structural components, such as the integrity of foundation piles, the rebound strength of concrete structures, cracks in concrete structures, and cracks in welds.

In flawless concrete, ultrasonic waves propagate through a continuous medium. However, if structural defects like voids or honeycomb areas exist, the concrete´s continuity is disrupted. The interface between the defective region and the concrete (air and concrete) is shown in Figure 1. At this interface, the propagation of ultrasonic waves changes. The defects of the foundation pile body can be detected.

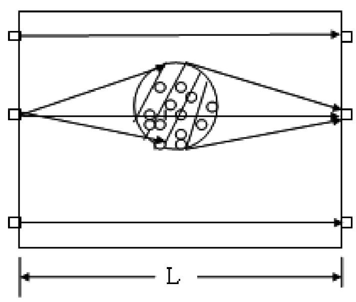

Figure 1 Schematic diagram of foundation pile integrity detection

2. 2. Magnetic particle testing

Magnetic particle testing operates on the principle of magnetizing ferromagnetic materials and the workpiece. Discontinuities cause localized distortion of magnetic field lines on and near the surface of the workpiece, resulting in a leakage magnetic field. This field attracts magnetic powder applied on the surface, forming visible indications under appropriate lighting conditions. These indications reveal the location, shape, and size of the discontinuity. Hence, magnetic particle testing promptly and visually pinpoints component issues and failures, detecting cracks, gaps, incomplete penetration, central inclusions, incomplete fusion, and surface pores. This identifies defect shapes and sizes, streamlining subsequent processing tasks[3].

Magnetic particle testing is a simple, quick and low-cost method. This method is also highly sensitive, and it can detect very small defects, up to a nanoscale degree.

2. 3. Image detection technology

Image detection technology uses infrared imaging and laser holographic imaging. Infrared imaging involves using materials with different thermal conductivity. High-precision sensors can detect the heat transfer and temperature inside the road and bridge. This allows a good analysis and inspection of the surface of the structure[4]. Laser holographic detection technology detects and analyzes the pictures that are taken by a camera, and then uses the images for mechanical analysis. Therefore, this intuitive and high-precision detection technology clearly display the defects on the surface of roads and bridges. At present, image detection technologies commonly used in highway engineering are used in inspection vehicles for tunnels and roads[5] (detection of road surface cracks, potholes, etc., recognition of landscape along roads, concrete structure crack width detectors, etc. [Figure 2]).

Figure 2 Image detection technology

The road surface imaging software of the multi-function inspection vehicle can identify, quantify, and classify the cracks (transverse cracks, longitudinal cracks, cracks, block cracks), potholes, and other problems of the road surface. The road surface shape data is processed by a software to obtain information on deformation of the surface such as rutting, wrapping and local subsidence. The front image stereo measurement software can measure the facilities along the road, check the road and its surrounding environment, and provide historical records for road condition monitoring, property cataloging, accident cataloging, etc.

The multi-functional inspection vehicle utilizes a high-performance onboard computer and a variety of sensors to automate data collection, thereby reducing the potential for human errors and enhancing precision. It achieves speeds of up to 80 km/h, ensuring efficient and rapid detection. Moreover, it operates without causing disruptions to normal traffic flow, which helps to minimize economic losses due to road closures or traffic congestion. Additionally, this vehicle decreases the labor intensity associated with manual measurements and reduces the potential risks of such operations.

3. Problems in non-destructive testing technology

Each type of non-destructive testing technology comes with their own advantages. These technologies can efficiently and quickly detect the performance and defects of structural components of highway bridges, which provides convenience for highway bridge testing. however, there are still some limitations to these technologies.

3.1. The quality of the tests performs depends on the experience of the personnel

The amount of knowledge or experience of testing personnel significantly affect the analysis and processing of test data. For example, possible defects can be identified according to the subtle differences of waves in the image, and the types and causes of defects can be analyzed.

3.2. Some non-destructive testing techniques have limited detection range

Ultrasonic testing utilizes the reflection of elastic sound waves in solids to determine the presence and location of defects in the workpiece. The size and nature of defects can be determined according to the reflected sound waves which include the following aspects: (i) the propagation time of the elastic pulse, (ii) the energy of the echo, (iii) the degree of attenuation of the oscillation after passing a certain distance. The limitation of this method is the instrument can only measure three physical quantities: propagation time, equivalent, and relative values. Besides, this method cannot detect the parameters of the defect such as size, shape, depth, inclination angle, surface roughness, internal filling, etc.

Furthermore, current research on the propagation theory of ultrasonic testing primarily focuses on a limited range of typical defects in solids. Additionally, defects of various shapes, sizes, inclinations, and surface roughness at the same depth can result in echoes at identical heights, making it impossible to differentiate these defects based solely on echo height. Therefore, this method is not 100% reliable with these shortcomings.

Magnetic particle testing also has its limitations. While it can accurately detect defects, it is not applicable to non-magnetic materials. Moreover, this method cannot determine the depth of defects, and it may not effectively identify extremely small defects hidden deep in the corners of the section' s surface.

3.3. The technology of non-destructive testing equipment is not mature enough, and its performance is unstable

While the equipment are highly sensitive, the accuracy of the equipment will decrease as it ages, and the inaccuracies are difficult to detect, resulting in inaccurate data, thus affecting the quality of testing.

4. Measures to improve the quality of testing

In order to reduce the limitations of non-destructive testing technology and increase their reliability, the following measures are proposed:

(i) The research and development new nondestructive testing technologies should be improved. New non-destructive testing instruments should be designed and developed, such as transducers and auxiliary equipment, based on new discoveries and new laws in mechanics, sonics, and magnetism. Building on the foundation of existing non-destructive testing techniques, efforts are being made to expand and enhance these methods, including refining the design of testing equipment to improve defect detection capabilities.

(ii) The training and assessment of technicians should be improved, more discussions regarding nondestructive testing technologies among experts should be carried more frequently. A national non-destructive testing technology practice information database can then be established based on previous experiences and failures, and various software can be created to aid road and bridge testing.

(iii) The standards and specifications of non-destructive testing technologies should be constantly updated so that they are in line the current situation and development of the industry, especially in terms of reliability.

(iv) Old equipment should be replaced, and the equipment should be well-maintained so that they can operate normally.

5. Conclusion

In conclusion, as science and technology advance, road and bridge inspection methods must continually evolve, adapting their approaches to keep pace with global progress. This includes innovative thinking and expanding the use of detection technology, integrating it with other advanced methods, and enhancing non-destructive techniques to elevate the overall quality of inspection and maintenance practices.

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Research on Ventilation and Heat Insulation Layer Design of Split-Type Roof Greening Based on Topological Interlocking Principle

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Abstract: In this paper, the roof ventilation and heat insulation layer modules are combined with the roof greening, and each module is assembled through the principle of topological interlocking. The assembly of these modules does not require any rivets or cement mortar, and the structural stability of the overall assembled roof is achieved only through the interlocking and limiting the movements of the interlocked units. The green roof designed in this paper has strong applicability and can be applied to roofs of different shapes. Such a roof can not only meet the aesthetic needs, but also beautify the urban environment and reduce carbon emissions.

Keywords: Roof greening; Overhead insulated roof; Topological interlocking; Module

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1. Introduction

Roof greening is more and more widely used as the awareness towards environmental protection increases. Besides, green roofs also play a role in the heat insulation of the building. Roof ventilation can reduce the indoor temperature of the building, increase comfort, and reduce the energy consumption of air-conditioning systems. Considering the advantages of both roof greening and ventilation, a modular roof with the functions of planting, greening and ventilation was designed, which will be described in this paper. These modules feature interlocking shapes that are misaligned and woven together, eliminating the need for mortar masonry and metal connectors. This design prevents aging and corrosion, enabling them to function as a permanent part of the building structure. Furthermore, these modules are easy to construct, have low maintenance costs, and can be disassembled and reassembled as needed.

2. Roof greening and construction of the insulation layer

2.1. Roof greening

Green plants have functions such as regulating air temperature and humidity, absorbing solar radiation, and absorbing external noise. The roof is called the "fifth façade" of the building. Green roofs primarily serve to enhance the aesthetics of building rooftops, protect the urban environment, and enhance living conditions. Furthermore, they contribute to thermal insulation, elevated air humidity, and noise absorption by incorporating green vegetation on the roof.

Traditional methods of roof greening include roof lawns, roof gardens, and container gardening. Container gardening involves utilizing prefabricated flowerpots that can be flexibly combined, causing minimal disruption to the existing roof while allowing for versatile layouts. However, there are some problems in using flowerpots. Flowerpots for container gardening are usually made of plastic, which is less durable. The flowerpots need to be placed under the sun, which makes them age faster. Besides, harmful gases are released when plastic ages, causing environmental pollution. These containers generally require other connectors, such as plastic or metal components, which are also prone to aging and rust, causing environmental pollution. These plastic products are often not strong enough to bear a heavy covering soil layer. Container gardening is suitable for simple plants or shallow-rooted shrubs but lack proper ventilation. There are also flowerpots made of materials like concrete, but they are less flexible and require cement mortar for anchoring.

2.2. Overhead heat insulation roof

The main function of an overhead heat insulation roof is to prevent solar radiation from directly irradiating the roof. Solar radiation can keep the air circulation between the overhead layer and the roof layer, and take away the hot air through thermal convection, resulting in thermal insulation. However, overhead heat insulation roof is often used on the roofs of older houses, which lack sufficient insulation conditions. And it is not combined with the green roof, so the insulation effect is relatively less than ideal. There are a few types of traditional overhead heat insulation roof. They are usually made of cement mortar, and they are relatively thin. Even with mortar, they are still not strong enough to resist extreme weather such as strong wind and heavy rain. In addition, because the traditional overhead heat insulation roof is made of masonry, it is not easily replaceable once it is damaged.

2.3. Flat roof

A roof consists of a steam layer, thermal insulation layer, waterproof layer, and protective layer. There are no gaps in the structural layers of the roof, so the heat insulation of the roof depends only on the thermal insulation performance of the material itself. In areas with strong solar radiation, the heat from the sun is directly transferred to the structural layer on the roof, and the heat gets trapped in the layers of the roof. Besides, flat roofs are monotonous and unattractive without any greening. Ordinary flat roofs have simple structures and functions, yet they demand significant energy consumption for indoor comfort, which contradicts modern energy efficiency goals and China's dual carbon policy focused on emission reduction[1].

3. Principle of topological interlocking

3.1. The concept of topological interlocking

The term "topological interlocking" has two meanings, namely "topology" and "interlocking." Mathematically, "topology" means that a geometric object still maintains some original characteristics after continuous deformation. For instance, a stick and a sphere share the same topology, so do a ring and a pipe. "Interlocking" indicates that objects are joined in a way that prevents relative movement, creating overall stability. The combination of these two terms implies that a collection of units sharing the same topology are arranged in a way that limits their relative movement, resulting in a stable cluster where individual blocks cannot be detached. This is achieved through specific geometric shapes and arrangement (except for blocks at borders, which will be discussed separately)[2].

As early as the 18th century, in the book *La theorie et la pratique de la coupe des pierres et des bois,* *pour la construction des voutes et autres parties des bâtimens civils & militaires, ou traité de stereotomie a l' usage de l' architecture*, Volume 2, Joseph Abeille an engineer and architect designed a flat vault and some block units that conform to the concept of topological interlocking (Figure 1)[3]. These block units can cover a certain area without the use of mortar, cementing materials, or trapezoidal stones. This structure is easy to disassemble and can be reused. The concept of topological interlocking was proposed academically by Dyskin *et al.* in 2001. The simplest topologically interlocked structure is a single-layer tetrahedron, and various topologically interlocked basic units can be derived through deformation in the topological sense[4]. Topological interlocking units and their arrangement have since become an important part of the field of material design. For example, researchers have used the unique properties of these interlocking units to create protective gear like body armor.

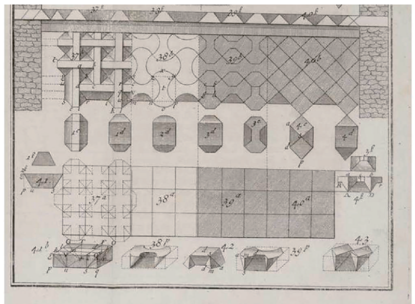


Figure 1　Drawings of some interlocking blocks designed by Joseph Abeille

Topological interlocking units can be divided into platonic solid and osteomorphic blocks. Platonic solid is a convex polyhedron with topological interlocking features. Dyskin initially confirmed that tetrahedrons can be interlocked through a specific arrangement (Figure 2). Subsequent research further confirmed that shapes like cubes, octahedrons, and other polyhedrons with twelve sides can achieve topological interlocking. These convex polyhedrons belong to the category of platonic solids. Osteomorphic blocks typically have curved edges, differing from traditional polyhedrons. Their shapes resemble bones, and the interlocking of their concave and convex contact surfaces also exhibits characteristics of topological interlocking.

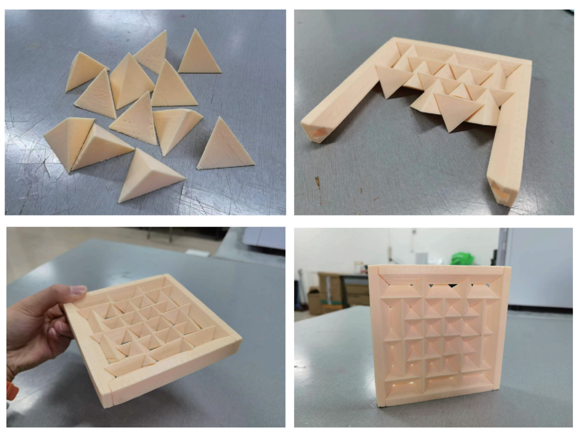


Figure 2　Tetrahedral topological interlocking walls

3.2. The locking principle of topological interlocking

To determine if a system achieves interlocking, two criteria are used: translational interlock and rotational interlock. In a group of units, if the units around a specific unit prevent that unit from moving away through translation, it can be said that the unit achieves translational interlock. Rotation interlock is also determined the same way. Furthermore, if all units in the system cannot be moved through translation (or rotation), then these units are considered translationally interlocked (or rotationally interlocked). A unit type is fully interlocked if the unit is both translationally and rotationally interlocked[5].

The mechanisms of forming interlocking units have been described in several works. According to Dyskin, if an element within an interlocking system is constrained by the kinematics of its neighboring units in one direction perpendicular to the assembly plane, while also being constrained in the opposite direction by the kinematics of other neighboring units, then interlocking is achieved[6]. Taking the most basic topological interlocking unit — tetrahedron as an example, in section A, the upward movement of module 4 is limited by modules 1 and 2 (Figure 3a); while in section B, the downward movement of module 4 is defined by module 3 (Figure 3b), thus the movement of module 4 in the up and down direction is fully defined; in section C (horizontal section in the middle position), the movement of module 3 is limited by the 4 blue modules at the periphery (Figure 3c). In short, the module' s translational movement in three-dimensional space is fully restricted, achieving translational interlocking. This design principle was subsequently applied in the development of structures called osteoids.

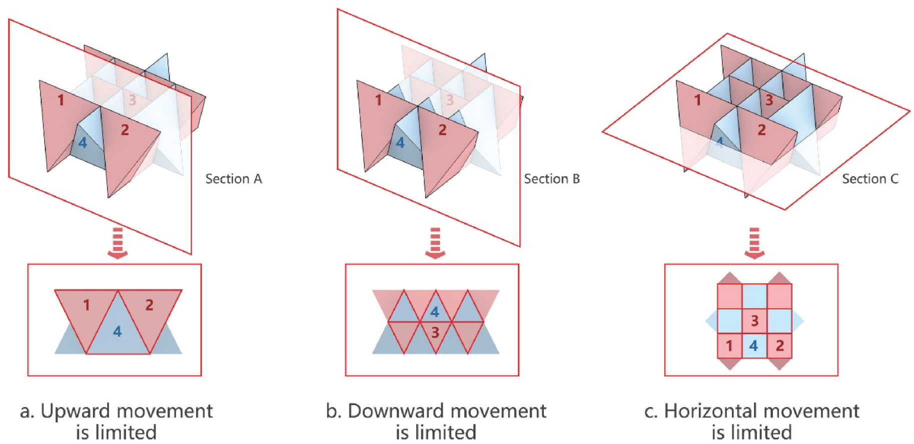


Figure 3 Interlocking principles of topological interlocking explained based on cross-sections at different locations

3. 3. The logic behind forming a topological interlocking unit

By applying the interlocking principles discussed earlier, we can deduce the underlying logic behind the creation of topologically interlocked structures. Taking cubes and octahedron as examples, a regular hexagonal mosaic grid is established first, and the plane is used as the middle section plane of the interlocking unit (Figure 4a). By extruding each regular hexagonal unit upwards and downwards, regular hexagonal prisms are obtained (Figure 4b). The hexagonal top edges located above the middle section plane are alternately offset in the direction of the arrow, while the hexagonal bottom edges located below the middle section plane are alternately offset in the opposite direction. As the offset progresses, the three sides that were offset outward eventually converge into points. Consequently, the top and bottom surfaces turn into regular triangles, transforming the entire regular hexagonal prism unit into an octahedron (Figure 4c). If the three sides connected to the top surface and the bottom surface extend upwards, causing the top and bottom surfaces to translate and extend upwards and downwards respectively, the areas of these surfaces continue to shrink until they ultimately become a point. This results in a cube interlocking unit (Figure 4 d).

