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Static Load Test Detection of Continuous Rigid-Frame Railway Bridge

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Abstract: The quality of the continuous rigid-frame railway bridge is related to the safety of train operation, so it is necessary to test its stiffness, strength, and other indicators. Static load test is a common technique for bridge inspection. This article summarizes the purpose of the static load test for a continuous rigid-frame railway bridge, including the required equipment, operation methods, etc., and lists examples to analyze the operation process and precautions of static load test, hoping to provide reference information for relevant personnel.

Keywords: Railway bridge; Rigid-frame; Static load test

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1. Introduction

In recent years, China's railway construction has made great progress, and the number of continuous rigid-frame railway bridges has increased significantly. The bearing capacity, stiffness, and stability of continuous rigid-frame railway bridges can have a great impact on the safe and stable operation of trains. Therefore, it is necessary to adopt effective methods to detect and evaluate its quality, and properly handle quality problems. The main function of the static load test is to determine the bearing capacity of the bridge and evaluate the degradation through the changes in structural strain and deflection. It can determine whether there are quality problems in the continuous steel structure railway bridge, thereby ensuring the safety and stability of train operation.

2. Concept and purpose of static load test for continuous rigid-frame railway bridge

The static load test of the continuous rigid-frame railway bridge mainly refers to applying a static load on the designated position of the bridge according to the predetermined test purpose and test plan, measuring the static strain, static displacement, settlement, cracks, and other indicators of the bridge structure, and determining whether the working performance and bearing capacity of the bridge structure under load are up to standard according to relevant regulations and specification requirements. The author believes that the static load test

of a continuous rigid-frame railway bridge can judge whether the stiffness, strength, bearing capacity, and stability of a continuous rigid-frame railway bridge meet the requirements of relevant standards, and effective construction measures can be taken for railway bridges that do not meet the requirements of relevant standards, thereby ensuring the safe and stable operation of trains [2].

3. Continuous rigid-frame railway bridge static load test instrument and loading method

The devices required for the static load test of the continuous rigid-frame railway bridge are as follows:

(1) Reaction device: To accommodate a design bearing capacity of 200 kPa, a reaction force device with a capacity of 60–80 tons is required. Technicians must prepare by constructing brick walls in advance and placing I-beams above them to serve as a load platform. Soil bags are then piled onto this platform and filled with sand to create the load-bearing surface [3].

(2) Force measuring device: The force measuring device employed is a hydraulic jack with a capacity of 100 tons. It should have a minimum lifting height of 180 mm, and a maximum height not exceeding 335 mm.

(3) Load plate: Load plates such as square steel plates or circular steel plates are utilized as load-bearing elements. To avoid deformation of the load plate, an additional load plate can be placed on top of it if necessary [4].

(4) Deformation measurement device: The deformation measurement device must be capable of providing precise measurements with an accuracy of 0.01 mm.

In terms of the testing procedure, the common loading method for a continuous rigid-frame railway bridge involves a gradual, continuous loading scheme. Technicians add the next level of load only after each preceding load level has reached a stable state. Subsequently, they perform staged unloading once the test piles exhibit signs of damage. Depending on the specific circumstances, technicians can also adapt alternative loading and unloading methods, such as the multi-cycle loading and unloading approach and the rapid maintenance load method. Those variations can be employed in combination with the actual conditions encountered during testing.

4. Static load test method for continuous rigid-frame railway bridge

4.1. Reasonable determination of test pier and control section

In the static load test of a continuous rigid-frame railway bridge, technicians can choose 1–3 representative piers to complete the test. The criteria for selecting piers including the piers are not conducive to the calculation of force, the construction quality is poor, there are many issues, and it is easy to erect scaffolding [5]. Meanwhile, technicians need to select an appropriate control section in combination with specific test items. In the process of selecting the control section, it is necessary to consider the relevant requirements for measuring the bearing capacity of the bridge, analyze and study the most unfavorable stress state of the bridge, and then determine the control section. If the structure of the continuous steel railway bridge is relatively simple, one control section can be selected, otherwise multiple control sections can be selected.

4.2. Setting of test points

Technicians need to set test measuring points on the premise of ensuring accurate test results and controlling the overall number of test measuring points. The same measuring point can be tested using different testing

methods. In the process of setting the main measuring points, technicians need to provide the maximum stress and maximum displacement of the inspected spans and adjacent spans, and each span needs to set 3–5 measuring points. In the process of measuring the stress and strain of the facility structure, it is necessary to ensure that each measuring point can measure the lateral and vertical stress distribution of the internal force control section [6]. In the process of setting the vertical measuring points of the beam section, it is necessary to set more than 5 measuring points along the height of the section and ensure that there are measuring points at the sudden change of the section. For cross-section bridges, it is necessary to set strain measuring points in areas with high stress. The locations of the measuring points are the upper and lower edges of the cross-section, and the number of measurement points should not be less than 3.

4.3. Static load test

During the static load test, technicians must adhere to the following operational plan:

(1) Preload test: Before the static load test of the continuous rigid-frame railway bridge is officially carried out, the technicians need to complete the preloading operation in order to find possible problems in the test and ensure the smooth completion of the static load test. During the preloading test, technicians need to set the load to 30%–50% of the maximum test load. The load of the reinforced concrete structure should be lower than the cracking load, and it needs to be maintained for 10 minutes after completing the first-level record [7].

(2) Static load test: During the actual static load test, technicians must rigorously adhere to operating guidelines, gradually increase the load and internal force of the section, and closely monitor the loading process to control the displacement of the measuring point. If the following situations occur during the loading process, the loading needs to be stopped in time: the displacement of the abutment is greater than the allowable range and cannot maintain stability; the deflection and strain of the measuring point under a certain load force exceed the check calculation control value or the limited range; the strain at the control point increases and becomes unstable; cracks occur during the loading process, and the crack width is greater than the limited range; the bridge structure is damaged during the loading process, affecting its normal use [8].

4.4. Static load test result analysis

After the static load test is completed, technicians need to analyze and study the test results, focusing on the analysis of the maximum crack width, maximum deflection, and other indicators, and evaluate the difference between the actual measured value and the theoretically calculated value of the control point, and then determine the safety and stability of the continuous rigid-frame railway bridge. At the same time, it is also necessary to compare and analyze the difference between the actual measured value of the control point and the specified allowable range, and then judge whether the working state of the continuous rigid-frame railway bridge is normal [9].

4.5. Precautions for static load test

During the static load test of a continuous rigid-frame railway bridge, technicians need to master the following precautions. Firstly, during the static load test, technicians need to choose a suitable location to paste the sensor and avoid sticking the sensor to the crack area of the structure, so as to accurately evaluate the stress state of the steel bar. Secondly, during the static load test, a PVC cable equipped with a protective sheath and a metal shielding device can be selected as the sensor test wire, and the wire diameter should not be too small to ensure the anti-interference performance of the sensor [10]. Lastly, technicians need to wait for the load on the structure

to stabilize before collecting data to save data collection time.

5. Case analysis

5.1. Basic information about the case

The continuous rigid-frame railway bridge examined in this study has the following specifications: it spans a total length of 14 m + 18 m + 18 m + 14 m. It adopts a well-digging foundation structure, featuring a T-shaped cross-section beam with uniform dimension. The entire beam has a height of 1.05 m equally, bottom width of 9.38 m, and top width of 11.24 m. The flange plate possesses an edge thickness of 12 cm, while the root thickness measures 35 cm. The pier body, which has a rectangular cross-section, is reinforced with ribs in the pier joint area. The ribs have a length of 140 cm and a height of 45 cm. Both the pier body and the beam are constructed using C40 concrete, while the foundation is made of C25 concrete. The steel bars employed in this construction are of HRB335 and Q235 varieties [11].

5.2. Static load test points

The static load test of this continuous rigid-frame railway bridge is based on the design load to detect the actual working performance of each structure in the upper area of the bridge. During the test, technicians adopted the scheme of equivalently loading the vehicle load to trigger changes in the strain and deflection of the structures in the upper area of the bridge, measured the relevant values, and compared them with the standard values to determine whether the bearing capacity of the bridge meets the requirements [12]. The static load test items of the continuous rigid-frame railway bridge include the original crack and new crack expansion status of the bridge, the deflection of the typical area, and the stress status of the reinforced concrete in the typical section area of the bridge span, the stress distribution and the changing trend.

5.3. Selection of measuring point

According to the characteristics of the continuous rigid-frame railway bridge, technicians set the measuring points in the mid-span, quarter-span, and fulcrum areas of the second span.

5.4. Test content of different test conditions

During the static load test, technicians used two diesel locomotives (model DF4) to implement double-line loading operations and completed the static load test according to the operating specifications. The test items of the static load test under different test conditions are as follows:

(1) The first working condition is the fulcrum loaded with the maximum negative bending moment. The test content includes the fulcrum crack, the maximum tensile stress of the fulcrum steel bar, and the maximum compressive stress of the fulcrum concrete [13].

(2) The second working condition is the maximum positive bending moment loading on the mid-span section. The specific content of the test includes the maximum tensile stress and compressive stress of the mid-span concrete structure, the crack situation of the mid-span, and the deflection of the mid-span.

(3) The third working condition is the maximum shear loading fulcrum section, and the test content includes the crack and shear stress of the fulcrum section.

(4) The fourth working condition is a quarter-span section loaded with high shear force, and the test content includes the shear stress and cracks generated after loading.

5.5. Static load test process

The static load test process of the continuous rigid-frame railway bridge is as follows. Technicians initially prepared various instruments and equipment in advance, conducted performance tests, completed the preload test according to the operating specifications, properly handled the problems existing in the preload test, and conducted the static load test after confirming that there was no abnormality. During the static load test, technicians then completed the test operations of the four working conditions one by one. The actual interval of the static loading time of different working conditions was 20 minutes. Technicians arranged the test vehicle to reach the predetermined position, turned off the engine in time, and dynamically recorded various data.

5.6. Modeling calculations and data organization

After the static load test data collection is completed, technicians combined the design drawings, took the overall structure of the continuous rigid-frame railway bridge as the analysis and research object, used specialized software to complete the modeling, determined the theoretical values under different working conditions through calculations, and compared them with the actual measured values. After the modeling was completed, technicians sorted out and analyzed various values. Among the measured values of the maximum compressive stress of concrete, the measured average value of the fulcrum was 3.75 MPa, the calculated value was 7.20 MPa, and the calibration coefficient was 0.52. Among the measured values of the maximum tensile stress of steel bars, the measured average value of the fulcrum is 81.55 MPa, the calculated value is 137.9 MPa, and the calibration coefficient is 0.58, the measured average value of the mid-span is 83.22 MPa, the calculated value is 136.9 MPa, and the calibration coefficient is 0.63. Among the maximum shear stress measurement values, the measured average value of the fulcrum is 0.71 MPa, the calculated value is 0.95 MPa, and the calibration coefficient is 0.77; the measured average value of the 1/4 span is 0.46 MPa, the calculated value is 0.66 MPa, and the calibration coefficient is 0.72. The test results of the maximum deflection in the mid-span show that the measured average value is 2.94, the calculated value is 5.12, and the calibration coefficient is 0.55. During the static load test of the continuous rigid-frame railway bridge, technicians observed the cracks at the top of the fulcrum, the bottom of the beam, and the variable cross-section area. The results showed that the original cracks in the cross-section remained stable under different working conditions, and no new cracks occurred.

5.7. Static load test result analysis

Analysis and research on the static load test results of the continuous rigid-frame railway bridge are as follows. Firstly, the static load test results show that the mid-span deflection calibration coefficient ranges from 0.55 to 0.65, which meets the requirements of relevant standards. The measurement results show that the maximum deflection at the bottom of the mid-span section beam is 2.90 mm, and the relevant regulations require a vertical deflection-span ratio of 8.42 mm, which meets the requirements of the relevant regulations. Based on this, it can be considered that the rigidity of the continuous rigid-frame railway bridge is normal and has no adverse effects on the safety of train operations. Secondly, the static load test results show that the maximum compressive stress of the concrete structure of the continuous rigid-frame railway bridge is 3.75 MPa, which is lower than the 16.2 MPa required by the relevant specifications, and the calibration coefficient is 0.54, which is in line with the range of 0.45–0.55 required by the relevant specifications. The maximum tensile stress of the steel bar is 83.22 MPa, which is lower than the 180 MPa required in the relevant specifications, and the calibration coefficient is 0.63, which is in line with the range of 0.55–0.65 required by the relevant specifications. The maximum establishment of the cross-section is 0.71 MPa, which is lower than the 1.34 MPa required in the relevant specifications, and the calibration coefficient meets the relevant requirements. The original cracks of

the continuous rigid-frame railway bridge were stable during the static load test, and no new cracks occurred. Through the analysis of the above data, it can be seen that the rigidity, strength, stability, and bearing capacity of the continuous rigid-frame railway bridge all meet the requirements of relevant standards, which can ensure the safety of trains. In order to avoid accidents, technicians need to conduct static load tests regularly and conduct appearance inspections, material defect inspections, etc., so as to find and effectively deal with various problems in time [15].

6. Conclusion

The stability and safety of continuous rigid-frame railway bridges can have a great impact on the safety of train operation, so it is necessary to accurately evaluate its quality through effective detection technology. Static load test is an effective technical solution for evaluating the stiffness and bearing capacity of continuous rigid-frame railway bridges. Technicians need to master the key points of operation, complete various operations in a standardized manner, and accumulate experience in practice to ensure the accuracy of test results.

Disclosure statement

The authors declare no conflict of interest.

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Preliminary Research on Water Supply, Drainage, and HVAC Equipment in Shanghai Historic Buildings During the Northern Warlord Period

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Abstract: During the Northern Warlord Period (1912–1928), the construction industry in Shanghai underwent robust development. As an integral element of buildings, equipment served both functional purposes and stood witness to the evolution of the economy and society, thus earning its place as part of the architectural heritage. However, due to various reasons, there are many loopholes in the protection of these building equipment. This paper examines the development of building equipment in Shanghai during the Northern Warlord Period, using water supply, drainage, and heating, ventilation, and air conditioning (HVAC) systems as examples. Through historical context analysis, it summarizes this development from a social-spatial perspective, infers the reasons behind it, and analyzes the importance of preserving such equipment, considering both past and present viewpoints. In this research, the importance of protecting historical building equipment is emphasized, which aims to give people a deeper understanding of their cultural value, and suggests that scholars conduct more practical research on their protection.

Keywords: Historic buildings; Water supply and drainage; HVAC; Protection

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1. Introduction

As one of the earliest treaty port cities in modern China, Shanghai was among the first to embrace new Western culture and ideas. Following the overthrow of the feudal monarchy in the Revolution of 1911, Shanghai entered the Northern Warlord Period (1912–1928), a time of political fragmentation led by Yuan Shikai. In its initial years, Shanghai's urban economic development leaned heavily on countries like the United States and Japan. However, with the end of World War I, the British and French forces reasserted their influence. The intervention of external forces directly catalyzed the construction and transformation of Shanghai. Meanwhile, during the decade following 1916, a myriad of ideological practices and innovative experiments emerged. As political forces waned, a trend of diversified development in thought, economy, and society emerged, greatly accelerating

urban construction in the realm of restless ideas [1]. In various districts, for instance, plans were formulated to rebuild or renovate buildings within the concessions, aligning them with urbanization, commercialization, and modernization efforts [2]. Despite the abandonment of numerous projects due to personnel shifts and political instability, many buildings successfully underwent suitable adaptations or reconstructions, with the Bund area standing out prominently. Significantly, the period of the Northern Warlord Government witnessed a transformation in architectural development, transitioning from Chinese Neoclassicism to the emergence of the International Style, underscoring Shanghai's evolving architectural landscape.