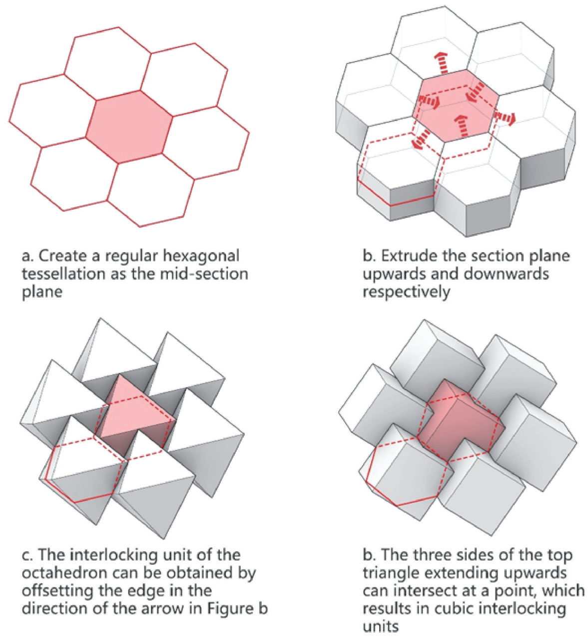


Figure 4　Generation process of octahedron and cube interlocking unit

The aforementioned logic can be applied to the generation of various other topologically interlocked units, including Platonic solids such as dodecahedrons, icosahedrons, and even Buckyballs[5]. In short, the concept of topological interlocking units can be simplified into a basic model (Figure 5). This simplified model allows a more intuitive understanding of Dyskin' s criterion for interlocking convex polyhedrons. By manipulating the normals of a row of units within the section, the edges situated above and below the middle section plane are translated in opposite directions. This setup ensures that the upper and lower sides of the middle section plane impose movement constraints in corresponding directions, thus effectively achieving unit interlocking.

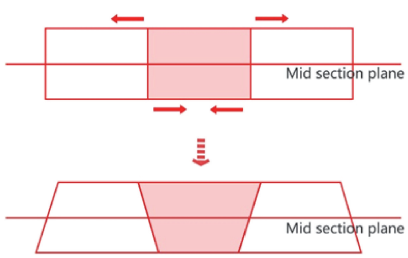


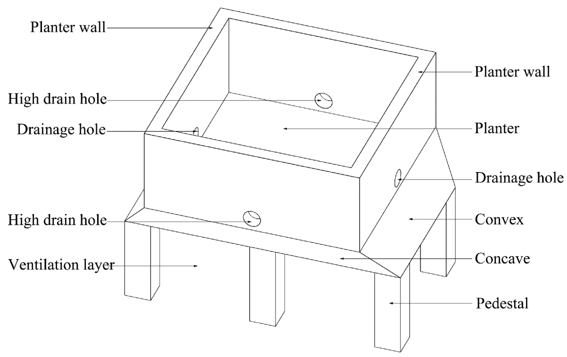
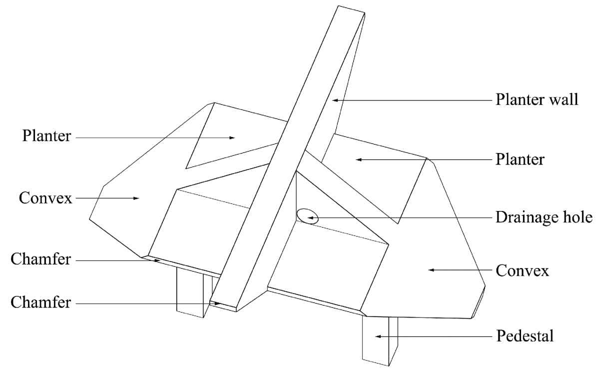
Figure 5　A simple generation model of topological interlocking units

4. Roof greening thermal insulation layer based on the principle of topological interlocking

The complete thermal insulation layer for roof greening is constructed using fundamental units, complemented by side units. The primary role of the central basic unit lies in planting and ventilating, while the side unit modules on the north and south sides mainly serve the purpose of ventilating. According to the formation mode of the planting trough, the modules designed in this paper can be divided into two categories, one is that each module comes with a complete planter, numbered as type A, and the other is that multiple modules are combined to form a complete planter, numbered as type B. The trough planters are labeled as Class B. Within Class A modules, based on the configuration of the central interlocking unit, further categorization can be made into Class A1, A2, and A3. These correspond to quadrilateral interlocking units, osteoid interlocking units, and hexagonal interlocking units, respectively.

The Class B module can also be subdivided into three types: B1, B2, and B3, which corresponds to quadrilateral interlocking units and two different forms of prismatic interlocking units respectively (Table 1).

Table 1 Type A and Type B basic unit modules

<table>
<tr><th>Basic unit module</th><th>Type A</th><th>Type B</th></tr>
<tr><td>1</td><td>
</td><td>
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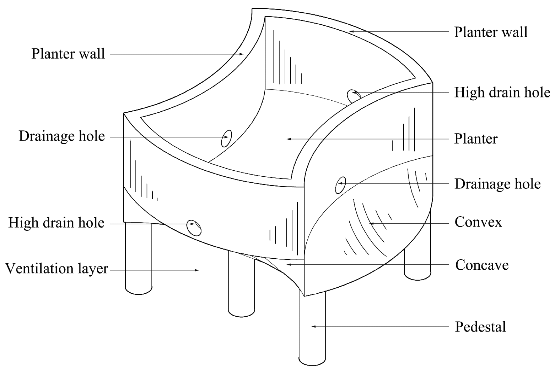
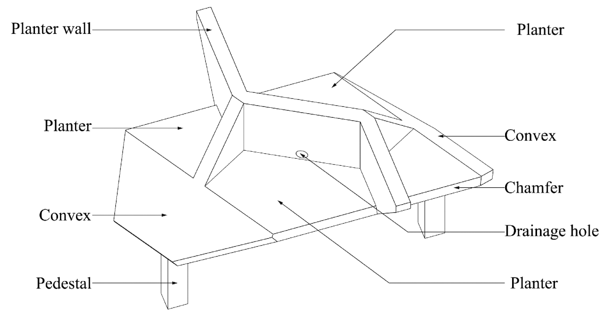
<tr><td>2</td><td>
</td><td>
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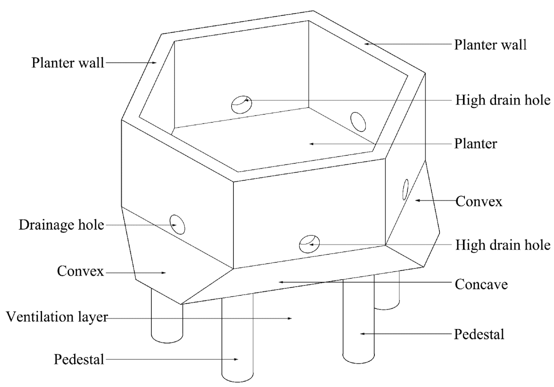
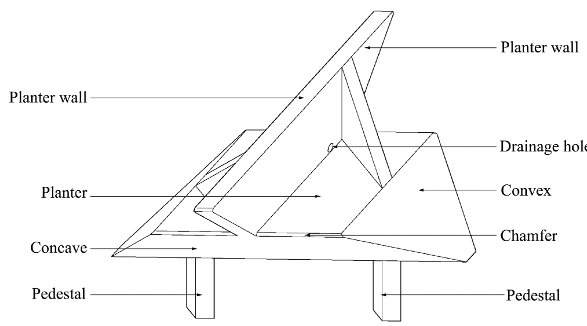
<tr><td>3</td><td>
</td><td>
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4.1. Design of basic unit modules

The basic unit module is composed of 3 parts, the upper part consists of a planting groove, the middle part consists of the interlocking unit and the lower part is the pedestal. The structure of the upper planter trough is similar to that of a green roof, and is equipped with drainage holes to remove excess water. The width of the planter trough is 25–80 mm, preferably 40 mm, with a height of 300–1 200 mm. The width of planter trough varies with different module types, generally in the range of 400–2400 mm. In type A modules, each planter wall has a drainage hole: A1 and A2 modules have 4 drainage holes, A3 module has 6 drainage holes, and all three types of modules include 2 high-level drainage holes. In the type B module, drainage holes are also found on the planter wall. In addition, there is also a drainage hole in the middle of the planter. The drainage holes on the walls of the planter troughs of different modules are set in the same position. When splicing, the drainage holes are opposite to each other, which can ensure that the water levels between different modules are connected. In this way, the excess water in the planting trough can eventually flow to the unit modules on the east and west sides. Drainage grooves are created at the drainage holes of the modules on both sides. The excess water can be directly discharged to the gutters on the roof, and then discharged from the roof through the drainage pipes.

The interlocking unit in the middle is the key to realizing topological interlocking. In order to prevent this part from being too heavy, there are certain grooves in the lower part to reduce weight and save materials. The inclination angle of the sides of the interlocking unit is 35–50°, preferably 45°. A suitable inclination angle of the sides allows for more stable interlocking. In a type A module, taking the A1 module as an example, the concave surface of a basic unit module is connected to the convex surface of an adjacent module, and the convex surface of the module is connected to the concave surface of another adjacent module, so that interlocking is achieved, forming a stable structure. The same applies to A2 and A3 modules. In the type B module, the interlocking method is similar to that of the type A module, and interlocking is achieved by joining the concave surface to the convex surface. The difference is that their planter walls are also concave or convex extensions that also participate in the interlocking.

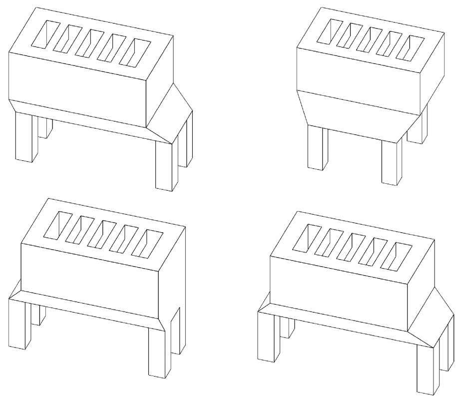
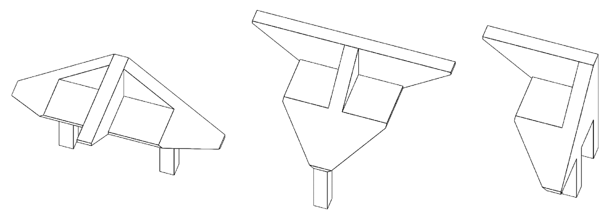
The lower pillars serve mainly to support the overall structure and facilitate ventilation. The number of pillars in the type A module corresponds to the sides of the planter walls, while for type B modules, there are generally two pillars. The recommended height for these lower pillars ranges from 150 to 500 mm, with 200 mm being the preferred choice. The primary function of this section is to elevate the modules, creating a raised layer between the green area and the roof. This structure functions similarly to an overhead roof. The upper planted roof absorbs solar radiation, resulting in heating and the consequent thermal convection of air within the overhead layer. This convection expels heated air, effectively achieving thermal insulation.

4.2. Design of the edge unit modules

In addition to a large number of basic unit modules, the entire green roof insulation layer also includes side unit modules located at the parapet. The side unit modules have a fundamental role in connecting with the parapet wall and filling any excessive gaps resulting from the shape differences between the basic unit module and the parapet wall. Depending on their placement, the side unit modules can be categorized into those positioned on the north and south sides and those located on the east and west sides. The structure of the side unit module is similar to that of the basic unit module, including the interlocking unit part in the middle and the pedestals in the lower part. The difference is that the upper part of the side unit modules located on the north and south sides is a vent. The primary purpose of the vent is to facilitate the airflow between the overhead layer and the external environment, allowing the warm air created by the thermal convection of the overhead layer to be expelled, thereby achieving thermal insulation. Typically, the side unit module has dimensions roughly half that of the basic unit module in one direction, while the remaining dimensions align with those of the basic unit module (Table 2).

Among the A-type modules, the A1 module only requires the installation of side unit modules with vents on the north and south sides because of its regular shape, and side unit modules are not needed on the east and west sides. The side units of the A2 module are similar to those of the A1. Although there are certain gaps on the east and west sides, the gap width is small and can be ignored. The A3 module not only requires side unit modules on the north and south sides, but also the east and west sides due to its larger gap. Type-B modules require a variety of side unit modules due to their more complex shape compared to type A. Corner unit modules are also needed to fill the gaps at the roof corners.

Table 2 Type A1 and Type B1 side unit modules

Basic unit module	Type A1	Type B1
1		

4. 3. Properties of split-type green roof insulation layer from the perspective of the topological interlocking principle

The insulation layer is mainly composed of side unit modules for ventilation on the north and south borders and basic unit modules for planting in the middle. The basic unit module in the middle acts as a thermal insulator, blocking the direct effect of solar radiation, and the ventilation layer below acts as a vent. The north and south side unit modules facilitate the exchange and circulation of air between the overhead section and the external environment through vents, removing excess heat and protecting the building from intense solar radiation.

The thermal insulation layer designed in this paper is composed of several unit modules. Each module can be prefabricated in the factory or fabricated on site. This design is container-gardening-based, which is in line with the current trend of BIM and prefabricated buildings in China[7]. The finished modules can be assembled on-site. The process of assembling is simple. Besides, the modules are easy to transport. By growing the plants before installation, they can be directly placed onto the roof along with waterproof and irrigation systems once they mature. This approach ensures higher plant survival rates and enhances the overall landscaping effect.

The module adopts the principle of topological interlocking. The advantage of topological interlocking is that the green roof can be modularized. This allows for easy disassembly and recombination. Once combined, it achieves a high level of overall stability. The topological interlocking unit module has the characteristic of small-amplitude motion within the kinematic constraints of realizing interlocking, which can avoid the failure of the whole system under the influence of high-amplitude vibration and dissipative vibration. This is mainly because the mobility of the topological interlocking structure absorbs part of the vibration energy, so this module has very superior seismic performance[8]. In addition, when a crack occurs in a module in the system, the modular design can prevent the crack from spreading to other adjacent modules, which might result in the destruction of the whole system[4].

The method of topology interlocking assembly reduces the need for numerous metal connectors and plastic parts, while also avoiding issues such as metal corrosion and plastic aging. The plants can be watered by simple spraying. The modules exhibit robust anti-aging properties, and when integrated with the building structure, they become a permanent part of the building. Its maintenance is straightforward with minimal costs. In case of damage to specific modules due to unique circumstances, the components can be disassembled and replaced easily, as there are no rigid connections between individual modules.

5. Practical application

5. 1. Production process

The module designed in this paper can be made of several materials, such as concrete, shale, coal gangue, fly ash, lime sand, etc. It can also be made with local specialty materials or abandoned construction waste that are crushed and processed according to local conditions, which can effectively reduce costs. Once the raw materials are processed and shaped, they can undergo pouring, sintering, cold pressing, or autoclaving. The manufacturing process for modules has minimal requirements. Moreover, secondary processing of industrial and construction waste is both energy-efficient and environmentally friendly (Figure 6).

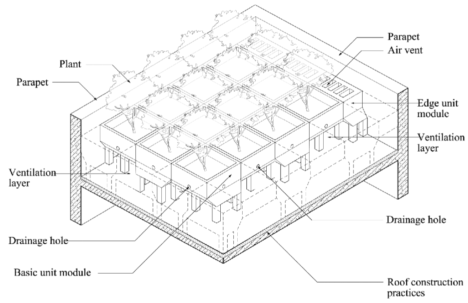
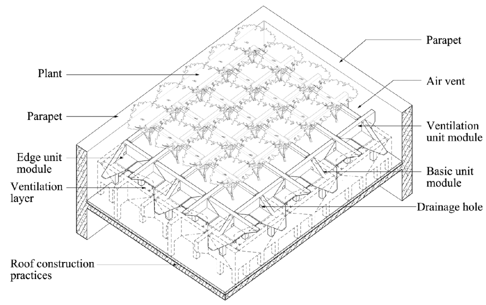
Figure 6　Type A1 and type B1 basic unit module concrete model

5. 2. Process of assembling the modules

For the assembly of the green roof module, the side unit modules are first installed on the north side of the roof, and then the corresponding basic unit modules are assembled sequentially from north to south according to the principle of topological interlocking (the installation of the side unit modules on the east and west sides is needed for some modules). It is important to ensure that the concave surface and the convex surface of the module are joint tightly. After completing the erection of the basic unit modules, the corresponding side unit modules are used to fill the vacancy on the south side, thus completing the assembly of the entire roof (Table 3 and Figure 7).

The structure of the basic unit module is similar to that of the green roof. After the roof is assembled, the corresponding layers are laid in the planter trough sequentially. The aquifer has the function of draining excess water and storing water, and the height of the drainage aquifer is the same as the height of the drainage holes on the wall of the planter. During a heavy rain, excess water can flow through the aquifer to the drainage hole, and finally to an open ditch or gutter. The thickness of the soil layer needs to be adjusted according to the type of plants, but the total height should be lower than the height of the planter trough.

Table 3 Type A1 and type B1 modular roof assembly method

Basic unit module	Type A1	Type B1
1		

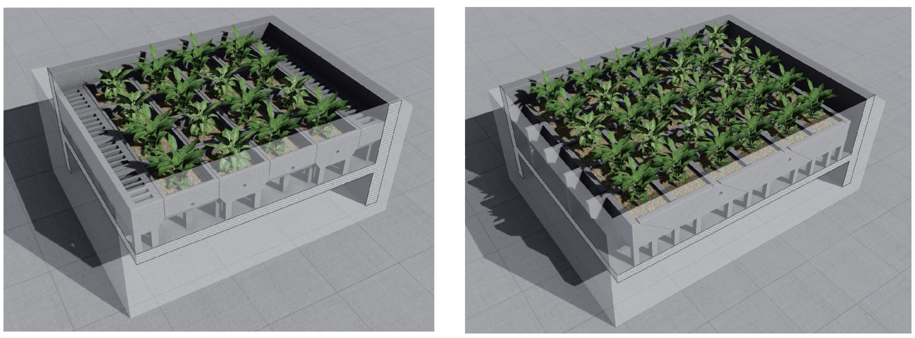


Figure 7 Rendering of A1 and B1 module roof assembly

6. Conclusion

This paper introduces a split-type green roof insulation design by blending the benefits of existing roof greening and overhead insulation methods while incorporating the principle of topological interlocking. While the theoretical aspects of topological interlocking have been studied for a while, practical applications have been limited. This study extensively explores the interlocking and generation principle of topological interlocking, utilizing its unique characteristics to create a series of interconnected modules that enhance both roof stability and aesthetics through planting and greening. This module series integrates the advantages of green roofs and overhead insulation layers, resulting in efficient heat insulation. Without the need for metal or plastic connectors, the modules exhibit robust weather resistance and can coexist as permanent structures with the building. Its maintenance is straightforward and cost-effective. The proposed module series addresses the limitations of current roof insulation systems, enhancing roof greening, insulation, and efforts to reduce carbon emissions. This advancement holds significant implications.

Disclosure statement

The author declares no conflict of interest.

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Analysis of the Application of Windbreak and Sand Fixation Technology in Desert Roads

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Abstract: In order to solve the problems in the construction of desert roads and improve the quality of desert roads in China, this paper discusses the current windbreak and sand fixation technologies in desert areas in China, and puts forward relevant suggestions and corresponding solutions for each problem. This paper is written with hopes of contributing to the development of windbreak and sand fixation technologies in China as well as the development of the economy, society and environment in China's deserts.

Keywords: Desert; Windbreak and sand fixation; Road construction

Online publication: August 29, 2023

1. Introduction

Desert roads are unique because they are designed for special climate and landform of deserts. Deserts are abundant in resources, but they also come with major ecological problems. Due to their unique climate and landform, deserts are also prone to desertification. Therefore, it is important to address the issue of desertification in our country. Road construction in desert areas is a good solution to this problem. Reasonable design of desert roads can effectively improve the ecological environment of deserts in China thereby promoting the harmonious development of China's economy and society[1-4]. Therefore, it is crucial to analyze the problems in the construction of desert roads in our country and propose corresponding solutions.

2. Problems with desert roads

2.1. Sand damage

Sand damage refers to some sand piles and sand ridges that appear on both sides of roads in deserts. These sand piles and sand ridges not only affect the quality of the road, but also cause serious damage to the ecological environment around the road. Secondly because deserts are dry and have huge areas, sandstorms are bound to occur. Sandstorms have a serious impact on desert roads. Therefore, this problem must be taken into account when constructing desert roads, and corresponding countermeasures should be taken. Deserts in China are also prone to strong winds, which will also seriously affect the desert road. Therefore, this issue should also be taken into account while constructing desert roads[5-7].

2.2. Wind erosion

Our country's desert roads are mainly distributed in the northwest region, where the natural environment and climate is relatively harsh. This makes the construction of desert roads in the northwest region extremely challenging. An important issue that should be taken into account during desert road construction is wind erosion. The problem of wind erosion mainly refers to the uneven subsidence of the road surface under the action of wind and sand, forming potholes and grooves. This phenomenon is mainly because the road sections selected in the process of desert road construction are often relatively wide and flat areas. Besides, these sections all have relatively high wind speed, and the wind speed varies from time to time. If these areas are not well-protected, wind erosion will occur. Wind erosion is mainly caused by wind-blown sand, which will damage the road surface to some extent[8-11]. The problem of wind erosion can be solved by properly designing the subgrade, setting up corresponding slope protection, and improving the drainage system.

3. Application of windbreak and sand fixation technology on desert roads

Currently, sand damage and wind erosion on desert roads are mainly countered by windbreak and sand fixation by planting trees. This method is mainly aimed at various types of sand damage, different methods are used for different types of sand damage. Usually, the following plants are used windbreaking and sand fixation: parsnips, reeds, licorice, etc. These plants are very effective in controlling sand damage and wind erosion. In addition, plants that are selected for these roles should be extremely adaptable. For example, shrubs are planted on the sides of roads to prevent the sand from moving around too much.

3.1. Highway slope protection technology

Desert road slope protection mainly adopts plant protection technology, in which the plants are used to reduce wind erosion on desert road slopes. Generally speaking, the slopes on desert roads are generally sandy, so plants that are planted on the slopes should have strong wind resistance. At present, the main sand control measures adopted in our country are as follows: grass seeds, plant fence, plant grids, etc. Among them, the grass are planted to prevent sand dunes from moving and stabilize the slope of the desert road, so as to reduce the damage to the road caused by wind and sand. Plant fences are installed to prevent the vegetation on the mobile sand dunes from being blown away, so as to prevent soil erosion. Plant grids are used to prevent the movement of sand dunes, so as to maintain the stability of the road. In addition, a new type of protection technology, spraying technology, can also be adopted. This technology can make the soil and seeds form a new layer of soil in a short time, thus playing a very good role in protecting the vegetation, thus improving the quality of desert road slope protection.

3.2. Sand barrier

Sand barrier can be built on both sides of the road, which can effectively protect the road and reduce the impact of wind and sand on the road. Usually, sand barriers are placed on both sides of the road, the barriers would be covered with and some sods, straw curtains, and plastic films. This can effectively block wind and sand, thereby ensuring the safety of the road. Besides, the sand barrier needs to be of a suitable height. If the sand barrier is too high or too low, the desert road will be affected to a certain extent. In addition, we can also use some other methods to prevent the sand from moving around, such as by planting some trees. Through these methods, the safety and stability of the desert road can be effectively improved, and the impact of wind and sand on the road can also be minimized.

3. 2. 1. Sand fence with grass and firewood

The “tree branch wall has been used for hundreds of years. The raw materials are cheap and can be found locally, such as branches, *Achnatherum splendens*, reeds, and straws (corn, sorghum, etc.). The softer part of the stem faces upward, while the roots are generally buried about 20 cm beneath the ground, with an exposed portion of 50–100 cm above the ground, achieving a density of approximately 35%. The walls can be arranged in the form of rows or columns. The row-column intervals of the walls shall be determined according to the slope and height of the gravel.

The sand fence with grass and firewood is and effective sand control method that prevents wind and fixes sand. However, it requires a lot of materials, and it collapses easily, thus needing frequent repairs. Therefore, this method cannot be used at a large scale. This method can be applied in many areas, such as residential areas, livestock pens, road sand outlets, and other places.

3. 2. 2. Grass grids

Grass grids are a semi-concealed sand barrier, which is usually made of wheat straw, rice straw, or soft crop stalks. Rice straws and other materials are buried at a depth of 10–15 cm, with an additional 20 cm layer above the surface, structured in grid units of 1 meter. Grass grids has sand-fixing and wind-proof functions. Based on measurements taken at Ningxia Sand Wave Peak, the grass grids measuring 1×1 m effectively reduces the internal airflow speed to 1 m/s when it makes contact with the ground at a wind speed of 6. 5 m/s. This slowdown in airflow speed helps prevent the movement of quicksand.

This approach offers benefits such as simple operation, abundant raw materials, cost-effectiveness, wind and erosion resistance, and no harm to vegetation. However, due to a growth cycle of 3–5 years, it requires collaboration with suitable local vegetation for effective sand control. As a result, aeolian sand subgrade construction often involves utilizing multiple varieties of unique willows for effective sand control.

3. 2. 3. Cohesive sand barrier

The sand in many areas of the Hexi region is cohesive sand, and there are more sand in the hilly areas, which can be used as the material for sand barriers. The installation process involves creating soil ridges with a height of 15–20 cm along the windward slope of the sand dune. These ridges have a triangular cross-section and are spaced at intervals of 2–3 m, aligned with the primary wind direction. Cohesive sand barrier has sand-fixing effect and is stable. However, a gelatinous layer can form on the small sand layer’ s surface, hampering rainwater infiltration and vegetation growth. Constructing cohesive sand barriers proves more efficient and cost-effective in areas with accessible cohesive soil; for distant locations, more resources, manpower, and costs are required.

3. 2. 4. Nylon grids

Nylon grids has a similar working principle as grass grid sand barriers. The grids are made of nylon, with a diameter of 20 cm and a density of more than 20%, making it a tight sand and gravel barrier. During installation, the pre-prepared pillars are first positioned on the sand surface at intervals of 1 × 1 m. Subsequently, a grid of 1×1 m is formed by wrapping nylon tape around the pillars, followed by securing the grid to the pillars on the sand surface using thin steel cables. However, this method is costly and leads to land pollution after degradation. Although it has found application in many projects such as those in Minqin, Gansu, Shabotou, Ningxia, and the Qinghai-Tibet Railway, its usage remains limited.

3. 2. 5. Geotextile sand barrier

Geotextile is used as a protective barrier in a way similar to traditional cohesive sand barriers. This involves creating 20 cm bags from nylon cloth, filling them with sand on-site, and placing them in rows or grids on the sand surface to control quicksand movement. However, this method is still being tested and has not been widely used yet.

4. Application of desert road windbreak and sand fixation technology

Windbreak and sand-fixation technology is crucial to ensure the smooth construction of desert roads. The utilization of windbreak and sand-fixation technology can effectively alleviate the problem of wind and sand in the process of desert road construction. Many windbreak and sand fixation technologies have been used in our country in the process of desert road construction, such as plant sand fixation technology and chemical sand fixation technology. These wind-proof and sand fixation technologies have played an important role in the construction of desert roads. However, their improper application and environmental consequences have considerably hindered the progress of such projects.

4. 1. Scientific and reasonable planning of desert road construction scheme

Incorporating windbreak and sand-fixation technology into desert road construction should adhere to the principle of "adaptation to local conditions, starting with the easier aspects and then tackling the more challenging ones." This approach entails considering local climate, environmental conditions, and other factors to meticulously design a scientifically and logically sound desert road construction strategy. Plant sand fixation method should be applied while considering local natural conditions and vegetation characteristics, so as to avoid unnecessary troubles in the road construction.

4. 2. Reasonable selection of windbreak and sand fixation plants

Plants are an important part of desert road construction, and the quality of road construction can be effectively improved through reasonable selection of windbreak and sand-fixing plants. Plants such as caragana, sea buckthorn, willow, and licorice have strong drought resistance and well-developed root systems, which can effectively fix quicksand. In the process of desert road construction, it is necessary to select suitable windproof and sand-fixing plants. Besides, the plants have to be highly adaptable and can be planted on both sides of the road to provide support for the construction of desert roads. Moreover, sandy shrubs and sandy herbaceous plants can also be used in desert road construction, which can improve the stability of desert roads and avoid sand flow in windy and sandy weathers.

4. 3. Scientific selection of windbreak and sand fixation technology

The selection of windbreak and sand fixation technology should be based on the actual conditions of desert roads, especially the climate and vegetation in the area where the project is located. The windbreak and sand fixation technology used should be selected after performing a comprehensive analysis to achieve the best results. In addition, care should be taken to avoid serious pollution to the environment when choosing windbreak and sand-fixation technologies, and environmentally friendly, economical, and practical technologies should be used. In addition, factors such as construction cost and construction quality should be considered when selecting windproof and sand-fixing technologies. In general, applying biological sand-fixation technology involves choosing drought-resistant plants, while chemical sand-fixation technology necessitates the use of environmentally friendly materials. Therefore, it is necessary to scientifically select windbreak and sand-fixation technology according to the actual situation of the area where the project is located.

5. Conclusion

To effectively apply windbreak and sand-fixation technology in desert roads in our country, it is necessary to first clarify the problems in the construction of desert roads. Then solutions should be formulated for different problems. These technologies should be applied based of "prevention, then control." Physical Engineering: This involves applying physical principles to enhance wind and sand flow resistance, leading to the deposition of sand particles. Common techniques include erecting tall vertical sand barriers, installing fences, and building sand-retaining walls. Several technical methods have been explored in this paper, which are describes below.

(1) Physical methods: This method involves enhancing wind and sand flow resistance, leading to the deposition of sand particles. Common techniques include erecting tall vertical sand barriers, installing fences, and building sand-retaining walls.

(2) Chemical methods: Chemical materials and techniques are used to create a consolidating layer on sandy surfaces or sand dunes prone to erosion. This layer prevents wind erosion, retains moisture, and enhances sand properties, thus managing and improving the sand-prone environment. Examples include the application of various chemical reinforcing agents, including asphalt compounds developed by the former Soviet Union.

(3) Plantations: This approach focuses on transforming desertified land by sowing hardy sandy plants to control and stabilize quicksand. The efficacy of this method arises from the robust root systems of sand-loving plants, which consolidate sand particles. The accumulation of organic matter from decomposed leaves further enhances the soil-formation of sand, making quicksand more stable. Examples of the application of this strategy includes creating shelterbelts, stabilizing sand by growing grass, and other similar techniques.

Lastly, it is necessary to strengthen the control of wind erosion on both sides of the road through sand fixation methods. Only in this way can we the problems in road construction in deserts of our country be resolved.

Disclosure statement

The author declares no conflict of interest.

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Application of BIM + VR Technology in Highway Design and Construction

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Abstract: The application of building information modeling (BIM) and virtual reality (VR) has become increasingly popular in highway design and construction, aiming to improve the efficiency and quality of design and construction. BIM and VR technology enable the digital management of expressway design and construction, facilitating a visual, interactive, and immersive operational experience. Using a highway construction project as a case study, this paper illustrates the specific application of BIM + VR technology in highway design and construction. This provides digital, intelligent, and efficient solutions for highway construction, ultimately enhancing the quality and efficiency of the design and construction processes.

Keywords: BIM; VR; Highway design; Construction application

Online publication: August 29, 2023

1. Introduction

China's highway construction industry has been developing rapidly and has become an important part of its economic development. It is necessary to make rational use of various advanced technologies in the design and construction stages. The design and construction scheme can be optimized through the combination of building information modeling (BIM) and virtual reality (VR) [1-4]. At the same time, the information distortion during the transmission process can be reduced, which facilitates the rational utilization of various resources. For example, BIM technology and VR technology can be effectively integrated in the process of expressway construction, in which and the engineering model is built using BIM technology, the model is experienced through VR. In this way, the design plan and construction plan can be better displayed, so as to better meet the needs of road construction.

2. Project overview

The project taken as an example involves a highway route with a total length of about 60 km, which is an important traffic artery in the area. The terrain in this area is dominated by plains and hills, and the climate is semi-humid and semi-arid. Therefore, the highways in this area are highly affected by the mountainous terrain, which makes the construction of highways challenging. Besides, this area also consists of many mountainous and hilly areas.