Simultaneously, numerous advanced technologies were introduced during this era. These innovations not only accelerated Shanghai's development but also solidified its position as a hub for modern architectural practices. In Shanghai, the introduction of these technologies often started within the concession and gradually expanded to the entire city [3]. Among them, building equipment, a pivotal facet of architectural engineering, also found its initial import and application in Shanghai before disseminating to other regions [4]. This pivotal role of building equipment in Shanghai transcends its mere functional impact on the establishment and evolution of municipal infrastructure; it also plays an integral role in shaping the city's identity, especially catering to the new concept called "modernity."

Common equipment includes water supply and drainage, air-conditioning, ventilation, lighting systems, etc. In the Northern Warlord Period, Shanghai's building equipment had undergone tremendous changes and development, which could represent the glory and gloom of that era and have important value in historic context. However, looking back at the development of historical building equipment in Shanghai, there are great loopholes in its contextual tracing and protection. Historical building equipment is often overlooked in preservation efforts. Factors like neglect, damage, or the loss of their original appearance contribute to the demolition or renovation of many such equipment pieces, erasing the historical memories they once held. Based on the above status, and also due to the lack of relevant research during the Northern Warlord Period, this paper mainly introduces the development of water supply and drainage and air-conditioning systems in Shanghai during this period.

2. Contradiction: The birth of new water supply and drainage equipment and the dilemma faced by reality

Before the Northern Warlord Period, the water supply and drainage system depended on the Yangshupu Waterworks and other foreign-invested waterworks[5]. Only the Neidi water plant was totally built by Chinese and belonged to the public sector. After 1912, those water plants continued to play a role, and all the water from the water plants came from the Huangpu River region. The main waterworks in Shanghai during Northern Warlord Period are listed in Table 1.

Table 1. Overview of Shanghai waterworks in Northern Warlord Period

District	Water supply area (km^2)	Name	Operation mode
1	77.10	Neidi Water Plant	Privately operated (Chinese)
2	44.30	Shanghai Water Plant	Privately operated (UK)
3	–	–	Privately operated (UK)
4	–	French Water Plant	Privately operated (UK)

Despite water supply systems covering most densely populated areas in Shanghai, a significant number of low-income residents still depended on water workers to deliver water to their homes, mainly because of water scarcity and high prices. As a result, it was difficult to guarantee the quality of the water that was being delivered. The water usually came from nearby wells or rivers, which may contain pathogenic bacteria [6], and it was also susceptible to contamination during transportation.

Due to a scarcity of water and high prices, many low-income residents in Shanghai relied on water workers for their supply, despite water supply systems covering densely populated areas. Additionally, inadequate resident hygiene awareness and government oversight led to disorderly and secretive wastewater discharge. Furthermore, the absence of a modern water treatment system hindered water recovery and reuse, causing domestic water shortages and environmental pollution. These issues not only affected residents' lives but also sparked discontent among some concession leaders. Consequently, in 1917, they sought legal intervention on sewage matters, resulting in a court ruling that prompted the Industrial Engineering Department to construct sewage ditches and pipes. These projects were completed by 1923 and implemented in specific areas.

During this era, the civilian use of toilets and their equipment underwent various challenges. These conflicts stemmed from the inability to discharge domestic sewage into municipal sewers, a situation that also led to discontent among many affluent individuals [7].

After persistent negotiations with the consular court, certain affluent individuals were eventually permitted to install sanitary equipment connected to the sewer. It was not until July 1918 that the S.M.C. Public Works Department approved the use of toilets. Due to a high surcharge, toilets were available only in public buildings and wealthy families at that time. In the 1920s, certain Shanghai local gentry were dissatisfied with the significant disparities between the Chinese community and the foreign concessions. Utilizing the "Local Self-Government Legislation," they mobilized resources and funding, emulating advanced equipment from the concessions. As a result, numerous regular households gained access to actual toilets and related facilities. This movement has benefited thousands of families and greatly improved the living standards of Chinese residents.

In addition, in 1916 (before the toilet was officially put into use), the New Western Style Building Rules were promulgated [8]. It clearly stated the procedures for toilet installation application, defined the names and drawing requirements of equipment such as fecal and sewer pipes, explained the methods of sewage treatment, and stipulated the number and capacity of septic tanks. All these laid the foundation for the application of sanitary ware in the next few decades.

In addition to the application in the toilet, it is worth mentioning that the water supply and drainage system was also widely used in the field of fire protection in public buildings, especially with the development of high-rise buildings.

In line with Louis H. Sullivan's concept of multi-level functional zoning for high-rise buildings, architectural designs incorporated equipment floors. Pipes were flexibly arranged within the buildings, relying on unique patios and structural columns. Historical records reveal that no major fires occurred in the buildings equipped with automatic sprinkler systems during their existence, highlighting the pivotal role of equipment in ensuring safety. This was also attributed to the progress in building structures and materials at that time, particularly in high-rise buildings where steel frames and reinforced concrete proved more fire-resistant compared to the original ordinary brick and wood structures.

The introduction and development of water supply and drainage equipment was of great significance to the development of Shanghai's buildings and the quality of the citizens' lives. The main applications and development of water supply and drainage equipment during the Northern Warlord Period are shown in **Table 2**.

Table 2. Development of Shanghai building water supply & drainage system in Northern Warlord Period

Time	Event
1916	The New Western Style Building Rules was promulgated to regulate the installation of toilet equipment.
1917	Began to build sewage ditches and pipes.
1918	Toilets began to be used in some public buildings and wealthy families.
After the 1920s	A large number of civilian families began to have toilets and water supply and drainage equipment.

3. Progress: Application of HVAC equipment

Shanghai is cold in the winters and hot in the summers, making heating, ventilation, and air conditioning (HVAC) systems essential. During the Northern Warlord Period, most of HVAC systems were contracted by foreign firms. As a result, HVAC systems were primarily found in the concession areas.

The development of HVAC technology in Shanghai is closely intertwined with the growth of the electric power industry. As early as July 1882, Shanghai established the Shanghai Electric Light Company, marking the commencement of electrical supply. Its establishment was only seven years after the construction of the world's first power plant, the Gare de l'Est Power Station in Paris, and it was founded in the same year as Japan's first electric power company, the Tokyo Electric Light Company, preceding Edison's Pearl Street Station in New York by two months [9].

The availability of fuel played a crucial role in the development of heating systems. In the early 20th century, as China produced more coal, Shanghai had a steady coal supply. During this time, due to the advanced foreign technology and strong demand in the local market, traditional stoves and braziers were gradually replaced by Western cast iron stoves, hot-water heating, and steam heating as the popular choices for heating systems. The earliest modern heating system in Shanghai was the steam heating in Astor Hotel in the early 20th century [10]. The earliest hot water system in Shanghai was installed in 1910 in 40 suites on the second floor of the Shanghai Club [11]. By the late 1910s, newly constructed buildings, such as office buildings in the Bund area, as well as upscale apartments and residences, began to install stoves and heating systems [12]. By the 1920s, steam heating had become the dominant method of heating in Western-style architecture. These heating systems were more efficient and environmentally friendly compared to traditional methods, which is why they gained popularity among middle and high-income households [12]. However, Shanghai did not have centralized heating systems like those in urban areas such as New York City in the United States. Instead, each building had its own boilers for hot water and steam supply, resulting in a decentralized heating approach. This arrangement offered high flexibility, ease of control, and minimized heat losses, making it well-suited for the practical conditions in Shanghai during that period. There were two reasons to this approach: firstly, Shanghai's winters were not as cold as those in New York, and snowfall was infrequent. Secondly, the key officials of the Public Works Department were from Britain, where centralized heating systems were not used. Furthermore, this approach was influenced by the relatively limited development of heavy industry in Shanghai during that era. However, for low-income families, the cost of purchasing and using this equipment remained prohibitively high. As a result, they often opted for traditional stoves or braziers, underscoring the significant wealth disparity in Shanghai's society at that time [13].

In terms of cooling systems, traditional hand-pulled fans were used in bathrooms, barber shops and other small public places. They needed to be operated manually, and most of the workers were underage boys, which was inhumane. Fortunately, Willis H. Carrier designed the world's first scientific refrigeration system in 1902 [14], which marked the arrival of the industrialization era in the field of cooling systems. In 1913, a refrigeration

specialty was established in Shanghai [15]. Then, in 1923, HSBC Bank pioneered the use of air-conditioning systems. Following this, numerous buildings in Shanghai, including the Majestic Hotel, Kadoorie Marble Building, Pacific Hotel, Capitol Building, and others, adopted comfortable air-conditioning systems.

Air-conditioning systems found applications in the light industry as well. The New Chinese Building Rules [16], introduced in 1917, outlined ventilation requirements for ground floors, specified the window-to-floor ratio in rooms, set guidelines for food storage rooms, and provided details on the location and size of ventilation equipment, as well as the minimum net height of rooms. Since air-conditioning projects were monopolized by foreign companies, and pertinent laws and regulations had not been established, these ventilation requirements from the rules were carried over and applied in the field of light industry.

For instance, in 1923, a soda company established by Watson employed York's refrigeration unit to meet the cooling needs for beverages and staff [17]. With the maturity and development of technology, the first set of ammonia system refrigeration equipment appeared in Shaxun building. However, this system fell far behind the first ammonia refrigeration system in the West in terms of technology. Moreover, it was not until after liberation that China achieved its first domestically developed ammonia refrigeration compressor [18]. Meanwhile, many buildings from that era started using electric fans, thanks to Yang Jichuan's invention of the electric fan and the establishment of the Huasheng electric appliance factory [19]. Even today, mechanical fans are still commonly found in places without air conditioning.

At that time, Shanghai was gradually integrating with the world and catching up with the new era of air conditioning. The main application of air-conditioning system in Shanghai buildings during the Northern Warlord Period is shown in **Figure 1**.

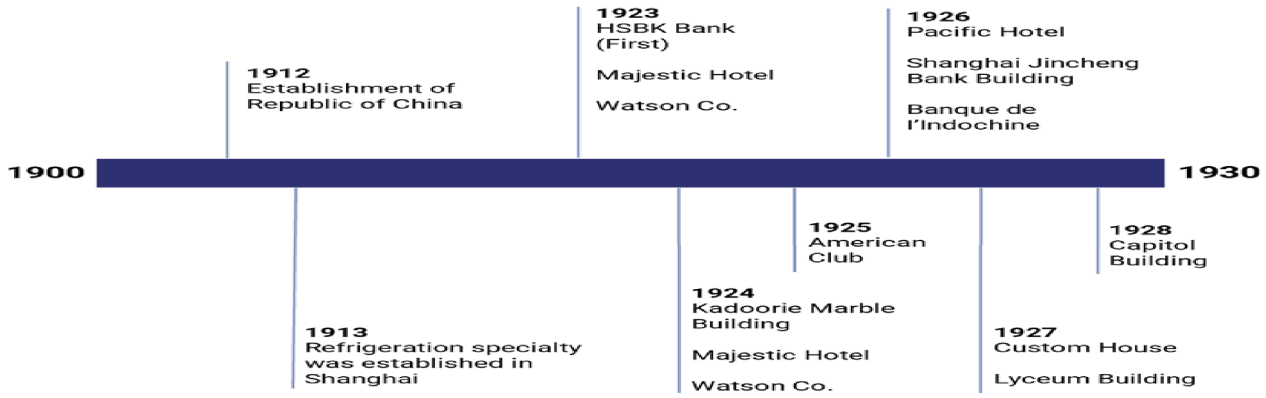


Figure 1. The typical application of air-conditioning system in Shanghai buildings during the Northern Warlord Period

4. Conclusion and prospect

Amidst the tumultuous backdrop of the Northern Warlord Period, Shanghai, a city characterized by its spirit of openness, witnessed a diverse array of transformations and advancements in the field of building equipment, particularly in water supply, drainage, and air-conditioning systems. During this era, driven by the intricate tapestry of historical circumstances, Shanghai's architectural apparatus underwent various changes, serving as a testament to the highs and lows of that age. A crucial facet contributing to Shanghai's rapid evolution from a humble fishing village to a bustling metropolis was the introduction and continuous refinement of advanced technologies, exemplified by the incorporation and ongoing enhancement of building equipment.

Historical building equipment can be seen as invaluable cultural heritage. Nevertheless, the current level

of attention and preservation efforts for certain historical building equipment within Shanghai's architecture is insufficient. Factors like disrepair, damaged appearance, and inadequacy for modern requirements have led to the replacement of numerous precious historical building equipment with contemporary alternatives, and some have even been demolished. Directly dismantling them is akin to removing a piece of the historical puzzle, leaving a particular period of history incomplete, which is undeniably a significant loss.

Therefore, we believe that the cultural value of historical building equipment must be taken seriously, and we must also take some measures to better protect them: (i) We must view historical building equipment through the lens of cultural heritage preservation and simultaneously enhance research efforts to delve deeper into their historical significance. (ii) We should bolster foundational tasks such as cataloging, selecting, and archiving historical building equipment. (iii) Leveraging advanced modern technology, we can also protect and restore these equipment pieces to maximize the historical memory encapsulated in Shanghai's building equipment. The protection of historical building equipment has a long way to go. Based on the points established in this paper, future research should focus on the following points:

(i) Solving the safety problems of historical equipment, such as the issue of short circuit caused by the aging of some air ducts or heating systems.
(ii) Allocation of funds in the protection of historical building equipment (daily maintenance, regular upgrading).
(iii) Dealing with equipment that has lost its function and deciding which ones to keep or dismantle.
(iv) Preserving the appearance of the original equipment while ensuring that it is coherent with the style of the reconstructed building.

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Application of Modified Asphalt in Municipal Roads

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Abstract: The article expounds modified asphalt technology by introducing commonly used modifiers and fillers and analyzing the construction technology of modified asphalt. The use of modified asphalt in municipal roads provides new alternatives for asphalt pavement materials, but also solves the existing construction problems and reduces project costs. Therefore, the research and application of modified asphalt using new materials and new processes is a crucial aspect in road construction.

Keywords: Modified asphalt; Municipal road; Construction technology

Online publication: September 27, 2023

1. Introduction

As a non-renewable resource, asphalt is an important guarantee for the development of urban economy and the improvement of people's living standards. This is because asphalt is an important material for municipal road construction. With the development of society, traditional asphalt is no longer suffice, so there is need for modifications. Modified asphalt consists of modifiers and additives instead of asphalt alone, which can improve the stability of the road and prolong the service life. With the development of our country's economy, the number of national infrastructure construction and municipal road engineering projects is increasing, which puts forward higher requirements for road construction technology, construction management, and engineering quality. However, there are several prevalent issues with the current use of modified asphalt in our country: (i) Limited variety options and challenges in quality assurance. (ii) Outdated production technology and inadequate raw material supply. (iii) Low utilization of modified asphalt. Absence of systematic research on modified asphalt construction techniques and a standardized construction management system. In view of the problems above, combined with the research and analysis of new modified asphalt materials and case studies, a set of systemic application schemes for modified asphalt in municipal roads that are in line with our country's conditions have been proposed, and have been popularized and applied. There are mainly two types of modified asphalt: the first type is physically-modified asphalt and the other is chemically/biological-modified asphalt [1-6].

2. Modified asphalt technology

2.1. Basic properties of modified asphalt

The composition of asphalt mainly includes colloid, asphaltenes, aromatics, ash, and volatile components. The properties of asphalt are greatly affected by temperature. When the temperature rises, the viscosity of asphalt will increase, and the color will change, thus losing its fluidity. When used at room temperature, if softener is added, the performance will be improved, but its basic properties will not change. Different types of high molecular compounds or natural polymers have different properties and advantages. Asphalt can be modified physically or chemically to improve road performance and service life. Different types of modifiers are often used to improve the performance of asphalt. Modified asphalt is commonly prepared by mixing two or more components according to a certain ratio. The performance of asphalt can be improved by adjusting the proportion of each component in the mixture according to the properties of the base asphalt. Modified asphalt has many advantages: improved road rutting resistance, improved high-temperature stability and low-temperature crack resistance, reduce water damage and reflection cracks, improved fatigue resistance, etc [7].

2.1.1. Physical properties of modified asphalt

Modified asphalt refers to the addition of a certain amount of chemical or biological modifiers using suitable technology to improve the performance of asphalt. This includes improving its low temperature performance, high temperature performance, anti-aging ability, and the adhesion with aggregates, fillers, and other materials. Physical modification involves heating the asphalt in an enclosed environment). Heating asphalt will cause it to undergo physical changes and produce modifier substances, mainly physical modifications, including rubber, fiber, inorganic pigments, etc. There are many types of modified asphalt, which are mainly divided into two categories: one is to improve the properties of asphalt by introducing new components, the other way is by adding modified asphalt into traditional asphalt [8].

2.1.2. Chemical and biological modification

The chemical modification method involves changing the molecular structure of asphalt by adding certain chemicals to improve its low-temperature performance and anti-aging performance. On the other hand, the biological modification method improving the ageing resistance of asphalt by adding various organisms. Both chemical and biological methods have their own characteristics, and the suitable type of modified asphalt should be selected based on the type of project. Chemical and biological modifications can be used alone or in combination. Chemical modification involves inducing chemical reactions in asphalt using chemical processes. On the other hand, biological modification utilizes organisms with specific activity or compounds that are easily decomposable to initiate chemical reactions within the asphalt.

2.1.3. Technical advantages

Currently, in China, modified asphalt is mainly used in municipal roads, with asphalt concrete pavement being the most used, accounting for more than 90%. Municipal roads require higher grades, higher standards and higher quality, and higher requirements for modified asphalt. Due to the high cost of new materials, technologies, and equipment, most roads still use ordinary asphalt. Therefore, popularizing and applying modified asphalt is of great significance to the development of municipal roads in China [1-6]. In the following sections, the characteristics of new materials technologies, and equipment and their application in our country's municipal roads are analyzed in detail, and relevant improvement suggestions are put forward.

2.2. Common modifiers and fillers

Modified asphalt is a new type of asphalt material with a wide range of applications. Our country has a long history of road construction. Traditional asphalt materials can no longer meet growing needs of road construction, and modified asphalt has become an inevitable choice. Modifiers and fillers are the most important raw materials in modified asphalt. With the development of economy and society and science and technology, the requirements for modifiers and fillers are also increasing. Modifiers offer significant potential and development prospects as they are substances used to treat asphalt materials, and different modifiers can enhance road performance, appearance, and durability. Mineral powder and fiber materials are among the most common and crucial modifiers. They are used to fill the matrix asphalt through dispersion, enhancing the performance of asphalt materials during road construction. Mineral powder is a natural substance consisting of calcium carbonate and silicon oxide. The mineral powder acts as a filler; mineral powder has good cohesiveness, high hardness, and good performance. Silica is a common inorganic filler that has good performance. Silica-modified asphalt can improve the mixing quality and performance of the mixture, which in turn improves the construction quality; at the same time, silica has good road performance and good durability to meet actual needs. Fiber is also a new type of additive. Adding fiber to asphalt can improve the technical indicators of asphalt materials such as hardness, wear resistance, and toughness. At the same time, fibers can reduce the aging of the bonding force between medium-base asphalt and aggregates and improve the quality of road construction [9]. These three commonly used fillers include have relatively large particle size and surface area, and light particles. These fillers can improve technical indicators and production efficiency, and the service life of roads. Through comparative analysis of various fillers, it is found that mineral powder has several advantages over other types of fillers: (1) low-cost, (2) improves the overall performance of asphalt materials, (3) good modification effect (mineral powder also shows good effect on the technical indicators when used together with other materials, but it is costly), (4) easily processed [10]. At present, this technology has been gradually promoted and applied with good results.

2.3. Analysis of aging resistance of new modified asphalt materials

Different road construction uses different materials. On road sections with heavy traffic volume, complex pavement structure, and prone to aging, modified asphalt materials are used. Its anti-aging properties are of great significance for improving the quality and service life of asphalt pavement. Various factors such as temperature and environmental conditions can lead to different types of damage to pavement, often irreversible. Some materials may meet road construction standards but fall short in terms of durability. In recent years, improved living conditions have resulted in increased road vehicle usage, which in turn has placed considerable stress on expressways. Overloading leads to more and more damage on the pavement. In addition to human factors, there are also natural factors. Ultraviolet rays and rain will cause certain stress and deformation of the road, resulting in a decrease in the strength of the structure, resulting in fatigue cracks. Styrene-butadiene-styrene (SBS) helps in improving the durability of asphalt [11]. The anti-seepage performance of asphalt concrete plays an important role in the stability of asphalt concrete pavement. Therefore, asphalt concrete must have strong corrosion resistance, especially in areas with a lot of rain. Adding SBS to conventional asphalt and properly adopting modified asphalt will have a greater effect on the anti-permeability of the road.

From a construction and operational perspective, we conducted an analysis of the workability of the new modified asphalt. Based on the performance study, we concluded that the new asphalt pavement is conducive to easy laying and compaction. The laying and compaction methods are critical aspects of engineering construction, and their quality significantly impacts the project's progress and surface smoothness. Therefore,

the workability of the modified asphalt will be directly related to whether the project can be successfully completed. In the current application of asphalt materials, there is no clear standard for its workability, and only the viscosity index of the material is used. The composition, aggregate, particle size, and compactness are important factors that determine the performance of modified asphalt. The ingredient ratios must be carefully adjusted to prevent challenges during rolling, which can result in issues like uneven mixing and hinder the project's progress to some extent.

3. Construction technology analysis of modified asphalt

(1) Quality control of pavement base

Before the construction of the pavement base, the surface of the base should be cleaned comprehensively and thoroughly. After cleaning the surface, the sundries and accumulated water on the ground should be discarded, and a drainage system should be set up to facilitate smooth drainage.

(2) Application of asphalt pavement construction technology

Before adopting asphalt pavement construction technology, the relevant technical requirements should be mastered, and then the asphalt paving and rolling can be carried out according to the design plan. First, the mixture should be mixed evenly and transported to the pavement base for paving and rolling. Secondly, the mixture is poured into the mold according to the design plan. Then, the mixture is compacted through vibration or other compaction methods. Lastly, the surface of the asphalt pavement is swept clean, and some water is sprinkled onto the surface and swept again.

(3) Construction of anti-collision barriers

Concrete is used in building road guardrails to better prevent traffic accidents. The concrete and reinforced concrete are combined to form a composite structure, which allows the guardrails to have better impact resistance. This composite structure can provide a good traffic environment for pedestrians by reducing interference and damage caused by vehicles, and prevent traffic accidents. In order to ensure the safety of pedestrians, the use of anti-collision barriers for isolation during road construction can play a very good role in protection.

(4) Sidewalk slab pavement and quality control

Sidewalk slabs, which are essential parts of municipal roads, often face quality problems during construction. This is because materials like cement and sand are added to improve their performance. Some companies may even resort to excessive additives in the production process to gain more profit [4]. Hence, strict control over material composition and additive levels, along with adherence to the designated design plan for raw material allocation, is crucial to minimize quality issues during municipal road construction.

(5) Paving and rolling work

The asphalt mixture temperature increases rapidly during paving, necessitating the use of vertical rollers to prevent this rise. When the temperature increases, cooling measures should be applied, and conversely, heating measures are required when the temperature drops.

4. Conclusion

The emergence of modified asphalt is inevitable and it has a wide range of applications. Therefore, it is necessary to do a good job in the research of modified asphalt and continuously improve the level of construction technology. Modifiers and fillers should be fully utilized to ensure that the quality of the mixture is

up to standard, while strengthening construction management and testing. It is necessary use modified asphalt and relevant technologies appropriately depending on the nature of the project. (1) Selection of modifier: suitable modifiers and fillers should be selected according to the needs of the project. For example, fiber can be added to the asphalt mixture to improve its performance. Besides, the mixture should also be prepared at a suitable temperature. (2) Controlling the construction process: The ratio of ingredients in the mixture should be determined according to the needs of the project. Besides, material testing and process management should also be strengthened. (3) Quality inspection: During asphalt mixture preparation, it is crucial to ensure that each step adheres to the design specifications and relevant standards. Rigorous quality inspections are essential to detect material issues promptly and address them to maintain construction quality.

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Construction Technology of Deep Foundation Pit Support in Municipal Civil Engineering Foundation Construction

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Abstract: Municipal civil engineering is the key content of municipal construction, and the construction scale is usually large. The quality of the project plays an important role in the development of urban economy. Due to the rapid increase of high-rise buildings, skyscrapers and underground buildings, the construction technology of deep foundation pit support has gradually become an indispensable construction technology. Therefore, the selection of foundation pit support construction technology is crucial in ensuring that whether the foundation is firm and stable, and whether the subsequent construction activities can be carried out smoothly. In view of this, the article discusses the application of deep foundation pit support construction technology in municipal civil engineering, aiming to provide reference for subsequent projects.

Keywords: Deep foundation pit support; Civil engineering; Foundation construction; Concrete pouring pile technology; Row pile support technology

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1. Introduction

Deep foundation pit support construction technology is a crucial field in municipal civil engineering. Continuous urbanization and the increase in the scale of urban construction, more and more high-rise buildings, underground complexes and underground transportation facilities have been constructed. However, due to the limited land resources and increasingly complex geological conditions in the city, the construction and support of deep foundation pits has become extremely challenging. The construction of deep foundation pits involves many advanced technologies, and there are many factors to be considered during the construction process. For example, groundwater level, mechanical properties of soil, and the influence of adjacent buildings. If the foundation is not properly constructed and supported, it may lead to foundation pit collapse, ground subsidence, damage to adjacent buildings, and even pose a potential threat to the surrounding environment and the safety of residents.

2. Characteristics of deep foundation pit support construction

The construction of deep foundation pit support is a complex and critical task. The construction of deep foundation pit support are highly complex and difficult compared to other structures, and it is affected by many factors such as geological conditions, hydrological environment, urban traffic and environment. In terms of its characteristics, the main points are as follows.

2.1. Varying geological conditions

Urban geology is often complex and varied, and subsoil layers may contain different types of soil and rock. These geological conditions play a crucial role in the stability and support scheme of deep foundation pits. In the design of deep foundation pit support, detailed geological survey and soil mechanics test must be carried out to ensure the rational design and construction safety of the support structure [1].

2.2. High groundwater levels

Urban water tables are often high, especially in areas near rivers, lakes or oceans. During the construction of deep foundation pits, if effective water level control measures are not taken, groundwater may flow into the foundation pit, resulting in soil loss, instability of the pit bottom, and settlement of supporting structures. Therefore, a reasonable precipitation scheme and water level control means are crucial.

2.3. Susceptible to the influence of neighboring buildings

Urban foundation pits are often located near adjacent buildings, so the impact of construction on surrounding buildings must be reasonably evaluated and controlled [2]. Foundation pit construction may cause ground subsidence, structural vibration and other impacts, posing potential threats to the stability and safety of surrounding buildings. In the design stage, it is necessary to formulate corresponding monitoring plans, keep abreast of changes in adjacent buildings, and make adjustments and responses based on monitoring results.

2.4. Urban traffic and environmental factors

Deep foundation pit support construction is usually located in busy urban areas, so the impact of construction on traffic and the environment must be considered. During the construction period, roads and construction sites may be occupied, affecting traffic smoothness and daily life of surrounding residents. In the design of the construction scheme, it is necessary to comprehensively consider measures such as traffic control, noise control, and dust prevention to ensure that the impact of the construction process on the city is minimized.

2.5. High technical requirements for construction

The construction of deep foundation pit support requires relatively advanced construction technology. Many innovative support technologies have appeared over the years, such as cantilevered steel support, geogrid, prestressed anchor cable support, etc. [3]. The application of these new technologies can improve the construction efficiency and the stability of the supporting structure, and drive the development of urban civil engineering.

3. Application of deep foundation pit support construction technologies

3.1. Row pile support

Row pile support is a commonly used and effective technology in deep foundation pit support construction. By laying neatly arranged reinforced concrete piles on the edge of the foundation pit, a strong support wall is formed to resist the lateral earth pressure of the soil wall of the foundation pit, as shown in **Figure 1**. Row pile support is widely used

in municipal civil engineering, and is favored for its stable structure, simple construction, and adaptability. Before the construction of the deep foundation pit, the construction site should be cleaned and leveled to ensure that it is free from obstacles [4]. Geological survey and soil mechanics test are then conducted to obtain relevant geological information in order to determine the appropriate row pile support scheme. The positions and spacing of pile rows are planned and arranged according to the geological survey results and the design requirements of the foundation pit. They are usually arranged evenly at the edge of the excavation to form a continuous pile wall. The reinforced concrete is then poured into the pre-excavated holes to form the pile body by using the drilling method or the extrusion method. The size and strength of piles should be designed according to geological conditions and bearing requirements. Each pile is connected together by connectors to form an overall pile-wall structure. This ensures sufficient stiffness and stability of the pile wall against lateral earth pressure. Horizontal support are installed on the inner side of the pile wall to support the bottom and side walls of the foundation pit [5]. The supporting structure is usually supported by steel, wood, or concrete to keep the foundation pit stable.



Figure 1. Row pile support technology

The pile wall formed by row pile support technology is rigid and stable It can effectively withstand lateral earth pressure and groundwater pressure, thus maintaining the stability of the foundation pit. Moreover, its construction is relatively simple and does not require complicated equipment and processes. The pouring of piles can be done on-site or prefabricated to improve construction efficiency. There is no need for supporting structures in the foundation pit for row pile supports, which saves the construction space and makes the inside of the foundation pit available for other construction operations.

3.2. Cast-in-place concrete piles

Cast-in-place concrete piles is a commonly used technology in deep foundation pit support construction. The pile body is formed by pouring reinforced concrete at the edge of the foundation pit excavated underground or inside the foundation pit to support the side wall and bottom plate of the foundation pit and prevent the soil from collapsing and instability of supporting structures. The concrete pouring pile technology has the advantages of simple construction, strong bearing capacity, and wide adaptability, so it is widely used in municipal civil engineering.

Before the construction of the deep foundation pit, several preparation works are done, including cleaning the construction site, conducting geological surveys and soil mechanics tests to determine the location and size of the cast-in-place piles. The layout and spacing of the concrete pouring piles are determined according to the geological survey results and the design requirements of the foundation pit. In general, concrete pouring piles

will be evenly distributed on the edge of the foundation pit or inside the foundation pit to form a continuous pile wall or pile network. The boreholes for the cast-in-place piles are excavated using a drilling machine or other suitable equipment. The depth and diameter of the holes must meet the design requirements to ensure the stability and bearing capacity of the pile. After the borehole is formed, reinforced concrete is poured into the borehole to form a pile [6]. When pouring concrete, it is necessary to control the construction quality to ensure the compactness and uniformity of the concrete. A connector can be reserved on the top of the cast-in-place pile to facilitate connection with other supporting structures, such as steel supports or beams.

The cast-in-place concrete pile is made of reinforced concrete. It has a high bearing capacity, thus it can effectively resist lateral earth pressure and groundwater pressure, and maintain the stability of the foundation pit. This technology is applicable to different types of foundation pits, such as slope type and foundation pits with large changes in cross-sectional dimensions, etc., and has strong adaptability. It should be noted that in order to ensure the quality and safety of deep foundation pit construction, the dewatering system supported by row piles should be reasonably designed and constructed to ensure that the groundwater level inside the foundation pit is controlled within a suitable range [7].