3. Application of 2BIM + VR technology in expressway design and construction

3. 1. The process of BIM + VR technology application

The overall flow of BIM + VR technology application is shown in Figure 1 and Figure 2.

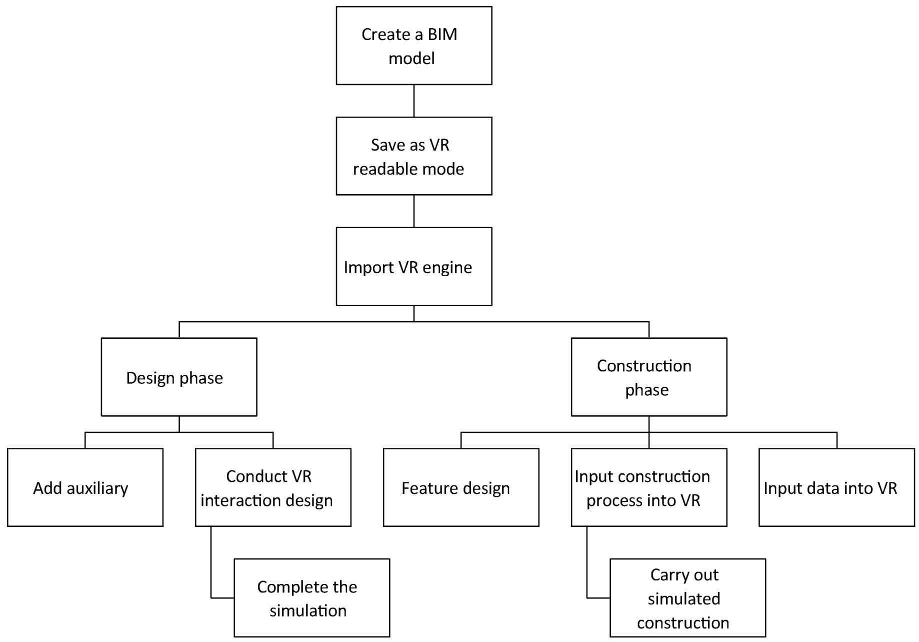

Figure 1 BIM + VR technology application scheme

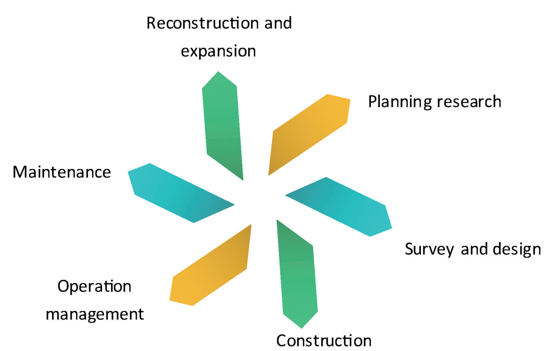

Figure 2 Areas of application

3. 2. BIM three-dimensional model

This project used more than ten BIM software from Autodesk, such as Revit and Navisworks, to gather geographical, meteorological, and geological data, including topographic maps, exploration reports, and meteorological data[5-6]. BIM software was used to establish the geometric model of the highway, including roads, bridges, tunnels, electromechanical equipment, etc. It is necessary to add attribute information while establishing the model, including materials, structures, functions, etc. Incorporating attribute information enhances the model´s description and improves efficiency and accuracy. In the process of building a 3D model, it is necessary to establish an associative relationships, including the relationship between structures, the relationship between equipment and pipelines, etc. Establishing associative relationships enhances the model´s description and improves the model' s reliability and accuracy. Moreover, collision detection should also be carried out during the design stage, including collision detection between different disciplines, different structures, etc[7-8]. It is also important to continuously improve the details of the model, which includes tasks such as processing and optimizing details, analyzing and optimizing the structure, and calibration (Figure 3 and Figure 4).

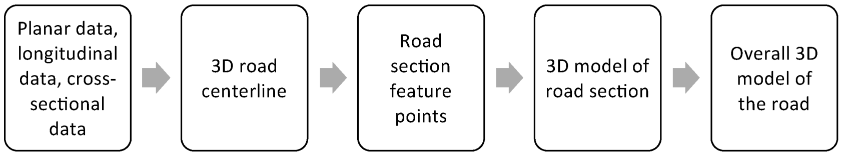

Figure 3 3D model generation process

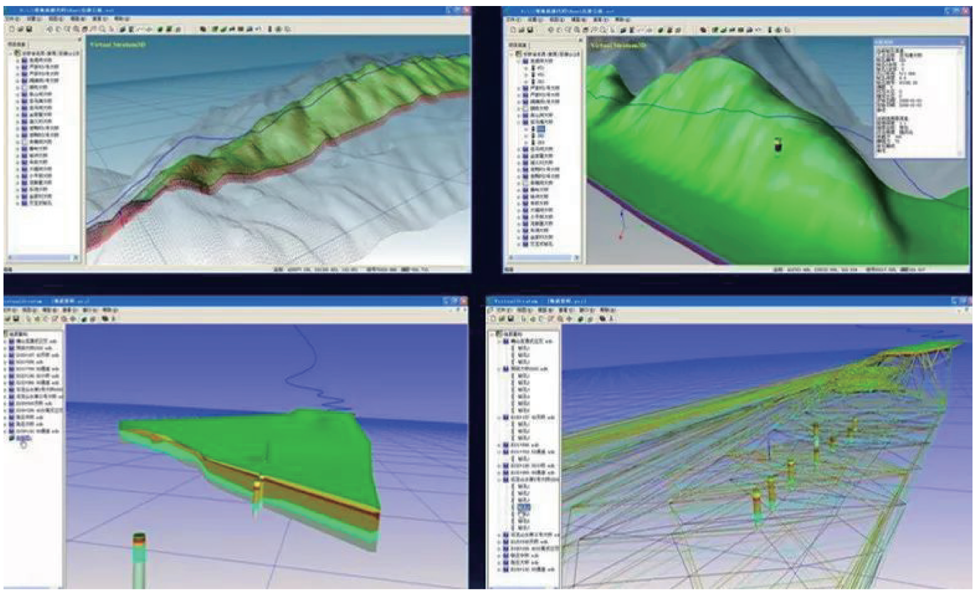

Figure 4 BIM 3D model

3.3. 3D visualization enhanced disclosure

The 3D-visualization-enhanced disclosure simulates and display the design and construction process of the expressway by using BIM technology and 3D visualization technology to improve the accuracy and efficiency of disclosure. The 3D model is visualized in terms of appearance, color, texture, etc. of the model. In the process of 3D visualization, interactive functions can be added, including roaming, zooming, rotation, etc[9-10]. By adding interactive functions, the disclosure can be made more flexible and convenient. BIM can be used for construction simulation, including the simulation of the construction process and progress. Following the completion of enhanced 3D visualization, disclosure documents can be generated, encompassing design and construction drawings, among others. By outputting disclosure documents, the results of the disclosure process can be recorded and saved to facilitate subsequent construction and management (Figure 5).

3.4. GIS + BIM site layout optimization

Geographic information system (GIS) technology is used to collect geographic information data along the expressway, including terrain, landform, hydrology, meteorology and other data. By processing and managing these data through GIS, we can better understand the geographical environment of the construction site and provide basic data for site layout optimization. In the process of building models, the construction site layout should be considered, including temporary facilities, material storage yards, and the placement of construction machinery[11]. The established GIS model is combined with the BIM model to integrate geographic environment information and construction facility information. The GIS+BIM model is utilized for site analysis, encompassing terrain analysis and visual analysis. Upon completion of the site layout optimization design, an optimized facility layout diagram and a road planning diagram is created.

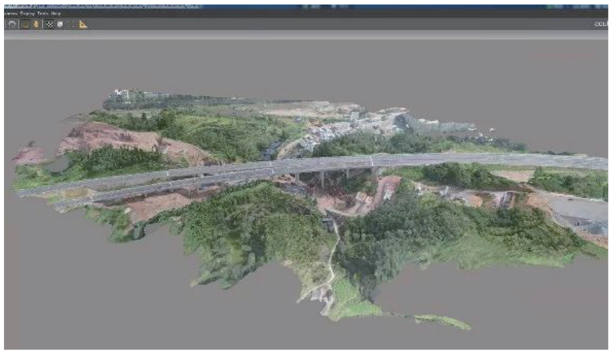

Figure 5 Overall rendering of expressway

3.5. 3D Collision check optimal design

In this project, Navisworks was employed to detect collisions among prefabricated box girder steel bars and bellows, including 40-meter orthogonal and 30-meter oblique components, and 20 collisions were found. An analysis of the collisions was conducted, and the coordination data was generated, which was submitted to the designer[12]. The designer optimized the design drawings based on the results of the collision detection, thereby avoiding changes in the design in the later stages and rework.

3.6. BIM-assisted calculation of engineering quantities

Revit form function was used to obtain the quantities of U-shaped bridges, prefabricated box girders, and cover girders, and a bill of quantities for concrete and steel bars was compiled to provide an accurate basis for project cost and cost control[13]. For the Ronghe road section, an unmanned aerial vehicle pitch camera was used along with Smart3D to realize the accurate measurement of earthwork excavation, transportation, and other aspects of the road section.

3.7. Construction simulation based on BIM

In the process of construction simulation, it is necessary to select the appropriate software according to the type of project to ensure that various scenarios can be simulated successfully. The software can be used along with BIM to realize construction simulation, and the data such as the overall progress of the project, resource requirements, and engineering quantities can be managed effectively. Construction simulation refers to simulating various resources involved in the project, and the construction plan can be modified according to the actual situation. In the process of construction simulation, it is necessary to ensure that the project progresses according to schedule, and that different stages of the construction are well-connected[14-15]. At the same time, it is also necessary to determine the relationship between various resources and predict and evaluate possible problems. Besides, it is necessary to collect, organize, and analyze various information to form a relatively comprehensive plan and perform quantity survey based on the plan to make scientific and reasonable arrangements for the entire project. During the construction simulation process, it´s essential to integrate the construction plan with the project´s actual situation in order to effectively manage the entire project (Figure 6).

Figure 6　Road rendering

3.8. Construction simulation using VR

In the process of highway construction, it is necessary to utilize various advanced technologies, and the use of BIM and VR is a great example of that. Specifically, VR technology can be used to simulate various scenes in the highway construction process through models. When using VR for construction simulation, information can be input into the BIM model, and the changes will be simulated accordingly. In this way, various problems in the actual construction process can be effectively solved. For example, in the process of expressway construction, various processes and sites can be virtualized. When problems are found, effective measures can be taken in time to solve them. In addition, it is also possible to simulate and analyze the progress and quality of the entire project, so as to realize the optimization of the entire project (Figure 7).

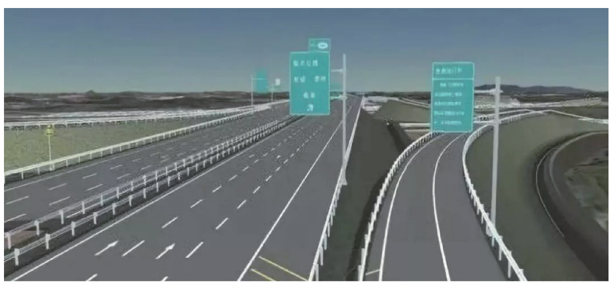

Figure 7　Signboard rendering

3.9. BIM collaborative management platform

Many construction companies were involved in the engineering, procurement construction contract, which made communication and coordination between companies relatively difficult. Therefore, the project team proposed a BIM collaborative management platform for roads and bridges, which aimed to achieve resource sharing and efficient collaboration among participating companies such as construction companies, supervision companies, design companies, and consulting companies. This platform effectively connects BIM models from various industries with two-dimensional construction drawings, engineering documents, and materials. This integration was aimed at encompassing project factors such as quality, safety, schedule, cost, and environment. This enabled real-time monitoring of project sites, allowing project managers to swiftly access information from login to query, typically within seconds. Compared to conventional construction, problems were reduced through this platform, and the coordination among participating enterprises was improved, which in turn increased the efficiency of information exchange between enterprises.

3. 10. BIM intelligent monitoring system

Due to problems such as insufficient control of the construction progress of the expressway project and difficulty in ensuring the quality of the construction link, the project team integrated BIM technology with computer network communication technology to build the Ronghe Expressway Intelligent Monitoring System. The monitoring system showcases on-site construction via video and project completion outcomes. It merges this visual representation with actual project progress within the BIM model and 3D construction simulations based on BIM. This intelligent monitoring system empowers project managers to swiftly understand the project' s status. In this way, delays in the construction progress of important sub-projects can be avoided.

4. Conclusion

With the rapid development of our country' s economy and society, the demand for transportation is increasing. Concurrently, computer, information, and intelligent technologies are advancing, leading to the widespread adoption of BIM+VR technology in expressway design and construction. This technology can not only improve the level of engineering design significantly, but also increases the efficiency of expressway construction. At present, BIM + VR technology has been effectively integrated with other advanced technologies in many highway projects, and the efficiency of design and construction has been largely improved.

Disclosure statement

The authors declare no conflict of interest.

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Research on Highway Bridge Inspection

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Abstract: Highway bridges are important transportation infrastructures in our country, and their quality is related to the people's lives. Highway bridge inspection, identification and test are measures to evaluate the quality of highway bridges. Through the comprehensive application of various technologies, quality problems of highway bridges can be found early, thereby ensuring traffic safety. This paper first summarizes the role and the types of highway bridge inspection and test. Then the problems and solutions in highway bridge inspection and test are analyzed and studied, and some examples are given, in hopes of providing reference for future testing.

Keywords: Highway bridge; inspection and identification

Online publication: August 29, 2023

1. Introduction

The construction of highways and local roads in our country has been developing rapidly. In recent years, and the number of highway bridge projects has increased significantly. At the same time, due to the large stock base of bridges, insufficient maintenance funds, and the increase of overloaded vehicles, accidents such as road bridge collapses occur from time to time. Such accidents not only endanger people's lives, but also cause huge economic losses. To this end, it is necessary to carry out systematic inspection, identification, and test before and during the use of highway bridges. The tests should include aspects like the appearance, material degradation, and bearing capacity of highway bridges. Problems that are identified through these tests should be addressed promptly, so as to ensure that the quality of highway bridges meets national standards, thereby ensuring traffic safety.

2. The role of highway bridge inspection, identification, and tests

Highway bridge projects are large-scale, and requires a variety of construction materials and construction technologies. Besides, various tests are carried out to determine whether the material quality, bearing capacity, and structural stability of highway bridges meet the national standards. Quality problems in highway bridges can also be detected through these tests. When the problems are resolved, accidents such as collapses can be prevented, thereby ensuring traffic safety[1].

3. Main contents of inspection, identification and test of highway bridge

3.1. Appearance inspection of highway bridges

In the process of appearance inspection to the highway bridge, technicians need to determine the items for inspection according to the type of bridge. When performing appearance inspections on highway bridges, the selection of items for inspection is determined by technicians based on the bridge type. The appearance inspection typically comprises three main components: superstructure, substructure, and bridge deck[2]. Inspection of the superstructure primarily focuses on composite elements like hollow slabs and small box girders. In the case of arch bridges, the inspection targets arch ribs. Inspection of the substructure concentrates on elements such as abutments, foundation caps, and piers.

3. 2. Material condition inspection

The quality of construction materials of highway bridges has a great influence on the overall quality of highway bridges. During the operation process, problems such as material weathering will also occur with the passage of time. Therefore, it is necessary to adopt effective methods to detect the condition and aging of existing materials[4]. It is necessary to focus on the quality inspection of steel bars and concrete. Ideally. under non-humid and dry environmental conditions, the mechanical performance indicators of steel bars should be consistent with the design drawings and inspection reports during construction. If quality problems are suspected of steel bars or there is no clear reference data, samples of the steel bar needs to be taken for inspections. To test the strength of the concrete, the ultrasonic rebound or core drilling method can be used.

3. 3. Bearing capacity inspection and identification

3. 3. 1. Static load test

Bearing capacity inspection and identification is an important aspect of highway bridge inspection. Relevant parameters of the bridge should be measured and calculated to determine whether the bearing capacity is sufficient. Taking the static load test as an example, a suitable test hole should first be selected. The hole should be of the most unfavorable condition, quality, with serious issues or defect. Besides, it should be easy to set up scaffolding or observation points, and easy to load during the test. After selecting the test hole, it is necessary to determine the loading scheme according to the actual position of the loading vehicle in order to obtain certain representative test data[5-6].