3.3. Soil nailing

Soil nailing involves pre-embedding soil nails made of metal or composite materials inside the foundation pit or at the edge of the foundation pit. The soil nails interact with the surrounding soil to form an overall support structure, as shown in **Figure 2**. Soil nailing is relatively simple, and it is adaptable. Therefore, it is widely used in deep foundation pit construction.

The construction site is surveyed before the construction begins, and the impurities on the site are cleaned up, soil mechanics tests are performed, and the specific size specifications and positions of the soil nails are determined. The layout position and spacing between the soil nails is determined according to the geological survey results and the design requirements of the foundation pit. The soil nails can be evenly distributed on the edge or inside of the foundation pit to form a supporting structure. Then, holes are drilled on the edge or inside of the foundation pit to install the soil nails. The nails are inserted into the holes and high-strength grouting materials are injected to enhance the bonding force between the soil nail and the soil. In order to further stabilize the edge of the foundation pit, slope treatment measures are usually taken, such as spraying concrete or setting a sprayed concrete retaining wall [8]. In addition, special attention should be paid to the protection of adjacent buildings to avoid the impact and damage caused by construction.



Figure 2. Soil nailing technology

3.4. Slope protection piles

Slope protection piles are also known as geogrid wall. Through this technology, a strong support structure is formed by embedding reinforced concrete piles into the soil to resist the lateral earth pressure of the soil on the side wall of the foundation pit. Slope protection piles are widely used in municipal civil engineering, and is favored because of its advantages such as structural stability, rapid construction, and economical efficiency.

The arrangement and spacing of the slope protection piles are determined according to the geological survey results and the design requirements of the foundation pit. They are usually evenly arranged on the edge or inside of the foundation pit to form a continuous support structure. Firstly, holes are drilled on the edge or inside of the foundation pit. The reinforced concrete slope protection piles are then embedded in the drilled holes, and high-strength grouting materials are injected to enhance the bonding force between the slope protection piles and the soil. Subsequently, the slope protection piles are connected with the support structure in the foundation pit or other stable strata to form an overall support system. Slope protection piles can be quickly constructed, allowing for rapid completion of large-scale pile construction, which facilitates project progress control. Furthermore, this construction technology generates minimal environmental pollution during the process, aligning with environmental protection standards.

4. Application strategies of deep foundation pit support construction technologies

4.1. Field survey in the early stage

Preliminary field survey is the first and most critical step in deep foundation pit support engineering. Proper on-site survey should be performed to understand the geological conditions of the area where the foundation pit is located, including geological structure, stratum distribution, rock and soil properties, etc. In the field investigation, it is necessary to conduct soil quality tests, which includes the determination of soil density, shear strength, permeability, and other parameters. Observing and recording changes in the groundwater level can help formulate a precipitation plan to ensure that the groundwater level in the foundation pit is within a controllable range and avoid problems such as foundation pit collapse caused by the influx of groundwater. It is also necessary to investigate and record the location and direction of underground pipelines. Collection of data from the construction area can aid the design of the support structure and the formulation of the construction plan, so that the foundation pit support can suit different geological conditions [9].

4.2. Accurate excavation and filling of foundation pit

The excavation and filling of the foundation pit are crucial aspects in the construction of deep foundation pit support. The size and shape of the foundation pit should be consistent with the design requirements, and the angle of the side slope should be strictly controlled to avoid soil erosion and landslides. The filling soil should meet the engineering requirements to ensure the uniformity and compactness of the filling soil to provide stable soil support [10]. At the same time, the drainage system should be reasonably designed and constructed to keep the groundwater level inside the foundation pit within a controllable range, so as to prevent the foundation pit from collapsing or the supporting structure from being damaged due to the influx of groundwater. In addition, it is necessary to utilize advanced technology for real-time monitoring of the excavation and filling process of the foundation pit, so as to facilitate timely detection and resolution of emergencies.

4.3. Optimization of construction scheme design

Optimizing construction scheme design of the deep foundation pits can improve engineering efficiency

and reduce costs. By rationally planning the construction process and selecting appropriate equipment, the construction process can be optimized and the duration of construction can be shortened. Safety and environmental protection factors should also be considered when designing the project to ensure project quality and safety.

4.4. Selection of foundation pit support construction method

It is crucial to choose a suitable method for constructing the foundation pit support. The selection of method depends on the depth of the foundation pit, soil conditions, groundwater level and other factors, such as steel support, concrete pouring pile, soil nailing support, slope protection pile, etc. Reasonable selection of support methods can improve construction efficiency, reduce costs, and at the same time ensure the stability and safety of the project.

5. Conclusion

In summary, with the expansion of municipal civil engineering construction scale, deep foundation pit support construction has grown popular. In order to ensure the quality and stability of the foundation of the project and improve the overall construction quality, full on-site investigations are required, and suitable technology should be utilized.

Disclosure statement

The author declares no conflict of interest.

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Construction Technology of Warm Mix Asphalt Pavement in Cold High-Altitude Areas

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Abstract: With the continuous development of domestic highway construction, highway civil engineering and service level quality have attracted much attention. Good pavement quality and high-quality service make people feel comfortable and smooth when traveling. High-quality pavement can significantly reduce the probability of traffic accidents. At present, there is a direct relationship between pavement quality and pavement construction operations. Carrying out pavement construction operations in cold high-altitude areas requires a reasonable selection of construction equipment and methods. The application of warm-mix asphalt pavement construction technology can ensure pavement quality. Therefore, this paper analyzes the advantages of warm-mix technology, the environmental characteristics of cold high-altitude areas, and construction preparations, and discusses the construction technology of warm-mix asphalt pavement in cold high-altitude areas in detail, to improve the overall road quality of cold high-altitude areas.

Keywords: Cold high-altitude areas; Warm mix asphalt; Pavement construction technology

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1. Introduction

At present, the expansion of highway construction has reached cold high-altitude areas, infusing new vitality into the development of road networks and economic progress in cold high-altitude areas. Cold high-altitude areas have significant temperature differences between day and night, thin air, low temperature throughout the year, and long duration of low temperature, which requires higher and stricter construction technology. In highway construction, asphalt concrete pavement construction is a typical example. When applying asphalt concrete pavement in regions with both extreme cold and high altitudes, it is necessary to take corresponding measures to ensure the durability of the pavement, thereby effectively prolonging the operational lifespan of the road.

2. Advantages of warm mixing technology

Warm mixing technology is a new technology in which temperature is between regular temperature mixing and hot mixing. In the case of the same raw materials, compared with hot mixing, the temperature change

technology's low temperature and compaction temperature should be lowered by 20°C–50°C. The key to warm mixing technology is to improve the operability of asphalt mixture construction through physical and chemical methods without damaging the normal function of the road. The evaluation of the warm mixing process is mainly based on the following two aspects: (1) there is sufficient operating cooling range; (2) all indicators meet the relevant technical indicators and technical requirements of pavement materials [1].

(1) Achieving manageable pavement quality: Warm mix technology can improve the compressive strength of warm mix asphalt mixture, increase the rolling time of actual construction, and make the compactness of asphalt concrete meet the standard requirements. At the same time, compared with hot mixing, the aging speed of asphalt in the warm mixing process is significantly reduced to extend the road's overall durability.

(2) Regulating construction timelines: In the case of a significant temperature difference between day and night, the application of warm mixing technology can still ensure the mixing and laying of asphalt concrete, resulting in increased asphalt concrete production. The construction time in cold high-altitude areas is extended.

(3) Managing investment wisely: In the case of long-distance transportation, the mixing volume of warm mixing technology is doubled, and the compaction requirements can still be guaranteed. At the same time, due to the lower heating temperature of the aggregate, the mixing output can be increased by about 20%, thereby reducing investment costs.

3. Environmental characteristics of cold high-altitude areas

Due to the harsh climate conditions in cold high-altitude areas, the altitude is high, the air is thin, the sunshine time is long, the radiation is significant, the temperature is relatively low, and the temperature difference between day and night is significant. The rainfall in high-altitude areas is significantly affected by terrain. The rainfall decreases gradually from the edge of high-altitude areas to the depths of high-altitude areas. The rainfall in the central river valleys is abundant. The surface vegetation mainly includes deciduous broad-leaved forests, alpine grasslands, subalpine shrubs, alpine meadows, and tundra. Permafrost is widely distributed in high-altitude and extremely high-altitude areas. Glaciers are in extremely high-altitude areas, and glacier changes are expected. Most lakes in high-altitude areas have high salt content, and there are few freshwater lakes [2].

(1) Significant diurnal temperature range and low annual average temperature: The air in cold high-altitude areas is thin and dry. In a year, the maximum radiation emitted by the sun can reach 190 kcal/km^2, more than twice that of other areas. Cold high-altitude areas receive much sunlight during the day, the surface heats rapidly, and the heat dissipates quickly at night. The lowest temperature in a day can be lower than 0°C, and the highest can reach 30°C. The annual average temperature is low, and the annual change is small. For example, compared with the plains at the same latitude, the average temperature in January and July is 15°C–20°C lower on the Qinghai-Tibet Plateau. Compared with regions at the same latitude, high-cold and high-altitude regions are affected by surface heat, so the climate is the driest and coldest, and the surface wind speed is the largest.

(2) Less affected by human factors: Due to the climate, fewer people are in cold high-altitude areas. For a long time, the impact of human activities on the ecological environment in high-latitude regions has been almost negligible. Especially in the central part of the Qinghai-Tibet Plateau, there are very few human activities, so people's production and life have relatively little interference with the environment in these areas. In addition, restricted by other factors, there are no large-scale human activities in cold high-altitude areas, so the development of cold high-altitude areas is still in its

infancy. The influence of regional ecosystems is increasing.

4. Particularity of pavement construction in cold high-altitude areas

Road surface rolling is challenging to form in cold high-altitude areas. In these areas above 2800 m, due to the influence of the microclimate in mountainous areas, the temperature is low, and the construction period of the hot-mix asphalt concrete pavement is less than two months. It often encounters rain and snow. The interference of weather factors. During this period, the construction work surface under the sun during the day meets the construction requirements. However, it is challenging to meet the requirements of the "Technical Specifications for Asphalt Pavement Construction" at night. Under such a temperature environment, the compaction process of traditional hot-mix asphalt mixture is relatively complicated, quickly leading to huge pores, and seriously affecting road pavement's durability. In addition, due to the long transportation route of mountainous roads, under normal conditions, the temperature of the mixing and discharging material has been dramatically reduced when it is transported to the paving area. During the construction process, the temperature of the asphalt mixture is higher than that of the general area, which leads to the difficulty of roller compaction of asphalt concrete. If, to ensure the on-site temperature of the mixture, a significant increase in the heating temperature of the aggregate and asphalt during mixing will lead to accelerated aging of the asphalt, thereby increasing the risk of road quality control [3].

Cold high-altitude areas have poor temperature conditions as these areas have high latitudes, most are over 2,000 meters high. According to research, the temperature drops significantly with the increase in altitude. According to calculations, the temperature generally drops by 6°C for every increase of 1,000 meters above sea level, and the temperature drops by 1°C for every increase of 150 meters in individual areas. In addition to the low annual average temperature in high-altitude areas, there are also apparent daily temperature changes. Summer is rainy and hail, and winter is dry, cold, and windy, which lasts for a long time.

5. Preparatory work for warm-mix asphalt pavement construction in cold high-altitude areas

The traffic volume in cold high-altitude areas may not be high, but the harsh natural conditions of the plateau, such as intense ultraviolet rays, significant diurnal temperature differences, freeze-thaw cycles, and strong winds on the plateau surface, are likely to aggravate the conventional diseases of the pavement structure. Therefore, it is essential to make reasonable choices regarding pavement materials and to incorporate thoughtful design and construction techniques to mitigate the occurrence of pavement-related problems. During the design stage, it is crucial to consider unfavorable natural conditions, such as hydrogeological and climate factors specific to the project area, along with the known issues related to the previous projects. This allows for the selection of appropriate design criteria that ensure the pavement functions as intended with extended service life.

(1) Basic design: The pavement base layer serves as the primary load-bearing component within the pavement structure and also serves the crucial function of distributing the wheel load pressure from the surface layer to the underlying structure, essentially acting as the "link" between these two layers. The design of the base course takes into account various factors, including the road's intended function, the magnitude of traffic loads it will bear, and the prevailing hydrogeological conditions. It involves a comprehensive assessment that entails comparing successful existing projects and carefully selecting the appropriate elements such as inorganic binder stability, aggregates, asphalt compositions, and cement concrete. Ultimately, the aim is to tailor these choices to suit the unique characteristics of

cold and high-altitude areas while ensuring the complete and reliable performance of the base layer. It is important to note that simply replicating the subgrade design used in lower-altitude areas for cold high-altitude areas can lead to a host of issues, including subsidence, soil instability, reflection cracks, shrinkage cracks, and susceptibility to water damage, particularly in permafrost areas. Thus, a more tailored approach is required to enhance crack resistance and overall durability.

(2) Surface design: The pavement surface directly contacts the wheels and the atmosphere, bears the load of the wheels, and is affected by adverse factors such as rainfall and ultraviolet rays. In addition to considering the conventional bearing capacity and fatigue durability in the design of the surface layer in cold and high-altitude areas, it is necessary to pay attention to the freezing and water stability, low-temperature crack resistance, high-temperature stability, and anti-aging performance of the surface layer, and to control and prevent peeling, cracks, and aging from the design stage. Solving ruts, potholes, and other issues may improve the pavement's service life.

(3) Equipment selection: Low regional temperature, thin air, and low air pressure are the salient features of cold high-altitude areas. Most of the time, advanced construction machinery and equipment are used when constructing asphalt concrete pavements. Under such regional characteristics, higher requirements for construction machinery and equipment are put forward. In terms of mechanical power, in addition to some mechanical parts that can withstand extreme cold, it is also necessary to choose mechanical equipment that uses diesel as power and configure corresponding supercharging equipment. When using a machine with a motor as the main power, it is necessary to choose a device with a higher driving power than ordinary mechanical equipment to ensure the machine's regular operation in cold and high-altitude areas. In addition, during the outdoor construction of asphalt concrete, mechanical equipment such as asphalt pavers, asphalt concrete mixers, and presses will significantly impact the quality of asphalt concrete construction. Therefore, when configuring this mechanical equipment, it must be based on factors such as the particularity of cold high-altitude areas and the differences in the construction sites of the project selected [4].

6. Construction technology of warm-mix asphalt pavement in cold high-altitude areas

6.1. Stirring of the mixture

In the mixing process of asphalt mixture, batch asphalt concrete mixing plants with closed characteristics are usually used and are equipped with devices for detecting mixing temperature and dust. The mixing station should have a laboratory to test its Marshall stability index (see **Table 1**) as well as the mineral-graded components and raw materials. It should be applied reasonably according to the determined ratio during the mixing process. The heating temperature of the asphalt should be between 150°C and 170°C, the temperature of the aggregate should be between 160°C and 180°C, the outlet temperature of the mixture should be between 140°C and 165°C, and the temperature of the aggregate should be between 120°C and 180°C. Due to the low temperature in cold high-altitude areas, the aforementioned temperature control method usually takes the maximum value. After mixing, it is necessary to ensure that the quality of the asphalt mixture is uniform and that the asphalt evenly wraps the aggregate to avoid graying, agglomeration, and separation of coarse and fine materials. The laboratory conducts daily sampling and inspection of the asphalt after mixing. Once any phenomenon that does not meet the requirements is found, it should be discarded immediately.

Table 1. Marshall stability index test of asphalt mixture

Outcome indicators	Theoretical maximum relative density	Gross volume relative density	Stability (kN)	Void ratio (%)	Voids filled with asphalt (VFA) (%)	Flow value 0.1 mm	Voids in mineral aggregate (VMA) (%)
Volume index	2.437	2.303	10.77	5.4	68.7	29	16.2
Skills requirement	-	-	≥ 8	3.0–6.0	65–75	20–40	-

6.2. Paving the mixture

During the paving process, 1–2 heated vibrating leveling equipment can be used to adjust the paving thickness by itself. The lower and middle surfaces can be constructed using a straight-line method. In surface structures, the equalized beam method can be used. Before paving, the paving route should be set, and the paving platform should be supported with longboards equal to the number of paving layers. When using an infrared thermometer, it should be ensured that the temperature of the asphalt mixture is between 110°C and 130°C and must not exceed 165°C. During use, the paving of the paver must be closely controlled to ensure the uniform operation of the paving.

Moreover, in front of the paver, there must be a transport vehicle full of mixed materials to ensure that there will be enough materials during the paving process. The construction unit should designate a person to inspect the paved surface's width, thickness, plane, and temperature. If there is any unqualified situation, it should be pointed out and dealt with in time. Manual methods should be used for construction in areas where the machine cannot be operated [5].

6.3. Mixture rolling

Asphalt pavement rolling is a critical link in the road construction process, and its construction effect is closely related to the quality of the pavement. Regarding machinery, rubber-wheeled and double-steel-wheeled rollers are commonly used [6]. The tonnage of the double-steel-wheel double-vibration road roller used in the road construction specifications for cold high-altitude areas is 12–15 tons, while the tonnage of the rubber-wheeled road roller is 25 tons. The rolling process of asphalt concrete is divided into three stages: initial pressing, re-pressing, and final pressing, and the temperature is controlled correctly.

(1) Initial pressure: Use a wheeled double-shock roadbed, and roll 1 to 2 times at a high temperature above 110°C.

(2) Recompacting: Use the above two types of rollers for recompacting, and repeat rolling 4 to 6 times at 80°C–100°C.

(3) Final pressure: Double-steel wheel rollers are used for final pressure, and the pavement is statically pressed 1–2 times without exceeding 65°C.

When rolling, it should be noted that the order of rolling should be from low to high at a uniform speed, and the width of adjacent superimposed rolling should not exceed 300 mm. Moreover, in the rolling process, it is necessary to ensure that the mixture does not stick to the wheel, and the method of atomization and spraying can be used to solve the problem. In addition, the road roller must run straight without any movement or cracks. Otherwise, it will directly impact the paved road [7]. Meanwhile, it is not allowed to stop the machine on the newly paved road to add water and refuel to avoid pollution to the road. After the roller is finished working, it should be driven away immediately. Since the paved road surface temperature has not dropped below the natural temperature, it is impossible to stop. Plate compactors or small vibratory rollers are used for work for the road sections that cannot be rolled or rolled by the roller.

6.4. Crack treatment

(1) Vertical: Regarding the treatment of longitudinal construction joints, the edges should be trimmed and cleaned before rolling. When rolling, walk on the compacted road surface and carry out 10–15 m of compaction, compact the newly paved part, and extend to the compacted pavement 10–15 cm so that the longitudinal joints can be compacted entirely [8].

(2) Horizontal: In the treatment of transverse cracks, parallel cracks are more common. Lateral rolling is the first step in solving cracking problems. Place the roller on the compacted mix, extending the new course by 15 cm, moving the new mix by 15–20 cm each time it is rolled until it is entirely on the new course.

6.5. Environmental protection

In the construction of highway sections, it is imperative to institute an excellent environmental protection accountability framework and implement practical measures to prevent environmental pollution and harm resulting from waste, refuse, and noise generated throughout the production and construction phases. The construction activities must comply with the pertinent laws and regulations mandated by the National Environmental Protection Department. Measures implemented within the construction site encompass preventing soil erosion and waste management, mitigating water and air pollution, preserving vegetation, and safeguarding land resources. The overarching objective is to minimize any adverse impacts on the surrounding environment during construction operations.

Throughout the construction process, there will be an enhanced focus on environmental awareness among the construction personnel. The workforce will be organized and directed in accordance with specific regulations to ensure adherence to established protocols in all tasks. There will be proactive efforts to promote the realization of "safe and compliant" projects, bolster oversight of engineering endeavors, foster a favorable working environment, and implement a strategic layout for engineering projects [9]. Management of equipment and raw materials will be intensified, with machinery and materials arranged systematically to guarantee the completion of work tasks while minimizing material wastage. Following the construction phase, collaboration will be fostered with local government bodies and the general public to facilitate the restoration of cultivated land. Disposal of raw materials and soil from the asphalt mixture will be conducted in a responsible manner, ensuring their transport to designated disposal sites.

7. Conclusion

In summary, various industries in China are developing rapidly, and great progress has been made in road construction in cold high-altitude areas. Warm-mix asphalt technology is a new eco-friendly and environmentally friendly construction technology and a key technology in road construction. Therefore, this paper studies the advantages of warm mixing technology, the environmental characteristics of cold high-altitude areas, and the particularity of pavement construction in cold high-altitude areas. At the same time, it also discusses the application of this technology, hoping to promote the development of this technology as well as provide safe and reliable guarantees for road construction.

Disclosure statement

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Assessment of the Safety Impacts of a Pit Construction on the Neighboring Subway

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Abstract: In order to study the impact of pit excavation on the adjacent existing subway structure, the safety impact assessment of a project was carried out using project under construction near the subway as the engineering background. The results show that the new pit construction will produce some additional deformation on the existing subway interval structure, the deformation values are within the permissible range for safe operation. Through analysis of the results, the risk point rating of the pit adjacent to the interval is level 2. In general, the impacts of the pit construction on the neighboring subway structure are less than the specification limits.

Keywords: Pit excavation; Safety assessment; Adjacent to existing subway

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1. Introduction

As China's urbanization progresses, the allocation of construction land resources is becoming increasingly tight, which makes the cases of construction of adjacent subway increase. No matter what kind of support method is adopted for the foundation pit construction, the construction process will cause disturbance to the surrounding strata, affecting the stress state of the neighboring subway tunnels, and its displacement, deformation, and local stress concentration. If the impact is large, it will lead to the destruction of the subway tunnel structure, thus affecting the normal operation of the subway. Therefore, it is particularly important to study and evaluate the safety impact of the pit before construction.

Regarding the research on pit construction adjacent to subways, Chinese and foreign scholars generally use theoretical calculations, on-site measurements, model tests, and numerical simulations to carry out research. Among them, Li *et al.* [1] summarized the key points to focus on the pit construction adjacent to the subway by using the method of numerical simulation combined with the actual project. Zeng *et al.* [2] analyzed the impact of different factors on the deformation of the operating station during pit excavation through numerical simulation. In order to solve the impact of pit excavation in loess areas on the operation of the adjacent subway, and to study the mechanism of the interaction between the pit project and the subway tunnel, Wang *et al.* [3] used indoor model test to analyze the force and deformation law of the impact of pit excavation on

the existing tunnel. Guo *et al.* [4] combined engineering examples, established elastic-plastic-enclosure finite element calculation model, analyzed the deformation of the tunnel between the neighboring shield interval and the change of tunnel internal force in the two pit schemes, and then came up with the relevant conclusions. It is concluded that the excavation and unloading of the foundation pit will disturb the surrounding geotechnical body, which will adversely affect the adjacent existing subway tunnel. For tunnels located in the outside of the pit and below the two directions, Liu *et al.* [5] carried out the relevant research on the existing tunnel impact mechanism, pit excavation caused by tunnel deformation of the impact zone, tunnel deformation prediction method by pit excavation and pit excavation on the tunnel impact control methods. Liu *et al.* [6] analyzed the relevant data in the construction process through actual engineering cases, and then summarized the disturbing influence characteristics of deep foundation pit construction under pile-anchor support and the deformation characteristics of the tunnel section, which provides guideline for similar projects. In addition to this, the research on the influence of deep foundation pit excavation on the adjacent existing subway tunnels has a certain guiding role in the actual project [7-12].

2. Overview of the project

There are 13 blocks of residential buildings, office buildings, hotels, commercial buildings, and ancillary structures to be constructed, with 2–14 floors above ground, 2 floors of basement, height above ground ranging from 11.4–41.8m, with foundation in the form of independent foundation, pile foundation, and raft slab foundation, and the superstructure in the form of concrete frame structure and shear wall structure. Typical sectional relationship is shown in **Figure 1**.

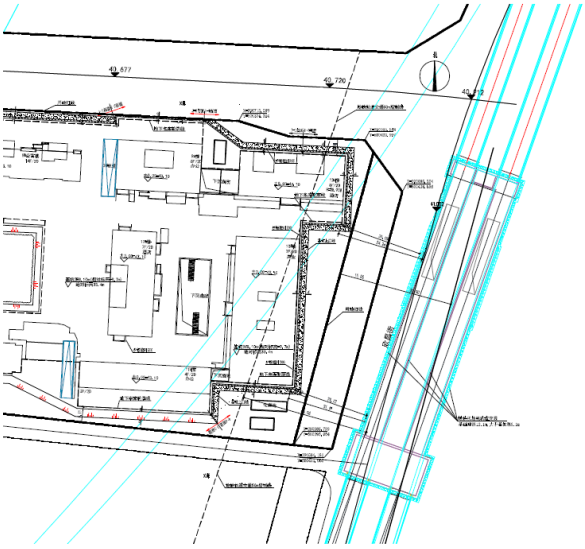


Figure 1. Typical sectional relationship diagram

The proposed pit depth is 8.75m, the pit support near the subway side uses the pile-anchor support, the nearest distance of pit enclosure piles from the subway structure is 29m. The distance of anchor cable from the nearest subway is 16.1m, which is smaller than the subway protection zone, thus the building pit design and construction need to solve the problem of reducing the impact on the subway.

3. Engineering geology

According to the geotechnical investigation report, the project site is top to bottom:

(1) Artificial fill:

Layer 1: Plain silty fill, mainly clayey silt, partly containing a small amount of brick slag and gravel, the top plate elevation is 38.83–42.06m, the depth of the bottom of the layer is 1.00–4.10m, the thickness of the layer is 0.40–3.40m, and the average thickness of the layer is 1.74m. Most of the sites are distributed.

Layer 2: miscellaneous fill, mainly construction waste, and composed of brick slag, crushed stone, and a small amount of concrete block, with a small amount of pulverized soil, the elevation of the top plate is 39.36–42.33m, the depth of the bottom of the layer is 0.50–4.00m, the thickness of the layer is 0.50–4.00m, and the average thickness of the layer is 1.55m. It is partly missing.

(2) Recently deposited soil (Q4al+pl):

Layer 3: clayey silt, locally silty clay and sandy silt thin interlayer, the top plate elevation is 32.85–40.56m, the bottom depth of the layer is 3.00–12.10m, the thickness of the layer is 0.50–8.60m, and the average thickness of the layer is 3.03m. Most of the site is distributed.

(3) General Quaternary alluvial-diluvial layers (Q4al+pl):

Layer 4: fine sand, top plate elevation is 30.53–35.95m, layer bottom depth is 8.60–13.70m, layer thickness is 0.40–7.60m, average layer thickness is 3.18m. It is distributed in the whole site, and there are chalk and medium sand in some sections.

Layer 5: silty clay containing ginger stone, ginger stone content accounts for about 10%, ginger stone grain size is 1–3mm, mainly calcium, partly containing clayey powdery clay thin interlayer, the top plate elevation is 28.46–33.28m, the bottom depth of the layer is 11.70–14.90m, the thickness of the layer is 0.80–5.90m, the average thickness of the layer is 2.25m. It is distributed throughout the whole site.

Layer 6: rounded gravel, gravel content of about 60%, particle size is 5–20mm, maximum particle size is 50mm, subrounded, parent rock composition is mainly sandstone, medium and coarse sand filling, top plate elevation is 22.16–29.78m, layer depth is 16.00–23.80m, layer thickness is 1.70–10.00m, average layer thickness is 6.99m. Most of the site is distributed.

Layer 7: pebbles, pebble content of about 60%, grain size is 30–60mm, maximum grain size is 100mm, subrounded, parent rock composition is mainly sandstone, medium and coarse sand filling, the top plate elevation is 17.38–27.16m, the layer has not been uncovered, uncovered layer thickness of 0.70–10.20m, the average thickness of the layer is 4.66m. Most of the site is distributed.

4. Content and methodology of the security assessment

The assessment was carried out using finite element numerical simulation to analyze the impact of different excavation conditions on the existing subway by modeling the actual project, and then carry out the safety assessment of the project.

4.1. Assessment contents

The assessment contents are as follows.

(1) Establishing a two-dimensional cross-section calculation model to simulate the construction process of the new project and provide the deformation analysis results of the existing subway interval structure.

(2) According to the calculation results, analyzing the impact of the construction of the new project on the

safety of the existing subway interval structure and track structure.

(3) Suggesting the construction sequence, technology, and protection measures of the new project, and providing the control indexes of the deformation of the existing subway interval structure and track structure during the construction stage.

4.2. Assessment concept

The focus of this project is the assessment of the impact on the safety of the interval structure and track structure of the existing Metro New Airport Line during the construction of the new project. Mainly through the collection, collation, and analysis of various geological, design, and status quo investigation and testing data, and the use of numerical analysis, engineering analogy, and expert review and other methods, the deformation caused by the construction of the existing Metro New Airport Line interval structure and track structure is predicted, and on the basis of which it is evaluated whether the interval structure of the existing Metro New Airport Line is safe, and whether the track meets the operational requirements.

4.3. Assessment methods

Mechanical models used for theoretical calculation of underground structures can be summarized into two kinds. The first is continuous medium model, i.e. stratum-structure model, and the second is action-reaction model, i.e. load-structure model. These two mechanical models have their own characteristics, the stratum-structure model is mostly used for structural deformation analysis due to the consideration of the joint action of the stratum and the structure, while the load-structure model only takes the structure as the object of computation, and is mostly used for the analysis of the internal force and deformation of the structure. Specifically for this project, considering that the structural settlement of the subway line caused by construction is closely related to the stratum, the stratum-structure model is used for deformation analysis. At present, the large-scale calculation software that can be used for stratum-structure model analysis include ANSYS, Midas, Flac, and so on. Midas GTS-NX software is used in this calculation to simulate the impact of the construction process of the new project on the safety of the interval structure and track of the existing Metro New Airport Line, to provide the results of the deformation analysis of the existing structure, to assess the safety of the interval structure and the track structure of the existing Metro New Airport Line, and to propose the deformation control of the interval structure and the track structure of the existing Metro New Airport Line during the construction of the new project by synthesizing the various influencing factors in accordance with the requirements of traffic safety. The deformation control standards and protection measures for the existing Metro New Airport Line interval structure and track structure during the construction of new projects are proposed according to the requirements of traffic safety by combining various influencing factors.

4.4. Calculation assumptions

The assumptions are as follows.

(1) The existing subway structure during the construction of the new project only considers the normal use of the working conditions, it does not consider the earthquake, human defense conditions.

(2) It is assumed that the material of the existing project is linear elastic material.

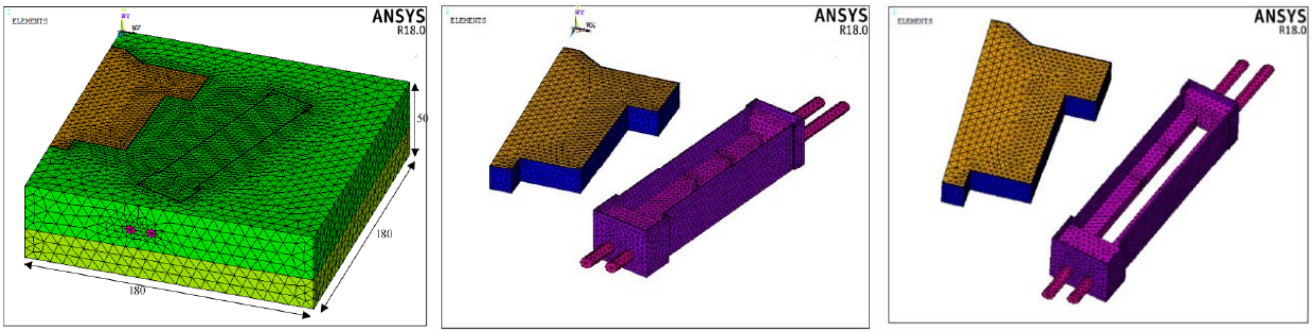
(3) It is assumed that the deformation coordination principle is met between the new construction, the structure of the interval of the existing subway New Airport Line, and the soil body.