3. 3. 2. Dynamic test

The dynamic testing process of highway bridges involves acquiring data such as dynamic strain, dynamic displacement or velocity, and acceleration from various components. This data is used to determine the structural dynamic characteristics and how the bridge responds to dynamic loads. The instruments used in the dynamic test of highway bridges mainly include signal amplifiers, test sensors, digital signal processors, etc. During the test process, it is necessary to select vibration methods such as pulsation, resonance, and natural vibration according to the structural characteristics of the highway bridge to accurately measure the natural frequency, damping, mode shape, impact coefficient, and other parameters of the highway bridge, and then evaluate the overall quality of the highway bridge[7].

4. Problems existing in inspection, identification and test of highway bridges

The problems in highway bridges inspection, identification, and test are summarized below.

Firstly, certain regions lack adequate attention to the inspection, identification, and testing of highway bridges, coupled with the absence of a well-established management system. Secondly, several highway and bridge inspection units lack a comprehensive management system, leading to deficiencies in the inspection and testing processes. This has also resulted in instances of irregular staff operations, compromising result accuracy. Thirdly, issues with technicians further compound the problem, as the specialized nature of highway and bridge inspection demands proficiency in utilizing various testing equipment and technologies. Some technicians lack the necessary professional skills, leading to ineffective use of test equipment and techniques, or an incomplete understanding of testing and identification aspects. This ultimately leads to inaccurate test results[10].

5. Highway bridge inspection strategy

5. 1. Developing a sound management system

In order to ensure the quality of highway bridge inspection relevant departments need to formulate a sound management system, clarify the highway bridge inspection and test items and standards, and frequency of tests, etc. Moreover, it is essential to establish clear guidelines for penalties related to violations, conduct regular assessments of testing agency operations, and promptly address identified issues. This ensures that inspection and testing efforts yield desired outcomes. Concurrently, testing institutions must develop management systems aligned with their specific circumstances, define operational protocols for inspection, identification, and testing, allocate personnel responsibilities, enhance equipment oversight, and rigorously enforce systems. This ensures that personnel can consistently employ diverse instruments, equipment, and technologies to execute testing tasks in a standardized manner[11].

5. 2. Standardizing operating procedures

Test institutions need to standardize the operating procedures for different tests and inspection, which include the workflow of sampling, equipment operation, and result analysis. Besides, the use specifications of various equipment should also be determined, and the error range of test results[12]. Test agencies should actively bring in new testing equipment, keep updating their testing methods, and learn from practical experiences. By identifying issues in highway bridge inspection, they can adjust and improve their strategies, leading to better quality inspection overall.

5. 3. Strengthen personnel management

The quality of highway bridge inspection, identification, and testing work is closely linked to the competence of the personnel involved. Thus, inspection organizations should enhance personnel management by establishing a comprehensive system, clarifying responsibilities and operational guidelines, and defining reward and penalty criteria. Vigilant supervision of inspection, identification, and testing procedures is essential, including the imposition of penalties for any violations to ensure high-quality work[13]. Additionally, testing agencies should regularly arrange training for staff, enlist experts to explain technical operational methods, and provide guidelines and precautions for different equipment. Moreover, the recruitment of skilled technical staff should be a priority to continually bolster the testing team´s capabilities and ensure compliance with relevant standards.

6. Case analysis

6. 1. Case overview

The highway bridge features a reinforced concrete rigid frame arch superstructure (2×50 m) with a sagittal height of $L/8 = 6.25$ m and a total length of 128. 50 m. The substructure employs a gravity pier design, constructed using prefabricated component suspension hoisting technology. The bridge has been operational since 2005, and due to its functional changes in 2020, it underwent structure reliability, bearing capacity detection, identification, and testing to ensure traffic safety. This process was conducted in accordance with relevant national regulations[14].

6. 2. General inspection and force analysis

The inspection results indicated that the highway bridge had undergone repairs and strengthening, as the traffic volume showed a consistent year-by-year increase. The component composition and force analysis yielded the following findings: Firstly, the main components of the rigid frame arch bridge. The highway bridge belonged to the arch system, with the force system along the bridge direction comprising the arch structure and the main arch circle. In the transverse direction, the structure was composed of the cast-in-place bridge deck and the girder slab. The rigid frame arch superstructure included structures such as arch leg supports, chord supports, and inclined leg supports. These design features ensured that the dead load thrust of the bridge remained significantly lower than that of conventional arch bridges. To maintain a reasonable bridge height, the rise-span ratio was set at L/8, usually falling within the range of 1/7 to 1/10. Secondly, the mechanical analysis of the rigid frame arch bridge. This type of arch bridge mainly experienced compression, leading to minimal internal bending moments within the arch ring. Under overloading conditions, the rate of tensile stress growth in the arch ring section was considerably lower than in the bridge deck. Simultaneously, the arch bridge exhibited a considerable load-bearing potential due to the combined effects of the arch structure and the main arch ring. Thirdly, the lateral stability and lateral force reinforcement scheme. Addressing the bridge´s unique characteristics and identified issues necessitated lateral rigid reinforcement to enhance overall structural stiffness and reinforce the rigidity of the consolidated beams between the arch ribs beneath the bridge deck.

6. 3. Inspection of rigid frame arch bridge

The results of the inspection and identification of the rigid frame arch bridge were as follows: Firstly, the concrete strength of the stressed parts in the main structures were tested according to the "Standards for Experimental Methods of Concrete Structures." The results indicated that the concrete strength met the design requirements. Secondly, a bridge deck inspection and identification were carried out. The assessment of the bridge deck pavement and flatness revealed that the flatness of the bridge deck pavement was generally normal with some bumps. Additionally, the height difference of the stretched area of the bridge deck was measured at 40 mm. Among these, the height difference between Piers No. 0 and No. 1 was particularly noticeable, potentially leading to issues like vehicle jolting. Therefore, this area should be flattened. The drainage test results for the bridge deck indicated that the drainage facilities were essentially normal, with minor water accumulation. Moreover, some parts of the sidewalk railings were damaged, requiring timely repairs.

6. 4. Structural test of the rigid frame arch bridge

Loading tests, section stress tests, deflection deformation tests, and support displacement tests were performed in accordance with the relevant standards. For the loading test, four vehicles with weights ranging between 35–37 tons were selected. These four vehicles were positioned side by side on the arch foot area of the rigid frame at the No. 0 abutment and the mid-span of the No. 0–1 abutment. Upon completion of this test, the four vehicles were rearranged into a square formation, and a loading test was subsequently performed on the mid-span of the No. 0–1 abutment. Secondly, the main section's displacement and strain were assessed. A dial gauge was used to measure the stress, strain, and displacement of the abutment. Proper equipment operation was standardized to ensure the precision of the test outcomes.

6. 5. Result analysis

Based on the inspection and test results, it is recommended to limit the tonnage of vehicles passing the bridge, prohibit parking on the bridge, and timely divert traffic if there is a traffic jam on the bridge. At the same time, highway bridges need to be inspected and maintained regularly, focusing on the deformation cracks of piers and abutments and arch foot cracks. Besides deteriorating components should be repaired and replaced accordingly[15].

7. Conclusion

The quality of highway bridges is related to people' s vital interests. Therefore, it is necessary to standardize the inspection, identification and test, determine the quality problems of highway bridges based on the test results, and take effective measures to prevent accidents such as highway bridge collapse.

Disclosure statement

The authors declare no conflict of interest.

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Analysis and Research on Interchange and Expansion options of Expressway

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Abstract: China's road network consists of numerous older expressways experiencing high traffic volumes and severe congestion, necessitating urgent reconstruction and expansion efforts. This study discusses the reconstruction and expansion project of the Yinkun Expressway's Chongqing High-tech Zone to Rongchang District section, with a detailed exploration of the entire design process. Through a comprehensive analysis, the strengths and weaknesses of different plans are examined, so as to determine the optimal plan. The design chosen saves costs while effectively addressing traffic demands. Additionally, the study summarizes the valuable design insights gained from this interchange transformation, aiming to provide valuable reference for similar interchange projects in the future.
Keywords: Expressway; Comparison and selection of expressway interchange reconstruction and expansion designs

Online publication: August 29, 2023

1. Introduction

G85, G93 Chongqing High-tech Zone to Rongchang District (Sichuan-Chongqing boundary) section (hereinafter referred to as "Chengdu Expressway Chongqing Section") belongs to the National Expressway Network G93 Chengdu-Chongqing Area Ring Expressway and G85 Yinkun Expressway, and is the pioneer in the expressway network planning of Chongqing's "Three Rings, Eighteen Radius and Multiple Lines." The Chengdu-Chongqing Expressway is the main channel connecting the main city of Chongqing, Yongchuan, Rongchang, Neijiang, Ziyang, Chengdu, and other major economic nodes between Chengdu and Chongqing. Since its completion and opening to traffic, the Chongqing section of the Chengdu-Chongqing Expressway has undertaken a large amount of long-distance transit traffic, providing strong support for the country's economic and social development, and driving the comprehensive development of the socioeconomy of the multi-node cities along the line.

The Chengdu-Chongqing Expressway from Hangu to Sangjiapo is 100.9 km long, with a design speed of 60-80 km/h, 2-way 4-lane, and the width of the roadbed is 24.12 m. According to traffic volume statistics over the years, in 2019, the traffic volume of the Chengdu-Chongqing Expressway from Hangu to Ring Expressway was 68,145 pcu/d, which was at the sixth-level service level, showing a normal congestion state; the traffic volume of the Jinyunshan tunnel section was 42,663 pcu/d, which was at the fourth-level service level; the traffic volume of the section from Bishan South to Yongchuan was about 32,034-38,040 pcu/d, which was at the third-level service level. According to the "Design Rules for Expressway Reconstruction and Expansion," expressway reconstruction and expansion should be implemented before the service level drops to the below third-level service level, so it is the right time to execute this project[1-4].

The reconstruction plan sets up a total of 16 interchanges along the entire line, including 6 hub interchanges and 10 general interchanges.

Among them, the Zouma Interchange serves as a comprehensive junction situated within Zouma Town. It connects Chongqing's High-Tech Zone with the main urban artery, Jinma Road, extending all the way to a secondary garbage transfer station. Its primary objective is to facilitate the traffic transition between Zouma Town and the interchange (Figure 1).

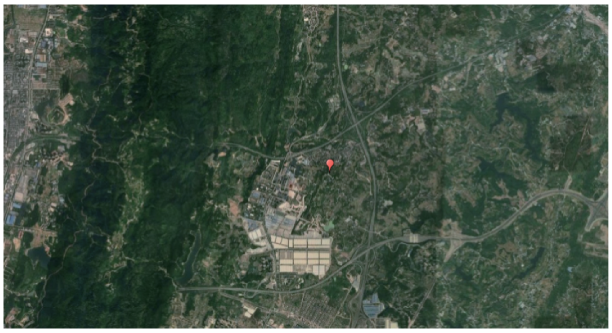

Figure 1 Geographical location map of Zouma Town

2. Current situation and intechange analysis

There are 14 interchanges (excluding the Hangu interchange) in the Hangu-Yongchuan Xiaokan section of the Chengdu-Chongqing Expressway, including 4 hub interchanges and 10 general interchanges (Table 1).

2.1. The status quo of Zouma interchange

The existing Zouma Interchange features an A-type single-trumpet interchange along with two ramps of the secondary garbage transfer station. The ramps span over the Chengdu-Chongqing Expressway, and the upper-span bridge does not allow for an 8-lane widening. The minimum radius of the main line within the interchange range is 600 m, and the maximum longitudinal slope is 3.8%. The radius of the ramp is relatively small, with a minimum radius is 30 m, design speed of 30 km/h, and a ramp width of 9 m–11.5 m. This interchange is a one-lane entrance and exit. There is an auxiliary lane between the interchange with the city ring, which is about 800 m long. However, this lane falls short of the required minimum length for an auxiliary lane at the junction of the 8-lane expressway's mainline side, and it does not meet the criteria for in-situ reconstruction[3]; the net distance from the Jinyunshan Tunnel is about 1 187 m. On the south side of the interchange is Zouma Town, where there are factories and residential buildings, and it is relatively close to the expressway (Figure 2).

2.2. Traffic volume analysis of Zouma Interchange

The interchange is designed based on its service function, taking traffic flow into account and considering the terrain and road network layout for selecting its location. The traffic volume analysis for Zouma Interchange: is described below.

The main traffic flow of this interchange is in the direction of Chongqing ⟷ Zouma, the long-term traffic volume (year 2044) will be 682 pcu/h. As for the Chengdu ⟷ Zouma direction, the long-term traffic volume (year 2044) will be 658 pcu/h. The traffic volume of the primary and secondary flows is not much different (Figure 3).

Table 1 List of current Chengdu-Chongqing expressway interchanges

No.	Name	Distance (km)	Shape of interchange	Type of interchange	Road grade	Current situation evaluation
1	Golden Horse Interchange	/	Semi-directional	General interchange	Third class road	The main line overpasses and the indicators of the interchange main line and ramp are good.
2	Raocheng Interchange	24	Diagonal-quadrant double-loop	Hub interchange	Beltway	The main line overpasses, the maximum longitudinal slope of the main line is 4.3%, and the index exceeds the limit. The ramp indicators are better.
3	Zouma Interchange	19	A-type single trumpet	General interchange	Secondary road	The main line passes downwards without widening. The ramp index is too low, the minimum radius is 22.5 m. The minimum distance from the bypass auxiliary lane is 810 m.
4	Bishannan Interchange	71	Diamond	General interchange	Urban secondary road	The main line overpasses, the ramp index is low, and the service capacity is poor. The minimum net distance from the Qinggang service area is 202 m, which is not up to standards.
5	Dingjia Interchange	7.8	B-type single trumpet	General interchange	City main road	The main line passes under, the radius of the circular ramp is only 35m, and the factory buildings are distributed in the southeast direction, so the land use is limited.
6	Xiaokan Hub Interchange	12.6	T-shaped	Hub interchange	Highway	The span of the bridge over the main line is small, limiting widening and reconstruction opportunities.
7	Daan Interchange	2.9	Diamond	General interchange	Municipal roads	The span of the bridge over the main line is small, making expansion and reconstruction limited.
8	Yongchuan Interchange	7.3	B-type single trumpet	General interchange	City main road	The main highway passes underneath, resulting in a suboptimal service level for the interchange. Moreover, the interchange is situated relatively close to the toll station, which hampers expansion and reconstruction possibilities.
9	Shuangshi Interchange	8.5	Single-ring deformed clover leaf	Hub interchange	Third Ring Expressway	The main highway is intersected from below, and the current Chengdu-Chongqing Expressway has a low linear index, which restricts its expansion and reconstruction potential. Additionally, the project is of significant national scale.
10	Youting Interchange	13.5	A-type single trumpet	General interchange	Municipal roads	The main line passes underneath, and the interchange and merging points are in close proximity to the toll station, with numerous nearby buildings, leading to limitations on expansion and reconstruction possibilities.
11	Rongchang East Interchange	11.1	AB clover leaf	General interchange	City main road	The main line passes underneath, the index of the existing interchange ramp is relatively low, and the distance to the existing Rongchang service area is relatively short.
12	Rongchang Interchange	3.1	AB clover leaf	General interchange	City main road	The main line overpasses. The existing interchange is close to Yudai Road. The function of this interchange is limited, so it needs to be rebuilt.
13	Kaiyuan Hub	11.7	Diagonal-quadrant double-ring half cloverleaf	Hub interchange	Tongrong Expressway	The main line overpasses. Upon completion of the mainline expansion in this project, adjustments will be necessary for specific ramps.
14	Ronglong Interchange	1.7	AB clover leaf	General interchange	City main road	The main line overpasses. After the reconstruction and expansion of this project, it is relatively close to the Kaiyuan hub, and the location of the interchange needs to be adjusted to be co-located with the parking area.