(4) The premise of this assessment and analysis is that the construction is under normal and well-controlled conditions.

5. Security assessment

5.1. Calculation model and parameters

The calculated parameters are shown in **Table 1**. Considering the spatial effect in the construction process, the calculation model takes the effective influence range of new construction and existing construction, and in this assessment, the scope of investigation includes the range of 180m longitudinally along the existing subway line, 180m horizontally, and 50m soil thickness. The focus is on the deformation and force generated by the existing structure due to the construction. The calculation model is shown in **Figure 2**.



(a) (b) (c)

Figure 2. Computational model: (a) Assessment overall model diagram (b) Assessment location relationship diagram (c) Assessment location relationship diagram

Table 1. Calculated parameter list

No.	Name	Density (kN/m^3)	Angle of internal friction (°)	Cohesion (kPa)	Poisson's ratio (v)	Modulus of elasticity (MPa)
1	Miscellaneous fill	18.0	15	10	0.3	12.0
2	Powdery clay	19.3	20	20	0.3	15.0
3	Clayey silt	19.2	20	20	0.3	30.0
4	Fine sand	19.5	25	-	0.3	50.0
5	Powdery clay	19.3	15	25	0.3	40.0
6	Gravel	20.0	30	-	0.3	150.0
7	Cut-and-cover interval (C40)	2.5	-	-	0.2	3.25e4
8	Shield interval (C50)	2.5	-	-	0.2	3.45e4

5.2. Simulation process

The new construction is open-digging foundation pit, according to the construction process of the new construction, the main stages of construction simulation are as follows.

(1) The first stage: completing the new perimeter piles, and carrying out the construction of the first anchor cable

(2) The second stage: excavating the first layer of soil, and carrying out the construction of the second anchor cable

(3) The third stage: excavating to the bottom slab

(4) The fourth stage: applying construction loads

5.3. Deformation prediction

The construction process of the new foundation pit produces a certain degree of additional deformation on the interval structure and ground surface of the existing Metro New Airport Line, in order to effectively understand this additional deformation, the lateral deformation and vertical deformation of the interval structure will be analyzed under each process. In order to reflect the deformation and the law of the existing structure, the deformation cloud map of the existing structure at each stage will be extracted after the construction is completed, and the deformation results and the law of the existing structure will be analyzed. It is known from the model calculation results that the vertical deformation of subway interval structure is uplift deformation, and the deformation part is in the neighboring subway side wall. The lateral deformation is biased to the excavation side of the foundation pit, and the deformation part is in the neighboring subway side top plate.

Evaluation of track safety of five existing subway new airport line is as follows. According to the three-dimensional finite element analysis calculation, the following track structure deformation conclusions are drawn. The impact of the new construction on the track structure of the interval of the existing Metro New Airport Line is relatively small, and the maximum lateral deformation of the track structure of the interval of the existing Metro New Airport Line is about 0.24mm, and the maximum vertical deformation of the track structure of the interval is about 0.41mm.

Evaluation conclusion is as follows:

(1) Through the establishment of a three-dimensional stratum-structure model and the deformation calculation, and analysis of the existing new airport interval structure and track structure, it can be seen that due to the construction of the new project, a certain degree of vertical deformation and lateral deformation has been generated in the existing structure.

(2) Based on the analysis of numerical simulation results, the new pit construction will produce certain additional deformation of the subway interval, and the deformation value is within the permissible range of operational safety.

(3) The impact of this project on the track is small, the deformation value is within the permissible range, and the status quo track condition meets the requirements of relevant standards.

Disclosure statement

The author declares no conflict of interest.

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Research on Weighing System and Debugging Technology for Batching Under Blast Furnace Ore Tank

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Abstract: The article introduces the composition and working principle of the batching and weighing system underneath the blast furnace hearth. Besides, the shortcomings of the batching and weighing system during installation, debugging, and calibration, as well as the dynamic errors in the batching process are also analyzed. Corresponding solutions are then provided.

Keywords: Blast furnace hearth; Hopper scale; Calibration; Error correction

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1. Introduction

Material charging is one of the primary process systems of blast furnaces [1]. The weighing and control of the batching of various ores, coke, and other raw materials are crucial aspects in ironmaking. The rapid and accurate batching process has an essential impact on the efficiency and quality of blast furnace ironmaking.

In specific situations, a static batching method, such as employing a hopper scale, can be utilized [2]. In ironworks, the blast furnace batching system incorporates electronic hopper scales. Given that the feeding quantity directly impacts economic metrics, like the coke ratio and the smoothness of furnace operations, it plays a crucial role in cost reduction, energy savings, and minimizing energy consumption [3]. The weighing system under the blast furnace hearth is used to weigh the ore, raw materials, etc. Calibration is a critical step during the installation, commissioning, and usage of electronic scales, as it directly determines their accuracy. The traditional method of calibration is to use standard weights. However, this method is labor-intensive and inefficient. The accuracy of the measurement highly depends on the position of the weights. Improper placement of weights will lead to uneven load distribution and significant eccentric loads, can result in calibration failure and potential damage to load cells. It may even pose a safety hazard by causing collapses that could harm individuals..

The weighbridge scale weighing system for the ore bin is the main equipment for weighing materials

below the blast furnace hearth. It is the core hardware that ensures accurate material distribution below the hearth. In the process of weighing and controlling the material supply below the blast furnace hearth, dynamic weighing error compensation has always been a major research topic in the direction of automation control of the blast furnace hearth material charging system.

In this case, ensuring both the construction progress and quality, as well as the safe installation, commissioning, and operation of weighing systems, is essential. Addressing dynamic control and compensation during material batching under the blast furnace hearth to eliminate dynamic errors is a critical challenge that needs immediate attention during on-site construction and commissioning.

2. Brief introduction of the batching system under the blast furnace tank

In the ironmaking process, solid raw materials such as iron ore, coke, and flux must be weighed and batched according to the process batching ratio of smelted products. The materials are then discharged batch by batch and finally sent into the blast furnace through the charging device at the top of the furnace for smelting.

A 1080 m^3 blast furnace of a steel plant will be used as an example. The blast furnace ore bins are arranged in a single row, with decentralized weighing, and materials are loaded onto the double cart inclined bridge. There are a total of 6 sinter ore bins, 2 pellet ore bins, 4 lump and miscellaneous ore bins, 2 coke bins, and 1 return ore bin, along with 2 coke nut bins and 2 coke powder bins in the storage area. The arrangement of the ore and coke bins, as well as the coke nut and coke powder bins, is symmetrically positioned to the left and right of the blast furnace. There are a total of 18 weighing hoppers, including 12 weighing hoppers under the ore bins, 2 concentrated weighing hoppers for ore and 2 concentrated weighing hoppers for coke in the material pits, and 2 weighing hoppers for coke nuts. There are 12 weighing hoppers under the mine trough, divided into left and right sides, and each side corresponds to a pit or centralized weighing hoppers. The primary function of the 12 ore weighing hoppers is to weigh the corresponding minerals according to the requirements and, simultaneously, discharge materials to the pit ore centralized weigh hopper according to a specific sequence. The 2 feed pit ore centralized weighing hoppers are used to weigh the total ore then send it to the top of the furnace through the feeding trolley. 2 pit coke weighing hoppers are used to weigh the coke. The coke is collected in the ore-weighing hopper in the pit and then sent to the top of the furnace by a feeding trolley.

The ore bin system has a total of 18 weighing hoppers, each supported by three resistance strain gauge-type load cells. They are equipped with compensation junction boxes to compensate for zero drift, temperature drift, and offset load of the load cells. The corresponding weight indicators are installed on the control room instrument panel, where they receive the direct current millivolt voltage signals (SIG+/SIG-) and convert them into standard current signals sent to programmable logic controller. The number and parameters of the weighing points are shown in **Table 1**.

3. Hopper scale weighing system

3.1. Working principle of hopper scale weighing system

The hopper scale comprises a weighing hopper, a load cell, a weighing junction box, and a weighing indicator (**Figure 1**).

The weighing hopper is designed to contain and convey the entire weight of the material being weighed onto multiple weighing sensors located between the weighing hopper and the foundation. When subjected to force, the elastic body inside the sensors undergoes deformation, causing a change in the resistance value of the internal strain gauges. Under the influence of the excitation voltage (EXC+/EXC-), this results in the generation

Table 1. The number and parameters of the weighing points

Location code	Weighing bucket name	Weighing range (*t*)
WE1101	Left coke nut weighing hopper	0–2
WE1102	1# Lump and miscellaneous ore weighing hopper	0–3
WE1103	2# Lump and miscellaneous ore weighing hopper	0–3
WE1104	3# Pellet weighing bucket	0–7
WE1105	4# Sintered ore weighing hopper	0–15
WE1106	5# Sintered ore weighing hopper	0–15
WE1107	6# Sintered ore weighing hopper	0–15
WE1108	Left pit ore weighing hopper	0–20
WE1109	Left pit coke weighing hopper	0–10
WE1110	Right coke nut weighing hopper	0–2
WE1111	7# Sintered ore weighing hopper	0–15
WE1112	8# Sintered ore weighing hopper	0–15
WE1113	9# Sintered ore weighing hopper	0–15
WE1114	10# Pellet weighing hopper	0–7
WE1115	11# Lump and miscellaneous ore weighing hopper	0–3
WE1116	12# Lump and miscellaneous ore weighing hopper	0–3
WE1117	Right pit coke weighing hopper	0–10
WE1118	Right pit ore weighing hopper	0–20

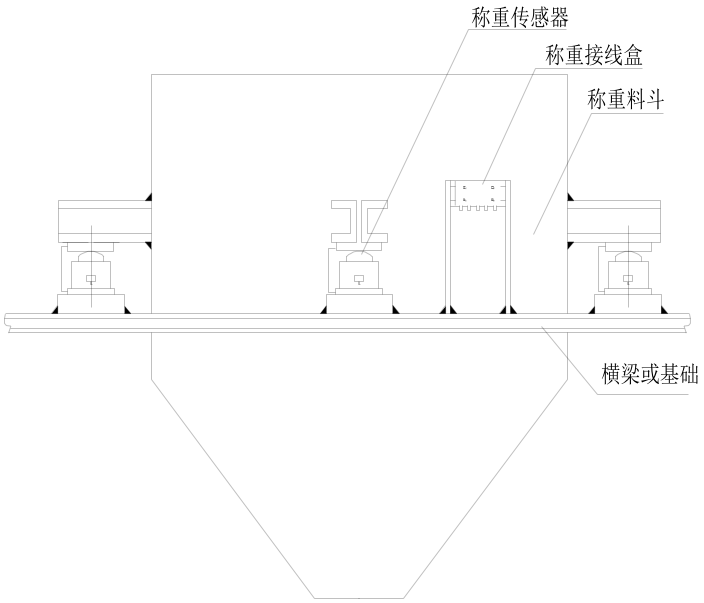


Figure 1. Schematic diagram hopper scale installation. Translation (from top to bottom): load cell, weighing junction box, weighing hopper, beam or base

W_x

of a direct current millivolt voltage signal (SIG+/SIG-) that is directly proportional to the weight of the material being weighed.

This voltage signal is then transmitted via shielded cables through the weighing junction box to the corresponding weighing display instrument or weighing module. Within the weighing display instrument or weighing module, the voltage signal is further amplified and converted by internal circuits into the corresponding weight display value. Simultaneously, the weighing display instrument outputs a 4-20mA standard current signal corresponding to the displayed value, which is sent to the PLC or other control units for automatic control of the weighing system. The wiring schematic diagram is illustrated in **Figure 2**.

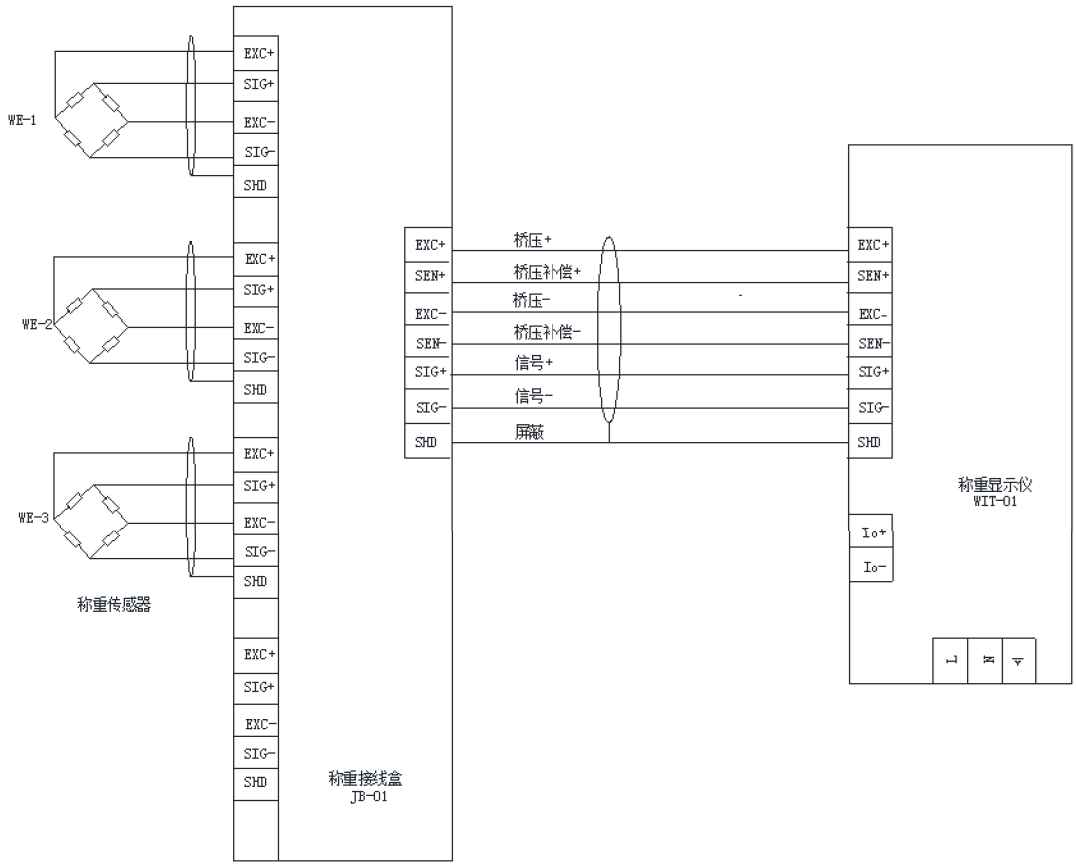


Figure 2. Hopper scale wiring scheme. Translation (from left to right, from top to bottom): weighing junction box JB-01, bridge voltage+, bridge voltage compensation+, bridge voltage-, bridge voltage compensation-, signal+, signal-, shielding, weighing indicator WIT-01

3.2. Static calibration of hopper scale weighing system

3.2.1. The working principle of the calibration device

During construction, the use of weighing hopper calibration devices with hopper-level detection instead of weights for calibrating the weighing hoppers ensures accurate measurement across the entire range of the hoppers. It not only guarantees precise weighing but also relieves employees from heavy labor, thereby improving work efficiency and reducing costs. The structure of the calibrating device is shown in **Figure 3**. Among these, the gantry frame is securely connected to the support beams or the foundation through welding or bolts. A hydraulic jack is installed vertically at the lower end of the central position of the horizontal beam of the gantry frame. The hydraulic jack is positioned vertically on top of the standard load cell used for calibration. Below the standard load cells for calibration is the pressure platform, and some padding is placed between the

gantry frame and the hydraulic jack.

The structure of a magnetic level gauge is shown in **Figure 4**. Each magnetic level gauge is connected to each other through connecting hoses, forming a closed series of level gauges. The pressure platforms are individually positioned on the outer sides of the hopper's various sides, with each bracket arm extending outward horizontally toward the respective sides. The weight display instrument is configured with each standard weight transducer and is located at an area that is convenient for observing the results. The number

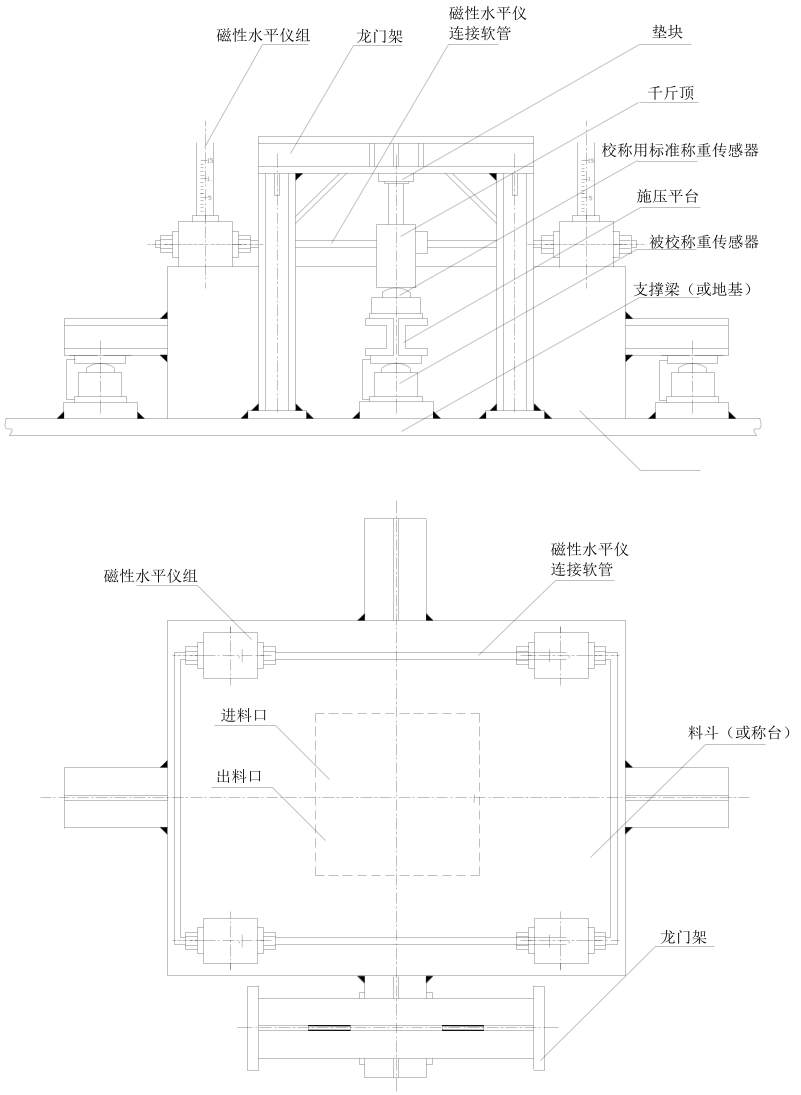


Figure 3. Structure of hopper scale calibrating device with hopper/silo level detection. Translation (from left to right, from top to bottom): magnetic level gauge assembly, gantry, connecting tube for magnetic level gauge, padding, hydraulic jack, standard load cells for calibration, pressure platform, calibrated load cells, supporting beam (or base); magnetic level, connecting tube for magnetic level, material inlet, material outlet, hopper (or weighing platform), gantry

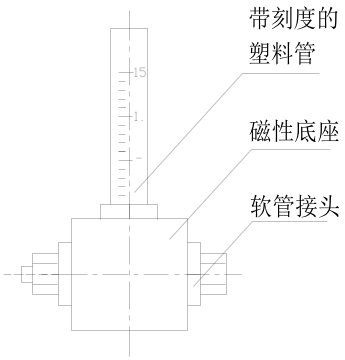


Figure 4. Structure of magnetic level gauge. Translation (from top to bottom): graduated plastic tube, magnetic base, hose connector

of sets of the calibration device corresponds to the number of weight transducers to be calibrated in the on-site hopper scale design. In **Figure 3**, only one set of devices is used as an example for illustration.

Before calibrating the electronic scale, the magnetic level gauge assembly, consisting of four magnetic level gauges, is positioned on the weighing hopper's horizontal plane so that it is evenly distributed at the corners. Water is then injected into the magnetic level gauge assembly via a scaled plastic tube using a funnel and a medical syringe. The hopper's levelness is assessed by monitoring real-time water level readings in each gauge. If any unevenness is detected, adjustments are made until the hopper is level. Next, the magnetic level gauges are removed from the weighing hopper, and zero-point calibration is conducted on the electronic scale. Then, the magnetic level gauges are placed back on the hopper's horizontal plane or evenly attached to the side of the metal weighing hopper at the same horizontal height to allow real-time observation during the loading process. The loading calibration can then be carried out.

During the loading process, the jack exerts upward force on the gantry, and the gantry forms the downward reaction force. The standard electronic scale composed of indicators can accurately display the pressure exerted by each jack and the total force exerted by all jacks. The setting of parameters setting of the central control unit can be performed by pressing specific buttons on the operation panel of the weighing indicator. The measured value of a particular sensor input channel will be displayed on a screen. The sum of the measured values of all sensor input channels will also be displayed. the number of standard load cells required is determined based on the actual number of load cells installed in the weighing hopper. These standard load cells are then connected to the respective sensor input channels on the weight indicator. The calibration device then converts the standard weights required for electronic scale calibration into conveniently applied standard mechanical forces. It accurately measures and serves as the standard load in place of weights, achieving the calibration of the weighing hopper. Additionally, by using four magnetic level gauges evenly positioned at the four corners of the hopper's horizontal plane, the horizontal alignment of the weighing hopper is continuously monitored in real time, preventing any occurrence of platform misalignment.

3.2.2. Individual calibration of load cells and weight indicators

Before installing the load cells and weighing display instruments, relevant inspections and calibration should be performed to determine their quality and accuracy. This is to prevent any delays in system commissioning. The key operational points for conducting the relevant inspections and calibration are as follows:

(1) Visual inspection

The appearance of the load cell to be calibrated and the weighing indicator is carefully observed. If the equipment is found to be damaged or deformed, it must not be used.

(2) Insulation resistance test

(i) The insulation testing is performed using the MΩ setting of a standard precision digital multimeter to check the insulation between the bridge supply voltage line (EXC+/EXC-) and the signal line (SIG+/SIG-) of both the load cell and the weighing indicator, as well as between the bridge supply voltage line (EXC+/EXC-) and the shielded wire (SHD), and, finally, between the signal wire (SIG+/SIG-) and the shielded wire (SHD).

(ii) The insulation status between the excitation voltage terminals (EXC+/EXC-) and the power supply terminals L/N, between the signal line terminals (SIG+/SIG-) and the power supply terminals L/N, as well as between the power supply terminals L/N and the grounding terminal of the weighing indicator should be checked using the MΩ range of a standard precision digital multimeter.

(iii) The resistance values between the load cell and the bridge supply voltage lines (EXC+ and EXC-) of the weighing indicator, as well as between the signal lines (SIG+ and SIG-), should be measured using the Ω file of a standard precision digital multimeter. These measured values should then be compared with the parameters provided in the product manual and technical data for verification.

(3) Individual adjustment of the weighing indicator

(i) After short-circuiting the EXC+ and SEN+ terminals, as well as the EXC- and SEN- terminals on the weighing indicator, the power cord should be connected to the weighing indicator according to the required working voltage (220VAC or 24VDC).

(ii) The weighing indicator is connected to a power supply, and a standard precision digital multimeter is used to measure the direct current voltage between the excitation voltage terminals (EXC+/EXC-) of the weighing display instrument. The accuracy and stability of the excitation voltage of the weighing indicator should be verified, ensuring it aligns with the technical parameters specified in the product's user manual.

(iii) The relevant parameters should be set according to the design process requirements, in conjunction with the operational steps outlined in the product manual of the weighing indicator, such as the instrument station number, measurement unit, and measurement range. During instrument calibration, preference should be given to the measuring range of a single load cell. Once instrument calibration is completed, the measuring range should be adjusted back to the required range as per the instrument design. For instance, if the weighing indicator provides a bridge supply voltage of 10VDC, and four 0–5t load cells are connected with a sensitivity of 2 ± 0.002mV/V and a corresponding output of 4–20mADC, the initial step in instrument calibration involves setting the weighing indicator's range to 0–5t (corresponding to a DC millivolt signal input of 0–20mV) and an output of 4–20mADC. Once all connected multi-channel load cells have been verified, the weighing indicator's range can be adjusted to 010t, with an output of 420mADC.

(iv) Using a high-precision standard signal generator, step 3 is taken as an example: DC signals of 0mV, 5mV, 10mV, 15mV, and 20mV are input. The corresponding display on the weighing indicator is 0t, 1.25t, 2.5t, 3.75t, and 5t, with the current output signal of the weighing indicator corresponding to 4mADC, 8mADC, 12mADC, 16mADC, and 20mADC. If the measured value or output signal exceeds the required accuracy range of the device or design, it should be adjusted according to the steps outlined in the product manual of the weighing indicator, and the calibration data should be recorded.

(v) The power supply is disconnected, and referring to Figure 3, a single load cell is connected directly to the corresponding terminal of the weighing indicator in preparation for load verification.

(4) Loading verification of weighing indicator and single-connected load cell

(i) A standard electronic scale, consisting of regularly calibrated high-precision load cells and corresponding weighing indicators (with an accuracy level one level higher than that required by the design of the electronic scale to be calibrated), is used. It is positioned using a gantry and jacks. Pressure tests are performed on the load cell to be calibrated (accounting for the weight of the load cell and the jack), and calibration is carried out at 25%, 50%, 75%, and 100% of the load cell's capacity. Each step (pressurization and depressurization) is executed at least twice, and

adjustment records are simultaneously created during the calibration process. These adjustment records will be provided to the owner as part of the handover documentation.

(ii) The weighing indicator that has passed the calibration are labeled and the connected multi-channel load cells and mark the corresponding station number for easy installation [4-9].

4. Dynamic control in the batching process

4.1. Basic principle of ingredient weighing

The materials should be weighed within a specified time to ensure its accuracy. The process of weighing materials is an accumulation of material weight. If the quantity of already weighed material is denoted as W, the feeding rate as V, and the feeding time as T, the following relationships can be established

$$W = \int_0^T V dt \quad \cdots\cdots(1)$$

$$V = W' \quad \cdots\cdots(2)$$

Assuming that the set weight for the material is W_s, the difference from the set value is denoted as W_x. Initially, the material is fed at a speed of V_0. When the material weight reaches W_s–W_x, the time taken is denoted as t_l. Subsequently, the weighing speed V starts to decrease, and with the increase in the cumulative weight W, the weighing speed V gradually reduces until it approaches zero.

$$V = \frac{W_S - W}{n} \quad \cdots\cdots(3)$$

n is the rate of decrease in speed. That is to say, the feeding speed V is segmented according to the weighing weight, which can be represented by the equation below.

$$V = \begin{cases} V_0\,(\text{constant}) & W < W_S - W_X \\ \dfrac{W_S - W}{n} & W \geq W_S - W_X \end{cases} \quad \cdots\cdots(4)$$

When the cumulative descent of the material, denoted as W, has not reached W_s–W_x, the velocity control operates as a constant value adjustment system. However, when the cumulative material weight exceeds W_s–W_x, the velocity control switches to a dynamic adjustment system. While constant value adjustment is relatively straightforward, more emphasis is placed on the variable speed aspect. These relationships can be represented by equations (5)–(7).

$$W' + \frac{W}{n} = \frac{W_S}{n} \quad \cdots\cdots(5)$$

$$W = W_S - W_X e^{-\frac{t - t_1}{n}} \quad \cdots\cdots(6)$$

$$V = W' = \frac{W_X}{n} e^{-\frac{t - t_1}{n}} \quad \cdots\cdots(7)$$

According to formulas (6) and (7), the relationship curves of the cumulative amount (W) of the weighing material, the feeding speed (V), and the feeding time (t) can be drawn.

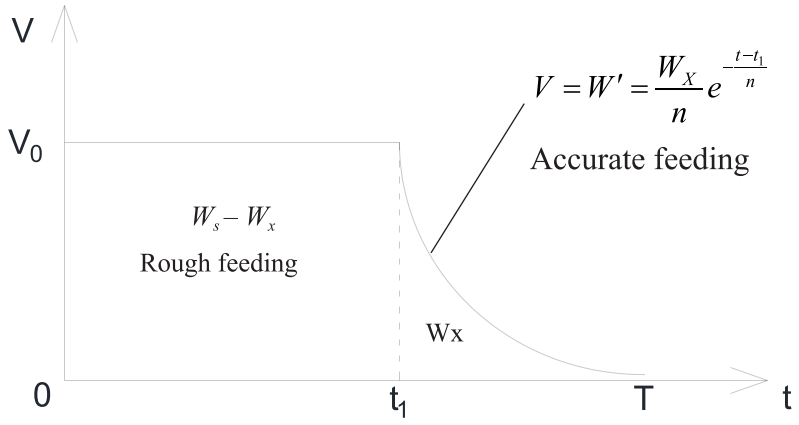


Figure 5. The relationship curve of the cumulative amount W of the weighing material, the feeding speed V, and the weighing time *t*.

It can be seen from **Figure 5** that the weighing speed (V) is continuously changing between 0 and $V_{0,}$ and W_x, and n are selected according to the characteristics of the weighing material. Proper selection of W_x and n can ensure the weighing speed. V depends on the weighing accuracy. However, it is important a suitable accuracy for weighing, or else and the weighing time will be prolonged, making batching process less efficient [10].

4.2. Dynamic error analysis of the batching process

The static error within the weighing hopper can be addressed in two ways. Firstly, by employing high-precision load cells and weighing indicators, so that the system's accuracy can surpass the precision required by the process batching, ensuring reliability. Secondly, periodic static calibration of the weighing system is conducted to ensure that its static error falls within the accepted range specified manual. However, during the material feeding process, factors such as the inertia of feeding devices and the material lag formed due to the height difference between the storage bin and the weighing hopper contribute to a delay in material discharge after the feeding machine is shut down. As a result, a portion of material continues to fall into the weighing hoppers, causing a discrepancy between the actual value and the instantaneous weighing value, as depicted in **Figure 6**.

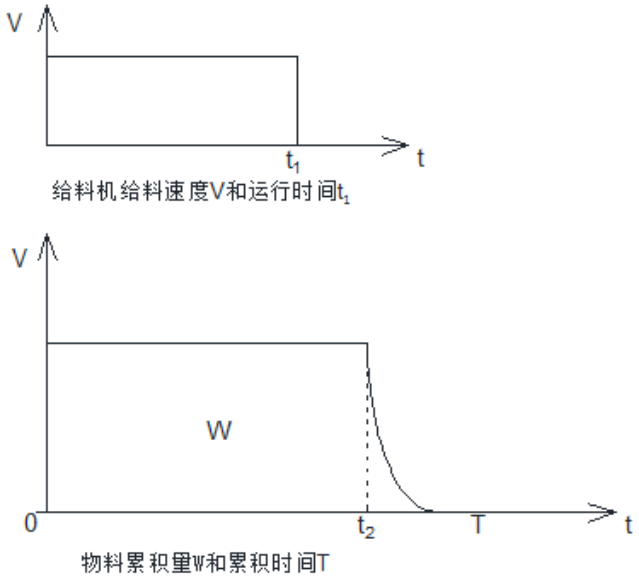


Figure 6. The relationship curve of cumulative weight (W), feeding speed (V), and weighing time (t). Translation (from top to bottom): feeding speed (V), and the running time (t_1) of the feeder, cumulative weight of material (W), and total weighing time (T).