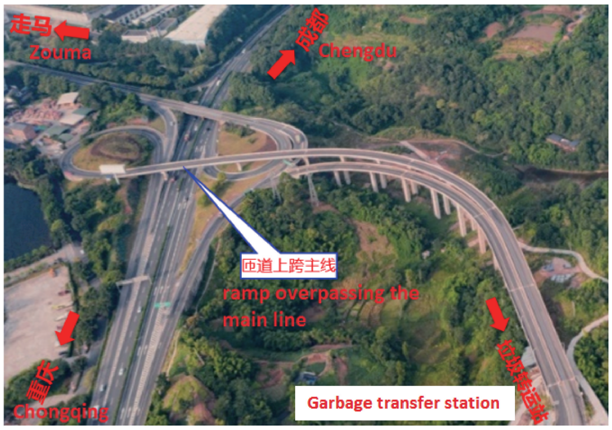

Figure 2　Status quo of the Zouma Interchange

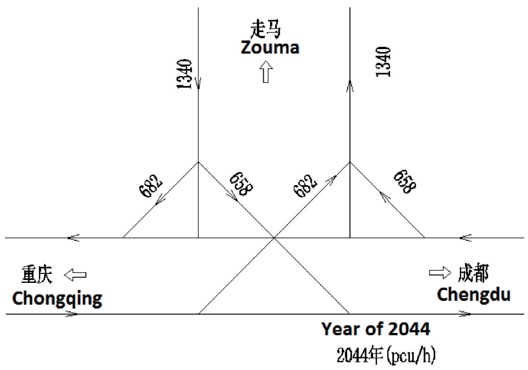

Figure 3　Traffic volume distribution map of Zouma Interchange

According to the traffic volume forecast, the mainstream traffic direction is Chongqing ⟷ Zouma direction, and the traffic volume is predicted to be 682puc/h at the end of the year, and the secondary traffic direction is Yongchuan ⟷ Zouma direction. On the west side, a new building with better indicators will be built for underground communication .

2.3. Analysis of the construction conditions of Zouma Interchange

(1) Connecting roads

In the short term, this interchange will connect to Jinma Road (Shizheng Road), which is a two-way 5-lane road; in the long-term, it will be connected to seven vertical lines, which will be a 2-way 6-lane road and a 2-way 4-lane auxiliary road.

(2) Terrain and geological conditions

The terrain of the interchange area is structurally denuded and hilly. The overall terrain of the site is high in the middle and low in the east and west. The inclination of the slope is 25–35°, with a maximum of 45–50°. The surface of the slope is mostly covered by quaternary residual slope deposit silty clay, with a thickness of 1–3 m, and the rock-soil interface fluctuates with the terrain. The quaternary residual slope deposit silty clay layer on the surface of the valley at the slope foot is relatively thick, usually 6–10 m. Some areas have been artificially filled, including the former spoil area of the Yin-Kun Expressway and the landfills for construction waste from the Yuxi Water Distribution Project. The interchange area is located on the west wing of the Beibei syncline, and the rock formations are monoclinic, with an occurrence of 100–119°∠34–49°. The developed strata are from the middle Jurassic Shaximiao Formation (J2s) to the lower system Ziliujing Formation (J1zl), and the bedrock lithology includes mudstone, sandstone, shale, limestone, etc. No landslides, collapses, or debris flows have occurred in this area. The filling area is generally stable, and only some parts have collapsed due to rain erosion.

2.4. Comparative analysis of Zouma Interchange transformation options

Considering the traffic volume, terrain and surrounding constraints, Zouma Interchange is not suitable for *in-situ* reconstruction. The initial design adopts a T-shaped interchange, and the engineering option has been adjusted. The interchange design comprehensively considers the reservation of the seven vertical lines, and forms a T + single trumpet shape with the seven vertical lines in the long run.

The main control elements of the interchange area are as follows: (1) The hub around the city, (2) The existing interchange, (3) Jinyunshan Tunnel, (4) Seven vertical lines (forward); 5. Water pipelines. A total of six options were drawn for comparative analysis.

2.4.1. Option 1

Option 1 adopts B-type single trumpet , and the main line is crossed on the ramp. The range of the main line of the interchange is K11+540−K12+780. The main line of the interchange spans 1 160 m, with a minimum radius of 1 250 m for the main line within the interchange range. The maximum longitudinal slope of the interchange area is 3.95%, and both the horizontal and vertical parameters of the main line meet the requirements for interchange configuration. The design speed of the ramp is 40 km/h, the minimum flat curve radius is 60 m, the maximum longitudinal slope is 4.0 %, and the total length of the ramp is 2 047.4 m. It connects to the auxiliary lane between the Chengdu-Chongqing hub expressway around the city. The length of the auxiliary lane towards Chengdu is 1 067.31 m, and the length of the auxiliary lane towards Chongqing is 1 020.455 m.

The toll station has 5 entries and 5 exits, and the management room covers an area of 6 000 km^2. The connection line adopts the third-class highway standard, with a design speed of 40 km/h. The road width is 8.5 m, the minimum flat curve radius is 60 m, and the maximum longitudinal slope is 6.27%[5−9] (Figure 4).

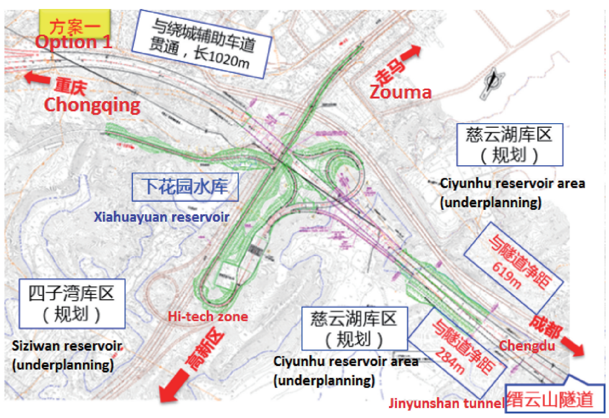

Figure 4 Layout plan of K-line Zouma Interchange (Option 1)

Translation (from top to bottom, left to right): Connected to the auxiliary road of ring expressway, 1020 m long; Clear distance from the tunnel, 619 m; Clear distance from the tunnel, 284 m.

2.4.2. Option 2

T-shape is adopted for Option 2, and the ramp crosses the main line at the top and bottom. The range of the main line of the interchange is K11+540−K12+780. The main line of the interchange range is 1 160 m. The minimum radius of the main line within the interchange range is 1 250 m. The maximum longitudinal slope of the interchange area is 3.95%. The horizontal and vertical indicators of the main line all meet the interchange setting requirements. The ramp has a design speed of 40 km/h, a minimum flat curve radius of 80 m, a maximum longitudinal slope of 4.6%, and a total length of 2 149.3 m. It connects with the auxiliary lane between the Chengdu-Chongqing hub expressway around the city. The length of the auxiliary lane towards Chengdu is 1 067.507 m, and the length of the auxiliary lane towards Chongqing is 1 021.495 m; the net distance from the Jinyunshan Tunnel towards Chengdu is 517.424 m, and the net distance towards Chongqing is 609.427 m.

The toll station has 5 entries and 5 exits, and the management room covers an area of 9 mu. The connection line adopts the third-class highway standard, with a design speed is 40 km/h, a road width of 8.5 m, a minimum flat curve radius of 60 m, and a maximum longitudinal slope of 6.27% (Figure 5).

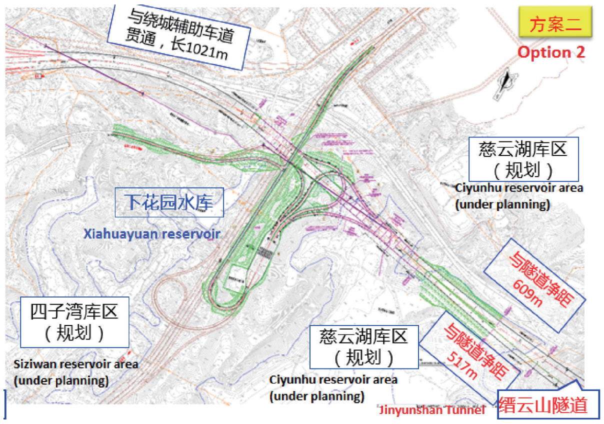

Figure 5 The floor plan of the K-line Zouma Interchange (Option 2)

Translation (from top to bottom, left to right): Connected to the auxiliary road of ring expressway, 1021 m long; Clear distance from the tunnel, 609 m; Clear distance from the tunnel, 517 m.

2.4.3. Option 3 and Option 4

Option 3: A B-type single trumpet is adopted, with the main line crossing the ramp. The short-term and long-term connection with Zouma Town, garbage transfer station, and seven vertical lines is the same as Plan 1. The main difference from Option 1 is that the positions of toll stations and connecting lines have been adjusted (Figure 6).

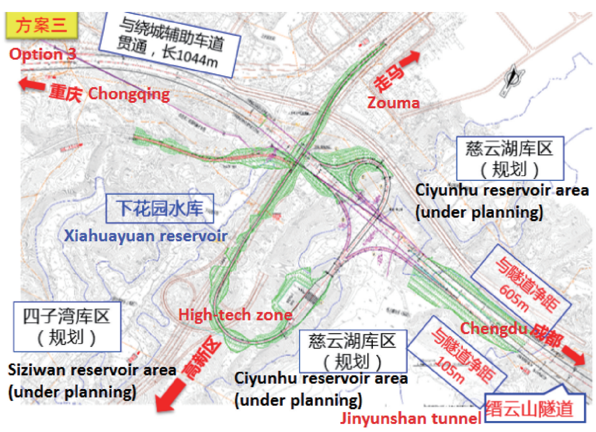

Figure 6 The floor plan of the K-line Zouma Interchange (Option 3)

Translation (from right to left, from top to bottom): Connected to the auxiliary road of ring expressway, 1044 m long; Clear distance from the tunnel, 605 m; Clear distance from the tunnel, 105 m.

Option 4: An A-type single trumpet is adopted, with the main line crossing the ramp. The short-term and long-term plan of Zouma Town, garbage transfer station, and seven vertical lines are the same as Option 1 (Figure 7).

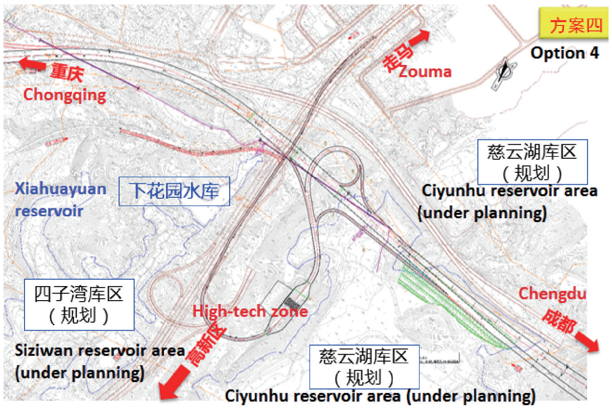

Figure 7 Layout plan of K-line Zouma Interchange (Option 4)

2.4.4. Option 5 and Option 6

Given the inconvenience caused by the cancellation of the Qinggang Interchange and the uncertainty surrounding the transfer of the original Chengdu-Chongqing Expressway to local reception, there is a need for further research on an interchange plan that directly connects the original Chengdu-Chongqing Expressway. This will enhance travel convenience for the southern part of Bishan District and the Qinggang area while ensuring effective connection with the seven vertical lines. Additional options to be considered are option five and option six.

Option 5: Double Ts are used to connect the new Chengdu-Chongqing with the old Chengdu-Chongqing. The old Chengdu-Chongqing connects to the municipal road network by crossing the seven vertical lines (Figure 8).

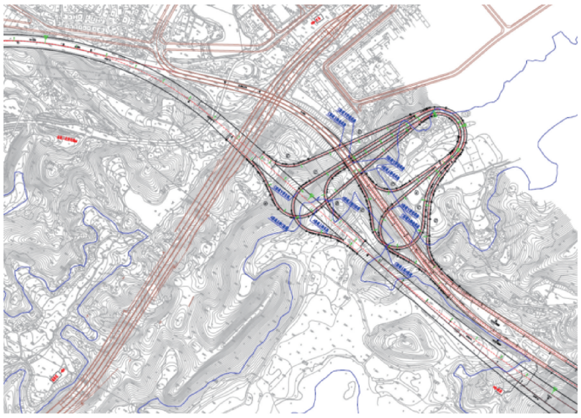

Figure 8 Layout plan of K-line Zouma Interchange (Option 5)

Option 6: The old Chengdu-Chongqing Expressways is connected through a T+A single trumpet interchange. The longitudinal section of the old Chengdu-Chongqing main line is modified to establish a link with the seven vertical lines via a level crossing in the Zouma direction. Additionally, a connection is established to the A-shaped ramp in the direction of Zouma to Chongqing by crossing the seven vertical lines on the ramp (Figure 9).

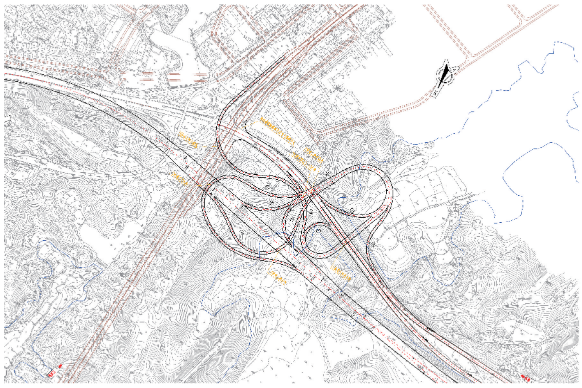

Figure 9　Layout plan of K-line Zouma Interchange (Option 6)

2.4.5. Option comparison and selection

(1) Option 1: B-type single trumpet

Advantages: The scale of the bridge is small, and the impact on the Ciyun Lake Reservoir is small.

Disadvantages: The shape of the interchange is irregular, the index of the connecting line in the direction of Zouma is low, and B-type trumpet shape is generally less safe.

(2) Option 2: T-shape

Advantages: Regular-shaped, better driving safety, less impact on Ciyun Lake Reservoir, smaller bridge scale, smaller land occupation.

Disadvantages: The index of the connecting line in the direction of walking is low.

(3) Option 3: Use B-type single trumpet.

Advantages: Relatively regular-shaped, and the index of the connecting line in the direction of Zouma is relatively high.

Disadvantages: The scale of the bridge is larger than that of Options 1 and 2, which will have a greater impact on Ciyun Lake Reservoir.

(4) Option 4: A-type single trumpet

Advantages: The scale of the bridge is smaller than that of Option 3, and A-type trumpet is generally safer. The indicator of the connecting line in the direction of Zouma is higher.

Disadvantages: The shape of the interchange is irregular, the longitudinal slope of the ramp is relatively large, and the longitudinal slope of the ramp bridge from Chengdu to Zouma is too large, about 5.5%, which has a great impact on Ciyun Lake Reservoir.

After a comprehensive comparison of the four options, it was found that Option 3 has a relatively large bridge scale, while Option 4 has a relatively low ramp index, particularly affecting the drinking water source of Ciyun Lake. Consequently, Options 1 and 2 are chosen for a comparative analysis with equal accuracy for this design.

Comparison between Options 1 and 2 and Options 5 and 6: Option 5 and Option 6 can better solve the inconvenience of traveling from Bishan south to Chongqing and the utilization of the original Chengdu-Chongqing Expressway after the cancellation of Qinggang Interchange. However, Options 5 and 6 involve larger project scales; their connection with the seven vertical lines is weaker. They require converting through local roads to reach the High-Tech Zone, making toll station setup challenging. Currently, the local government has favored using local roads and seems inclined towards Option 1, maintaining a comparison of equal accuracy between Option 1 and Option 2[10].

The comparison between main economic and technical indicators of Options 5 and 6 are listed in

Table 2.

Table 2 Comparison of main economic and technical indicators between Option 5 and Option 6

Project	Work plan	Preliminary plan 1 (single trumpet)	Preliminary plan 2 (T-type)	Preliminary plan 2: work reduction plan
Range of the main line	K11+500-K12+860	K11+5400-K12+800	K11+5400-K12+800	
Length of the main line (m)	1360	1260	1260	-100
Length of the ramp (m)	2807	2047.4	2149.3	-657.7
Connecting line/overpass length (m)	1294	1888.04	1888.04	594.04
Subgrade earthwork/excavation (m^3)	684424	1421418	1324757	640333
Subgrade earthwork/filling (m^3)	412619	865148	829809	417190
Bridge construction (m/seat)	Main line, 1112/2 Blocks; ramp, 1494/5 blocks; connecting line 661/1 blocks	Main line: 611/2 blocks; ramp: 699.5/3 blocks; connecting line no	Main Line: 633.5/3 Blocks; Ramp: 465/3 Blocks; Connecting Line No	Main line: -478.7/1 block; ramp: -10295/-2 blocks; connecting line -661
Occupied land (mu)	350.89	389.9 (Added 357.07)	350.14 (325.08 added)	-0.75
Construction fee (RMB)	42457.29	35631.28	33791.70	-8665.59

2.5. Analysis of Zouma traffic management

(1) Step one

(i) The construction of the interchange will not affect the current main line and ramp passage

(ii) Traffic organization will start one year before the completion of the interchange at Jinyun Mountain, and the remaining part should be constructed subsequently.

(iii) The widening segment will be constructed on both the left and right sides between the Ring Interchange and the Zouma Interchange. Simultaneously, the existing portion will be repaired. This involves connecting the newly constructed right mainline to the existing right mainline (Figure 10)[10].

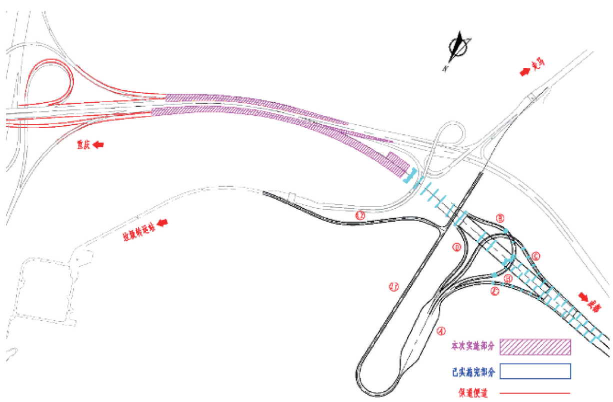

Figure 10 Schematic diagram of the transportation organization of Zouma Interchange

Translation (from right to left, from top to bottom): Zouma, Chongqing, garbage transfer station, Chengdu, in progress, completed part, access road.

(2) Step two

(i) The through traffic will be transitioned to the widened sections on both sides.

(ii) The internal area of the widened sections will be developed and linked with the existing roadway segment.

(3) Step three

(i) The traffic between Chongqing-Zouma and Chengdu-Zouma will be closed, and the traffic in and out of Zouma Town will be transferred to the Three Ring Interchange of Jiuyong Expressway and the Shuangfu North Interchange of Ring Expressway;

(ii) Access Road 1–4 will be constructed

(iii) The traffic from the garbage transfer station will be transferred to Access Road 1–4.

(4) Step four

(i) Bridge Number 1 of the main line of Zouma Interchange will be constructed

(ii) The remaining part of the connecting line to the garbage transfer station will be constructed.

(5) Step five

(i) After the Jinyunshan Tunnel is completed and the main line is opened, a one-way and two-way connection will be created between the hub around the city and the Zouma Interchange;

(ii) Then, the remaining part of the main line will be constructed.

(iii) The existing Chengdu-Chongqing Expressway will be excavated, and the connecting path of the L1 line will be established.

(iv) After the completion of all restoration work, the direct route will be accessible for traffic to Zouma Town, followed by site cleanup.

3. Conclusion

Taking the Chengdu-Chongqing Expressway as an example, this paper introduces the idea of reconstruction and expansion of the interchange, plan research and comparison, and status quo investigation, etc., to provide reference for this type of interchange reconstruction. The main conclusions obtained are summarized below.

(1) The process of interchange reconstruction necessitates a comprehensive assessment of the prevailing factors influencing interchange functionality. A meticulous analysis of the existing interchange's deficiencies, its compatibility with traffic flow, and its operational safety is crucial.

(2) The renovation of an existing interchange is inherently more intricate than constructing a new one, requiring a comparative evaluation of multiple alternatives while accommodating the various stakeholder requirements.

(3) During the formulation of the renovation plan, a holistic approach encompassing traffic management considerations is imperative. This approach ensures that the ongoing highway operations remain undisturbed and that construction activities are conducted in a manner that prioritizes safety and continuity.

Disclosure statement

The author declares no conflict of interest.

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Settlement Control Technology of High Filled Soil-Rock Embankment in Alpine and High-Altitude Areas

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Abstract: China's infrastructure has gradually achieved large-scale development, and transportation construction has also shifted from east to west, transitioning from plains to mountainous areas. High-fill embankments of different sizes in mountainous areas are unavoidable, and the settlement of high-fill embankments is usually the most concerned issue in high-fill projects. According to the current research of highway projects, most of the high embankments in mountainous areas are soil-rock mixed embankments or rock-filled embankments, and their post-construction settlements are directly related to construction technology and the type of filler used. In this paper, the problems in the settlement control of earth-filled embankment and related factors are analyzed in detail. The settlement control technology of high-fill embankment in high-cold and high-altitude areas is also discussed, so as to ensure the overall quality of high-fill embankment.

Keywords: High-altitude and cold areas; High soil-rock embankment; Settlement control technology

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1. Introduction

The scale of highway network in China has been increasing, and road traffic has gradually shifted from rolling terrain to hilly terrain. Especially after the development of western China was initiated, the development of road traffic has been heading towards the western mountains. Western China is dominated by hilly terrain. Compared with plain areas, the geological conditions are more complex, with harsh working environments, making road construction difficult. Therefore, due to limited resources, it is inevitable to use soil-rock mixture to fill the embankment. The soil-rock filling material is made of a mixture of soil and rock. The particle diameter is larger than that of the soil filler with less cohesion. It is quite different from the soil filler in terms of mechanical properties and structure.

2. Problems in settlement control of high-fill soil-rock embankment in cold and high-altitude areas

2.1. Permafrost

Frozen soil refers to all kinds of ice-containing soil and rocks, which can usually be divided into permafrost, seasonal frozen soil and short-term frozen soil. Permafrost has certain rheological properties and is more sensitive to temperature. Alpine and high-altitude areas, often situated in permafrost regions, typically fall within the inland alpine climate zone. These areas are characterized by an extended freezing period, abundant sunshine, and significant temperature fluctuations between day and night. The roads in the study area generally have seasonal frozen soil, which gradually starts to freeze from October and melts gradually from April of the following year, with the maximum thickness of the frozen layer being 0.9–1.5 m.

Seasonally frozen soil is when the soil is frozen in winter and thaws in spring. Weak frost heave, no frost heave, frost heave, and strong frost heave are the main types of seasonal frozen soil, and thaw collapse, strong thaw settlement, thaw settlement, weak thaw settlement, and no thaw settlement are the five types of settlement of seasonal frozen soil. During the freezing process, the mechanical properties of the frozen soil will change sharply with the decrease of temperature, and the strength of the soil layer will decrease significantly after the frozen soil thaws. Frost heave and thaw settlement are important causes of common faults in subgrades containing frozen soil. According to existing data, frost heave and thawing account for 15% and thaw settlement account for 85%. Frost heave is mainly caused by raised cracks on the subgrade, frost heave mounds and ice cones, etc. Thaw settlement is mainly composed of longitudinal and transverse cracks, slope deformation, pavement damage, etc. [1]. Therefore, in the construction and management of seasonal frozen soil regions, the adverse effects of thawing and frost heaving on road structures and subgrades should be studied.

2.2. Geological disasters

2.2.1. Debris flow

The landforms in the alpine and high-altitude areas are more complex, with large differences in height. Most of the slopes exceed 30°, with higher peaks and lower canyons, and most of the canyons are surrounded by mountains. It is conducive to the convergence of rivers. The middle reaches of the river are relatively narrow and steep, while the lower reaches of the river are dominated by open canyon terraces, which are conducive to the accumulation of clastic materials. This area is mainly composed of schist and thin crystals, where soft and hard joints and beddings are developed. Due to the geological changes and weathering in the geological history period, the rocks are generally in a broken state, which is the main reason for the debris flow in this area.

2.2.2. Slope body

Slopes in cold and high-altitude areas are more prone to disasters, which can be divided into two types: rocky unstable slopes and soil unstable slopes. The foot of slopes that are close to the river bank are usually unstable, and its bottom is easily damaged and deformed by the erosion of the river. Most of the rocks are quaternary gravel soil and loose slope silt, which can easily lead to deformation and instability of the slope during excavation. Unstable rocky slopes are mainly concentrated on both sides of the valley and the steep slope area of the mountain. The original slope height is about 20–50 m, and the slope is about 50°–60°. There are mainly strongly weathered rocks here, and there are one or two sets of tension cracks of varying lengths with low current stability. Landslides are prone to occur, and the slope may become unstable due to heavy rain, which may lead to disasters such as landslides and collapses. Most of the unstable slopes are far away from the road, so the road is less impacted.

3. Factors affecting the settlement control of high-fill soil-rock embankments in high-cold and high-altitude areas

3.1. Construction quality

3.1.1. Porosity

Studies showed that the porosity inside the foundation will change with time due to rainfall, which is related to the erosion of a small amount of fine aggregate layer inside the foundation. The investigation of a certain kind of embankment foundation filled with soil and stone shows that there are many fine-grained substances in the interlayer of piled slope rock mass[2]. Although the soil-rock mixed road has high strength, the particles in the roadbed will be rearranged under the vibration of the vehicle load, and the fine-grained substances in the roadbed will settle. As a result, the void ratio of the roadbed gravel filling increases and the subgrade becomes less stable. In order to eliminate the change of void ratio caused by the migration of particulate matter in the soil-rock mixed fill embankment, the root problem must be solved. When permafrost thaws, the change of pores is also an important factor for soil fusion. Generally, the porosity that subsides due to uneven melting is called the optimal void ratio, and the optimal void ratios of some frozen soils are shown in Table 1.

Table 1 The measured optimal void ratio of representative frozen soils

Filler	Optimal void ratio e_{md}
Sandy soil	0.55
Pebble gravel soil with silt and clay content greater than 12%	0.35
Clay and loam	0.65
Pebble gravel soil with silt and clay content less than 12%	0.40
Gravel clayey soil	0.40

3.1.2. Degree of compaction

If the degree of compaction of the subgrade pavement does not meet the design standards, it will be difficult to compact the border areas on both sides of the embankment. In addition, the side slopes on both sides are eroded and infiltrated by rainfall, and partial settlement often occurs here. During the construction process, the height difference between the edge of the subgrade and the middle position increases, and in severe cases, cracks between the subgrade and the edge of the subgrade will occur, and staggered platforms and subsidence will also occur during the construction process. Because there is a gap under the lane, the rainwater can seep from the gap to the base layer. During heavy traffic, the lane would be affected and the road surface will be damaged[3].

3.2. Filler

3.2.1. Soil quality

In various types of embankments, as long as they have a certain strength and can form a stable filling by tamping, they can be used as embankment materials. Different soil-rock mixture will have different effects on embankment settlement. For example, roadbed mixed with rock materials has better drainage and permeability due to its high density and strength. Therefore, its post-construction settlement is much smaller than that of stone packing, which has lower water permeability.

Soils with different properties have different thaw-sedimentation coefficients. It has been found through several experiments that the relationship between the thawing characteristics of various soils is as follows: sandy gravel soil < heavy clay < silty clay; under the condition of water saturation, the thawing coefficient of the coarse-grained frozen soil increases with the increase of silt viscosity, and when its composition exceeds 12%, the thawing coefficient will increase rapidly. Therefore, 12% is an important value of the viscous component of the powder[4].

3.2.2. Soil-rock ratio

The rock content in the filler is the soil-rock ratio of the filler. The soil-rock ratio is directly related to the compaction of each layer of the embankment, and then directly related to the settlement of the entire embankment slope. The results show that the maximum dry density of soil-rock mixture changes with the stone content, and this maximum value can be divided into three periods, namely, the slow growth stage, the rapid growth stage, and the gradual decrease stage. The stone content of each stage must be determined through relevant analysis. In addition, under the same stone content, the particle size of the coarse aggregate directly affects the maximum dry density of the soil and stone mixture.

3. 2. 3. Foundation

There are mainly two types of foundations, artificial foundations and natural foundations. Among them, natural foundations are limited by conditions such as soil stress and groundwater level, while the artificial foundations are affected by the treatment method and the soil used. Although the weight of the natural ground itself has basically consolidated the subgrade, but as the construction progresses and the number of applied layers increases, the natural foundation will also settle, and the size of the settlement is directly related to the embankment filling and filling height. In addition, the shape of the foundation will also have a certain impact on the settlement of the subgrade. The settlement of a flat embankment is mainly concentrated in the middle of the roadbed, which is also where the maximum settlement occurs. The momentary subsidence in the middle of the embankment increases with each upward loading, and decreases again in the intermittent stage. However, maximum settlement does not occur at the top of the embankment but close to the slope. The settlement should gradually increase from the inner side of the side slope adjacent to the embankment to the outer side of another free surface[5].

4. Settlement control technology of high-fill soil-rock embankment in cold and high-altitude areas

4. 1. Shallow soft soil construction technology

4. 1. 1. Dredging

To control the sediment of high-fill soil-rock embankment in cold and high-altitude areas, the soft clay in this area was penetrated by using a lightweight dynamic penetrometer, so as to clarify the scope of dredging in this area. When the filling depth of the high-fill embankment exceeds 20 meters, the allowable load should exceed 320 kPa. Since the lightweight dynamic penetrometer does not measure the depth accurately, , if there is still soft soil observed with the naked eye even after penetrating to the supposed soft soil depth, further penetrating experiments should be carried out to determine the depth for soft soil removal. The key is to remove all soft soils. The next step of construction can only be carried out after being checked and accepted by relevant supervisory and management personnel.

4. 1. 2. Temporary drainage

Drainage is a key step in roadbed construction. Water can cause great damage to the roadbed and road surface, and poor drainage will increase the moisture content in the filler, resulting in soft soil. This reduces its strength and stability, causing subsidence or plastic deformation. It is important to keep the moisture content of the foundation at a certain level. Intercepting ditch, diversion ditch, and temporary drainage ditch should be excavated according to the subgrade boundary and land boundary to create an unimpeded drainage system. Temporary drainage pipes must be equipped with permanent drainage pipes, and the water flow cannot be directly discharged to the field to avoid affecting surrounding environment, or else can it cause sediment and erosion. Therefore, the water should be discharged as far away possible.

4.1.3. Paving and leveling

The most important step in embankment construction is the paving of soil-rock filler. The selection of this process can be related to the overall quality of soil-rock filler embankment, and the quality of each layer is related to the settlement of the whole embankment after construction. When lithological materials are used in the fillings, the paving of the subgrade will directly determine the structural form of the subgrade compaction layer, thus having a direct impact on the compaction of the subgrade. It is necessary to select a suitable paving method so that the filler can be evenly distributed among the layers, and the segregation of the filler can be prevented. In this process, strict requirements are put forward for the thickness of the loose layer, the maximum particle size of the filler, and the gradation of the asphalt mixture[6].

In the current subgrade construction, there are mainly three common paving methods:

(1) Progressive paving method

In the progressive paving method, the unloading vehicle unloads the material sequentially on the filling surface from the beginning to the end, and a bulldozer is used to complete the paving and leveling[7].

(2) Backward paving method

In backward paving method, the unloading truck unloads the material on the surface of the rolled layer from the end to the front in a backward manner, thereby forming many compact packing piles; and then paving and leveling is carried out. In general, this method is suitable for fillers with finer particles.

(3) Mixed paving method

In the mixed paving method, the backward paving method is used to unload the material when laying a new layer, thus forming a certain filling pile, and then a bulldozer is used to pave it a certain thickness is achieved. Next, the progressive paving method is used to discharge the material onto paved layer. This method is suitable for applying thicker fillers[8].

Three different paving methods on the same thickness of filling were compared in terms of soil-rock high-fill road, surface smoothness, and compaction. The flatness of the surface was observed with the naked eye, and in the compaction process, the same machinery and compaction method were used, and the degree of compaction and porosity after compaction were tested and compared.

Table 2 shows the comparison of rolling effects between the backward paving method and the progressive paving method under the same compaction method, with a paving thickness of about 70 cm.

Table 2 Comparison of rolling effect between retreat paving method and progressive paving method

Paving method	Compactness (%)	Sedimentation rate (%)	Porosity (%)
Progressive paving method	92.6	9.32	22.7
Back paving method	94.8	9.74	20.1

(3) Key quality control

(1) Cross-section measurement and construction stakeout should be carried out. The stakeout accuracy of high-fill embankments is the primary link and key content of high-fill embankment construction quality monitoring. (2) The original roadbed should be treated and consolidated according to relevant specifications provisions. (3) Strengthen the management of loose laying thickness and cross slope of each layer[9]. (4) Materials that meet the design requirements should be selected, and the maximum dry density and optimal moisture content of the filler should be measured accurately. (5) The high-fill embankment should be started early, but not too early, so that the high-fill embankment has more settlement time[10]. (6) When treating the original surface of the high-fill embankment, the embankment

can be widened correspondingly or built with back pressure slope protection.

5. Conclusion

There are many deficiencies in the construction and management process of high-fill soil-rock embankments in high-altitude and cold areas in China, resulting in self-produced tunnel spoils piling up and the insufficiency of filling materials. Therefore, this paper analyzes the permafrost and geological hazards in the settlement control of high-fill embankments in high-cold and high-altitude areas. Besides, factors that affect the settlement of high-fill embankments, such as construction quality, fillers, and foundations are also explained. The technical requirements for filling layers of high-fill earth-rock embankments are also clarified, so as to provide support for the research and development of high-fill earth-rock embankment settlement control technology in cold and high-altitude areas.

Disclosure statement

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Exploring the Ideological and Political Education Reformation of Architecture Professional Courses in Higher Education Institutions

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Abstract: "Ideological and political education" is an essential implementation for moral cultivation, which promotes the basic principles of "three comprehensive education". Its teaching effectiveness is related to the overall improvement of the quality of talent cultivation; hence it widely attracts the attention of the academic community. In order to combine professional architectural courses with ideological and political education, and at the same time to realize the innovative teaching concept of collaborative education, teachers in higher education institutions continue to explore and practice their ways, constantly innovate and optimize their knowledge and education systems.

Keywords: Ideological and political education; Three comprehensive education; Reformation research

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1. Introduction

As the General Secretary of China pointed out at the National Conference on Ideological and Political Work in Colleges and Universities: "We must insist on moral cultivation as the central link, and carry out ideological and political education throughout the entire education and teaching process, so as to realize the nurturing of all teaching staff in the whole processes and positions, and strive for a newer and better development of China's higher education"[1]. The Ministry of Education issued the "Guidelines for the Ideological and Political Construction of the Curriculum of Higher Education Institutions", combined with the professional characteristics to promote the ideological and political construction of the curriculum, integrated the ideological and political education into the teaching of professional courses, and achieved the purpose of the ideological and political education by means of subject penetration[2]. In order to change from "ideology and politics courses" to "ideological and political education", professional courses should focus on having professional skills and knowledge as the main carriers, promoting their underlying ideological and political values, integrating ideological and political education into all aspects of curriculum teaching and reformation, and realizing moral cultivation and further improving the values, humanistic quality, and professional ethics of higher vocational students. As higher vocational institutions are the essential place for delivering professional and technical talents to the next generation, they have also changed their role in the field of talent cultivation to a certain extent[3-4]. "Three comprehensive education" is an important concept and development direction in China's higher education at present as it is a requirement for the effective premise of ideological and political education that is put forward by the Central Committee of the Communist Party of China and the State Council in the "Opinions on Strengthening and Improving Ideological and Political Work in Colleges and Universities under the New Situation[5]. Recently, the system of "three comprehensive education" has attracted people's attention in the talent training of higher institutions, with the main issue of how to adapt this system to the current talent training of higher institutions in China and to build a talent training mode with exclusive Chinese characteristics[6-8]. To spice up the elements of ideological and political education in professional courses teaching, educating future generations with both curriculum education and ideological and political education, it is necessary to carry out research on classroom teaching reformation under the guidance of an efficient education model system, implement "ideological and political education" through teaching reformation, and further carry out the fundamental task of moral cultivation[9-10]. However, "ideological and political education" can be relatively difficult to realize in some courses such as architecture, and its implementation effect in architecture is found to be relatively poor. In this regard, this paper will discuss the ideological and political reformation of architectural professional courses in higher education institutions under the model of "three comprehensive education".

2. The teaching optimization strategy of "ideological and political education" in high institutions with the implementation of "three comprehensive education"

"Ideological and political education" is an essential implementation for moral cultivation, which promotes the basic principles of "three comprehensive education". As a teaching reformation, its implementation should be guided by the concept of "all staff, whole-process, and all-round education", focusing on teaching problems, carrying forward teaching experience, and building a systematic teaching strategy.

2.1. The teaching strategy of "ideological and political education" with the implementation of "all-round education"

2.1.1. Reconstruct the teaching objectives of the course and comprehensively shape the ideal value

For professional architectural courses, "ideological and political education" is neither a new course nor a complete negation of the original courses. It is a diagnosis of various courses based on the professional knowledge in the current course teaching, whereby there is a separation of current professional courses education and ideological and political education, hence it requires teaching reformation of various courses to realize the integration and penetration of ideological and political education and professional knowledge education and promote the all-round development of students. For this reason, when higher institutions carry out the teaching of "ideological and political education", it is necessary to reform the original courses and reconstruct the teaching objectives of various courses. On the one hand, it is to make the original teaching objectives "live", as there was no three-dimensional teaching goal in the teaching of various courses as well as teachers often ignore emotion, attitude, and value goals in the teaching process. Teaching should truly implement three-dimensional goals so that the teaching goals of each dimension can be used in teaching activities. On the other hand, to avoid generalizing the goals of moral education, specific courses and teaching content should be combined to express the goals of moral education concretely, so as to better guide teachers' teaching activities. In the teaching process, based on an in-depth analysis of various courses' teaching objectives and ensuring their professional knowledge education quality, the moral education objectives of different courses are condensed.

For the requirement of human all-round development, the value shaping of students must not be based on patriotism as the only content, even the concurrent integration of "ideological and political education" into the professional architectural courses consisted of the issue of "education content is based on the family and the country, hence it is difficult to comprehensively shape the values". Therefore, college teachers must uphold the "student-oriented" teaching concept in the future teaching of "ideological and political education", forge the values, ideals, and beliefs of young students in an all-round way, and not only promote the main ideals of "passion for the political party, patriotism, passion for socialism, passion for the people, and passion for unity" in the teaching process but also cultivate future generations' good qualities such as "dedication, justice, integrity, benevolence, and friendliness". Meanwhile, while stimulating students to establish the great ideal of becoming builders and successors of socialism, it is ideal to combine traditional Chinese culture and regional culture to guide students' ideal values. For example, the teaching of "ideological and political education" in Chongqing higher education institutions must combine their local cultural characteristics to shape the value contents. As a humanistic city, Chongqing has unique traditional, landscape, and Red cultures, thus the teaching of "ideological and political education" should be based on the culture of self-improvement, pioneering culture, tenacity, urgency, hard work, innovation, seeking truth from facts, anti-Japanese patriotism, and Lei Feng spirit of "becoming good", enriched by the rich landscape, excellent traditional, and Red culture resources in Chongqing area, as well as incorporate with the outstanding deeds of people emerging in Chongqing area. The teaching of "ideological and political education" must utilize the all-round development of people as the guiding ideology, take the traditional Chinese and Chongqing characteristic cultures as the content, and cultivate future generations in an all-round way in terms of value shaping.

2. 1. 2. Reform students' academic evaluation and unify explicit and implicit education

Under the background of "three comprehensive education", the teaching of "ideological and political education" in higher education institutions should ensure students with all-around development. From the learning perspective of students' all-around development, students' learning activities are not only about knowledge uptake but also include abilities, moral cultivation, and habits development. It can be seen that the evaluation of students' learning should not only focus on students' knowledge learning but also pay attention to the development of skills, abilities, moral qualities, and habits, thus a single examination and evaluation method cannot be used to measure academic performance, instead students' academic evaluation methods should be comprehensively formulated according to the tendency of learning activities. For teaching activities that focus on students' cognitive learning, methods such as tests, experiments, and evaluations can be used to evaluate students' academic performance. For teaching activities that focus on learning skills, teachers can use observation and work performance methods to evaluate students' academic performance. For teaching activities that focus on students' emotional learning, teachers can use observation methods and questionnaires to evaluate students' academic performance. For comprehensive teaching activities, teachers should comprehensively formulate students' academic evaluation methods in combination with key teaching objectives, students' learning conditions, and realistic conditions. However, regardless of the student academic evaluation methods being used, the teachers of the "ideological and political education" must comprehensively evaluate students and promote students' all-round development as the general purpose of student academic evaluation.

Explicit and implicit educations are not two separate parts, each course contains both explicit and implicit education resources. In order to solve the problem of "teaching activities are mainly explicit, and explicit and implicit education are not unified" that exists in the teaching of "ideological and political education" in higher education institutions under the implementation of "three comprehensive education", teachers should consciously explore the hidden aspects of the curriculum on the basis of grasping and optimizing the explicit education methods in teaching activities, seeking and exploring implicit education teaching methods, and unifying the two in the teaching activities that serve the teaching objectives. For example, immersion teaching is used to promote the integration of explicit and implicit education, while using explicit teaching methods such as lectures and conversations to directly impart specific professional knowledge to students, materials such as audio and video as well as technologies such as virtual reality, artificial intelligence, augmented reality, and human-computer interaction are encouraged to create an educational atmosphere that fits the teaching objectives for students' classroom learning and achieve its educational effect.

2.2. The teaching strategy of "ideological and political education" with the implementation of "whole-process education"

2.2.1. Flexible use of teaching methods, penetrate the whole process of teaching evaluation

To use teaching methods flexibly, we must pay attention to the learning students, meet their needs, and tailor them to their development characteristics. In the age of network information, "ideological and political education" must adhere to "student-oriented" and fully understand the needs of higher education institutions, where acknowledging students having a high demand for the Internet and the modern characteristics of "network natives", changing the use of the Internet from "blocking" to "sparse", carrying out online teaching of "ideological and political education", and simultaneously building a network teaching resource library, enriching the teaching resources of the online "ideological and political education", and expanding the scope of students' choices. With the use of online education platforms, micro-classes, and other methods are adopted to meet students' fragmented learning needs and ensure their acceptance. At the same time, by organizing students to watch live broadcasts in classrooms, dormitories, and activity rooms to participate in learning discussions through computers and mobile phones, the interaction between teachers and students is enhanced. The flexible use of teaching methods must also be combined with the course nature, teaching objectives, and teaching situations of specific courses. Teaching is not a static model, different teaching methods should be used in different teaching stages, for example, lecturing methods and moral education stories can be used in the "understanding" stage, discussion methods can be used in the "joint" and "system" stages, and inquiry methods can be used in the "method" stage so that students can communicate with each other and explore independently in the moral situation constructed by the teacher, which then improve the moral educational effect of the whole teaching process.

In future teaching, in addition to further integrating teaching evaluation into the whole teaching process, the measurement, diagnosis, and evaluation functions of teaching evaluation will be better utilized to grasp the students' learning foundation in advance, timely discover the problems existing in the teaching activities that are being generated, and summarize the completed work. In addition to the teaching experience of teaching activities, it is necessary to reform the teaching evaluation method and evaluate the teaching activities of teachers in a targeted manner. Under the background of "three comprehensive education", the teaching of the higher education institutions' "ideological and political education" should highlight the teacher's investment in education and the effectiveness of education in teaching activities, under the command of "intellectual education", teaching evaluation should be focused more on the achievement of professional education goals and the discipline of students' learning. After the reformation, teachers' teaching evaluation should not only pay attention to the course content management and focus but also plan and incorporate specific moral education columns into the teachers' teaching evaluation, allowing the school authorities and teachers themselves to have a clearer understanding of their evaluation results. In addition, when students evaluate teachers' teaching, teachers tend to understand students' satisfaction with the effectiveness of professional courses teaching and incorporate the evaluation results into the teacher's teaching evaluation moral education column.

2.3. The teaching strategy of "ideological and political education" with the implementation of "all staff education"

2.3.1. Encourage teachers to extend their education time and improve teachers professionalism

The focus and difficulty of "ideological and political education" teaching lies in the teachers. Encouraging higher education institutions teachers to concentrate their energy on curriculum education and extending teachers' education time is related to the teaching effectiveness of "ideological and political education". To this end, on the one hand, it is necessary to strengthen material incentives, through the issuance of "ideological and political education" teaching subsidies, and the establishment of special teaching bonuses for "ideological and political education" to enhance the sense of teaching acquisition of higher education institutions teachers; on the other hand, it is essential to link the "ideological and political education" to its role evaluation, performance appraisal, and selection and training. Establishing and clarifying the national, local, and school three-level "ideological and political education" excellent teacher incentive standards, and establishing a curriculum education honor system, such as the selection of "ideological and political education" teaching masters, excellent teaching team, are means to enhance the sense of honor of higher institutions teachers participating in the teaching of "ideological and political education". To extend the time for teachers to educate people, it is necessary to fundamentally enhance the education awareness of the majority of teachers, and break the traditional and narrow concept of education, that is, "teaching" and "educating people" are not separated from each other, and they are not the same, thus it is necessary to stick to the educational concept of "teaching and educating people", correct one's consciousness, and continuously improve the ability to educate people. For this reason, in higher education institutions teachers must not only strictly abide by teacher standards and demand themselves the "four necessities" that good teachers should have but also insist on educating people in action, improving the ability to educate people in teaching, and expand educating people beyond the theoretical teaching time and to the whole teaching process, as per the quote "good teachers are not naturally born but develop from teaching experiences".

Teachers are the main force in the teaching of "ideological and political education", and the quality of teachers is directly related to the quality of "ideological and political education" teaching. From the overall perspective, the professional qualities of higher education institutions teachers involve four dimensions: morality, knowledge, ability, and psychological quality. On the one hand, college teachers must establish the concept of lifelong learning, constantly replenishing and improving their knowledge and optimizing their knowledge structure; fresh teachers should take the initiative to seize the valuable opportunities of induction counseling and post-employment training, seek the teaching experience of "ideological and political education" from experienced teachers, actively discover their teaching problems, and improve their ability and quality; higher education institutions should fully protect teachers' right to further training, and strengthen the teaching and training of "ideological and political education" for teachers, and support teachers to improve their knowledge and ability. On the other hand, teachers should take the initiative to relieve psychological pressure, devote themselves to the teaching of "ideological and political education" with an optimistic mental state and emotions, and avoid releasing negative emotions to students; higher education institutions should take the initiative to care for teachers' mental health, provide psychological counseling and psychological guidance for teachers who have difficulties. In addition, teachers must establish lofty professional ethics and achieve "four passions", that is, "patriotism, passion for students, passion for the career, and passion for unity"; higher education institutions must resolutely implement the "one-vote veto system" for teachers' morality and ethics, and strengthen the supervision of teachers' professional ethics, keeping alert to teachers' morality and style.

2.3.2. Integrate the professional education of ideological and political education, and explore the elements of curriculum education

For professional architectural courses, it is very difficult to identify ideological and political elements in course content, as there were few elements found in this type of professional course. However, it does not mean that professional architectural courses cannot realize "ideological and political education". "Ideological and political education" emphasizes the identification of the educational elements contained in various courses and the educational functions carried out by them, and to find out the connection point and matching point between ideological and political education and professional knowledge education in terms of content and form. The issues of how to develop the ideological and political education resources of various courses and how to find the connection point of its integration with ideological and political education arise and require to be solved urgently in higher education institutions. Hence, it is necessary to set up "ideological and political education" design and development groups and centers, give full play to the "business" advantages of different teaching teams, increase the proportion of frontline teachers in the group, encourage frontline teachers to exert their subjective initiative and utilize different media to explore the ideological and political functions of their businesses, so as to find the meeting point between the content of ideological and political education and the professional knowledge of their disciplines. It is worth noting that future higher education institutions' "ideological and political education" teaching reformation should be focused on having frontline teachers in the "ideological and political education" teaching and research center and increase the research on "ideological and political education" to improve the integration between the professional courses and "ideological and political education".

The learning of professional knowledge and the ideological and political content should also be combined in the teaching process of professional architectural courses. Based on the subject nature, course content, and teaching methods of different courses, "ideological and political education" seeks variety rather than uniformity, and in the correct sequences while investigating the function of the underlying ideological and political aspects of the professional courses without affecting its original professional knowledge education function. In addition, it is necessary to formulate and introduce a systematic and comprehensive teaching reform plan for "ideological and political education", plan the entire process of teaching design, implementation, and evaluation for "ideological and political education" in higher education institutions, build the "ideological and political education" teaching resource database, share the excellent teaching design, experience, and case resources of "ideological and political education", and improve the teaching quality of the "ideological and political education".

3. Conclusion

As a strategic measure of the political party and the country, the construction of "ideological and political education" in higher education institutions has a profound impact on major issues such as successor training, national development, and national rejuvenation. Teaching is the leading pathway for the construction of "ideological and political education", and it is also a key link in the construction of the "three comprehensive education" pattern. The importance of improving the teaching quality of "ideological and political education" in higher education institutions is self-evident. It is hoped that the "ideological and political education" will move from teaching theory research to teaching practice research, so as to help higher education institutions effectively improve the teaching quality of the "ideological and political education”.

Disclosure statement

The author declares no conflicts of interest.

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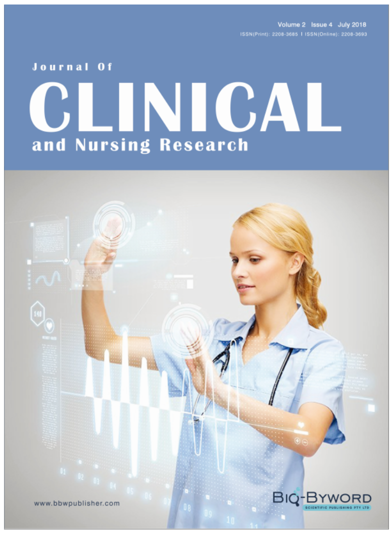

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