Moreover, during the unloading process, there tend to be residual material due to the conical structure at the lower part of the hopper and variations in the size and moisture content of the material particles. These factors can lead to errors that accumulate over time, impacting the quality of ironmaking products and resulting in energy wastage if not dynamically controlled promptly. Therefore, before weighing the coke and the 12 ore weighing hoppers, it is essential to perform a series of calculations and corrections based on the set value (theoretical value determined according to the smelting process, known as the "dry value"). These corrections include moisture correction procedures (conducted using a neutron moisture meter), feeding error corrections, discharge error corrections, and more, all aimed at determining the actual weight accurately.

4.3 Dynamic error correction in the batching process

4.3.1. Feeding error correction

(1) Material preparation weight $W_{material\ preparation}$

Before weighing the hopper to prepare materials, firstly, according to the theoretical value W_{theory} of the ore required for the smelting process, and then combined with the weight that needs to be compensated for the previous weighing error, calculate the material preparation value W for this time.

$$W_{material\ preparation} = W_{theory} - \Delta W_{final} \quad (8)$$

(2) Advance control of actual blanking value ($W_{material\ preparation}$)

After the feeding device, vibrating screen, and other components come to a halt, the mechanical inertia and the discharge hysteresis due to the height differential between the storage silo and the weighing hopper lead to a lag in the measurement value of the mine hopper scale's weighing system. This lag can result in the actual discharge value exceeding the predetermined $W_{material\ preparation}$. To mitigate this situation, when the real-time measurement value from the hopper scale's weighing system reaches $W_{control}$, the PLC sends a shutdown control signal to the feeding device in advance, so that the final weight of the blanking is within this time. within the allowable error range of the secondary material preparation value.

$$W_{control} = W_{material\ preparation} - W_{material\ preparation} \times (10\%–15\%) + W_{last\ remaining\ material} \quad (9)$$

4.3.2. Compensation calculation of nesting error

When the material preparation is completed, the final weight W_{final} (the value corresponding to the hopper scale) can be obtained. Then, discharge rate will be automatically adjusted, and the weighing signal of the weighing hopper is monitored. When it detects that the discharge rate falls below a certain set value and the weight in the weighing hopper is low, it indicates the end of the discharge process and sends a signal to the electrical department to initiate the closing of the gate. After the gate is closed, the value of the empty hopper, that is, the weight of residual material, $W_{residue}$ (inevitably remaining in the hopper due to its conical structure, particle size, moisture, and other factors), is used for the weight correction (the principle of weighing correction is that the weighing error of this particular weighing hopper is compensated by this hopper and is not related to other hoppers). If the discharge rate is lower than a specific set value, but there is still a lot of material left in the weighing hopper, a discharge failure signal will be issued. In this case, it will not be read as $W_{residue}$. This particular weighing hopper will then be disabled until the fault is resolved.

$$W_{net} = W_{final} - W_{residue} \quad (10)$$

$$\Delta W = W_{net} - W_{spare} \quad (11)$$

After the first weighing, the batching deviation ΔW can be obtained, and then the batching variation of this time is used to correct the $W_{advance\ amount}$ of the following material preparation.

The first $W_{advance\ amount} = W_{material\ preparation} - W_{control} = W_{material\ preparation} \times (10\% - 15\%)$

$$W_{advance\ amount\ n+1} = W_{advance\ amount\ n} + \alpha \Delta W_n \quad \cdots\cdots (12)$$

ΔW represents ingredient deviation, α represents correction coefficient, with a range of $0 < \alpha < 1$

$W_{complement\ n+1} = \Delta W_n$

4.4. Debugging effect of dynamic batching weighing under the tank

Taking the coke batching scale (range 0–10*t*) in the left pit as an example, during the trial production, the first five batch weighing were tracked and recorded. The required batching amount of the first three batches of coke in the left coke tank was 8500kg/batch. The batching of the last two coke batches was 7500kg/batch, and the cumulative batching and weighing of 40500 kg was required.

When batching 8500kg for the first time:

The compensation weight ($W_{compensation\ 1}$) is 0. The material preparation value ($W_{material\ preparation\ 1}$) is equal to the theoretical value of the ore required for the smelting process, ($W_{theory\ 1}$), which is 8500 kg. The advance amount, ($W_{advance\ amount\ 1}$), is calculated as $W_{material\ preparation\ 1} \times 10\%$, which equals 8500 × 10% = 850 kg. The final weight ($W_{final\ 1}$) is 8521 kg. Since the material is empty and the remaining material is $W_{residue}$ = 30 kg, the net weight ($W_{net\ 1}$) is 8491 kg. The batching deviation (ΔW_1), is calculated as $W_{net\ 1} - W_{prepared\ 1}$ = 8491 – 8500 = -9 kg. When the second batching is 8500kg:

$W_{compensation\ 2}$ = batching deviation ΔW_1 = -9kg, material preparation value $W_{preparation\ 2} = W_{theory\ 2} - W_{compensation\ 2}$ = 8500 – (-9) = 8509kg.

$W_{advance\ amount\ 2} = W_{advance\ amount\ 1} + \alpha \Delta W_1$ = 850 + 0.8 × (-9) = 842.8 kg (α = 0.8). Because the material is empty and the remaining $W_{residue}$ = 42 kg, the actual weight ($W_{final\ 2}$) is 8553 kg, and the actual unloading value $W_{net\ 2}$ = 8511 kg.

The first to fifth batching weighing corrections can be deduced by analogy, and the results are shown in **Table 2**.

Table 2. Results of batching and weighing

Correction parameters	Weight of the first ingredient (kg)	Weight of the second ingredient (kg)	Weight of the third ingredient (kg)	Weight of the fourth ingredient (kg)	Weight of the fifth ingredient (kg)	Remarks
Theoretical weight, W_{theory}	8500	8500	8500	7500	7500	Cumulative 40500 kg
Material preparation weight, $W_{material\ preparation}$	8500	8509	8498	7478	7478	
$W_{compensation}$	0	-9	2	22	22	
$W_{advance\ amount}$	850	842.8	844.4	862	879.6	
Final weight, W_{final}	8521	8553	8550	7545	7526	
Residue weight, $W_{residue}$	30	42	30	45	38	
Weight deviation, ΔW	-9	2	22	22	10	
Net weight, W_{net}	8491	8551	8520	7450	7488	Cumulative 40510 kg
Accuracy (%)	0.25	0.52	0.61	0.89	0.64	0.12

It can be seen from the above table that through a series of error corrections, the influence of dynamic errors in the batch weighing process is well resolved, ensuring the accuracy and stability of the batch weighing.

5. Conclusion

Calibrating the hopper scale using its fast calibration device, instead of traditional weight loading makes the calibration process much more efficient and less labor-intensive. Besides, it guarantees accurate measurements across the hopper scale's entire range. This method liberates construction personnel from strenuous labor, boosting efficiency, and cost savings. Furthermore, it addresses dynamic weighing errors during batching under the blast furnace hearth by proposing a compensation and control scheme, ensuring stable, efficient, and accurate weighing and control for blast furnace batching.

Disclosure statement

The author declares no conflict of interest.

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Identity Change Before and After the Regeneration Project of the Waterfront Area Based on Industrial Heritage—A Case Study of Yangpu Waterfront (China)

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Abstract: This paper takes Yangpu Waterfront, a famous industrial heritage belt in Shanghai (China), as the research object, with the purpose of sorting out the identity transformation that this waterfront industrial area has experienced in the past century. Taking the comprehensive development on both sides of the Huangpu River carried out in Shanghai in the early 21st century as the dividing line, Yangpu Waterfront has also been reborn after the waterfront regeneration projects that have been in full swing in recent years. This identity change is reflected in physical settings, observable activities, and meanings. The article is based on historical research and current situation analysis, including a part of user satisfaction evaluations.

Keywords: Waterfront regeneration; Place identity; Industrial heritage

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1. Introduction

The renewal of waterfront industrial areas is a process that Shanghai and many waterfront cities are undergoing. In 1883, British merchants built the Yangshupu Waterworks on the Huangpu River, followed by the Shanghai Weaving and Paper Machine Bureau, the first machine and light textile industry in China [1]. This industrial layout, which relied on easy access to waterways for transport and adequate water resources, was the development model of the industrial era. Driven by the riverside industrial belt, in the 1970s and 1980s Yangpu's total industrial output accounted for a quarter of Shanghai.

However, along with rapid globalization, the urban economy has changed from an industrial era characterized by standardized production to a post-industrial era of production characterized by knowledge and innovation [2]. In the 1980s and 1990s, with the tide of reform and opening-up, Shanghai's urban and social structure has undergone profound changes and industrial restructuring. Yangpu's traditional industries were declining and the proportion of total industrial output value in Shanghai dropped from 25% to less than 3%. In

addition, industrial restructuring has left Yangpu with more than 5 million square meters of dilapidated factory buildings, more than 3.4 million square meters of simple housing in old districts, and more than 200,000 laid-off workers, leaving the city under unprecedented pressure to transform [3]. Plus, it is time to change the identity of this area from the "birthplace of modern Chinese industry" to "a new thing" adapting the new age.

The industrial heritage of many urban centers around the world has been regenerated through various means of reuse and reinvention. For now, the transformation of China's waterfront industrial areas is focused on creative industrial parks, art centers, museums and exhibition halls, and ecological green spaces [4]. Since 2016, the Shanghai Municipal People's Government has drawn up specific renovation strategies for the eight waterfront areas along the Huangpu River to highlight the characteristics of each area and has coordinated the development positioning of each area from a macro perspective [5]. The Yangpu Waterfront was strategically positioned to become a waterfront area where history and modernity complement each other and where technology and ecology are highly integrated. This top-down policy guidance has set the scene for subsequent shifts in the direction of development in each region and foreshadowed the fate of historical industrial areas undergoing different identity changes.

2. Research question

As waterfront regeneration progresses, some of the industrial heritage along the waterfront has lost its unique historical appearance and spirit of place, while there are also many successful urban regeneration cases where the industrial buildings no longer retain their original function but their value as former industrial centers is developed, which emphasizes the historic meaning of industry. This kind of identity transformation is common with the different developing demands in changing time and how the identity is changed during this process provides wide experience for other waterfront areas that have not yet undergone urban regeneration.

The research question of this study is "How does the identity of waterfront space change before and after regeneration projects in early 21st century incorporating industrial heritage?" by taking Yangpu Waterfront area as an example. The article will start by making a timeline of industrial heritage of Yangpu's Waterfront area to figure out the identity of this place before the regeneration project was carried out. Then focusing on the 21st century, especially after the urban renewal project implemented by the Shanghai government on both sides of the Huangpu River in 2015, this paper analyzes the current waterfront identity and make a comparison of Yangpu's industrial heritage areas before and after the renewal project in terms of place identity. The further goal is to comprehensively evaluate the impact of waterfront renewal on the transformation of identity produced by industrial heritage, and to provide a possible guideline for other cities.

3. Study area

The southern section of the Yangpu Waterfront is selected for this paper, as shown in **Figure 1**. The area is densely populated with legacy industrial heritage buildings and is the launch section of the Yangpu Waterfront public space renovation, which has played an important role as a demonstration for the construction of the Yangpu Waterfront public space and even the entire 45km Huangpu River Crossing Project, providing an effective reference. The "Shanghai Urban Space Art Season" was held here on 28 September 2019, which attracted many artists in different fields to show their understanding and creation of city open space [6].

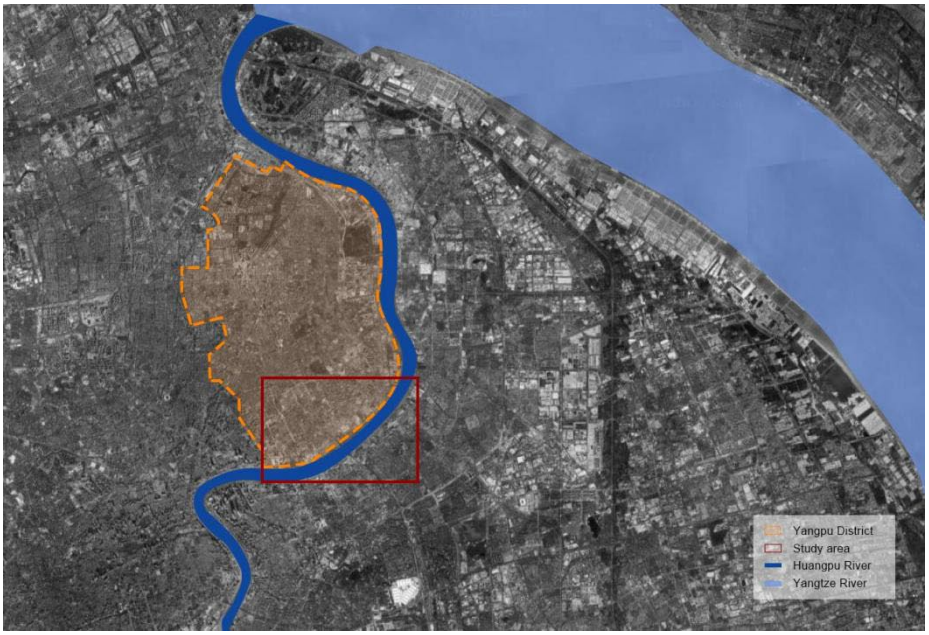


Figure 1. Huangpu River and Yangpu District

4. Theoretical background

4.1. Place identity

The definition of place identity is a complex issue. Kevin Lynch [7] defines the identity of a place simply as that which provides its individuality or distinction from other places and serves as the basis for its recognition as a separable entity. That means a place makes an impression or resonates because of its own unique characteristics and when put in the urban context, identity is also a trait that sets an area apart from other areas with the same function. Plus, identity is a subjective term without a correct explanation, and in most cases, it depends on our experience of places which both influences and is influenced by those experiences [8]. According to Proshansky *et al.* [9], place identity refers to its symbolic significance as a repository of emotions and relationships, providing life with meaning and purposes, and representing a sense of belonging and importance to the well-being of an individual. To evaluate the identity of a real place, some specific components should be clarified. When demonstrating the components of the identity of the place, Edward Relph [8] used Albert Camus' essays on North Africa to introduce the three significant attributes which are the basic elements of the identity of place: physical setting, observable activities, and meanings. Importantly, these three components work together to give a clue on the identification of a place, otherwise, people will fail to experience it correctly.

4.1.1. Physical setting

According to the essays, Camus described in detail the living environment including sand, sea, climate, trees, and buildings to record his life in northern Africa. These are all apparent physical settings that can provide those who live or visit the space with a direct first impression and basic recognition of one specific place, no matter what will happen or usually happen there. Apart from the landscape elements mentioned above, the physical setting has a broad meaning which contains different aspects. In summary, physical settings are objective elements that consist of the first and most basic stone on the way people walk to a deeper understanding of a place and try to identify it.

4.1.2. Observable activities

In addition to the physical setting, activities organized by people which take place in those physical settings are also significant elements composing place identity. Different kinds of activities including public activities, and private behavior and the people actively involved in these events shape the place identity together. Meaning is born out of daily activities, and out of the people who participate in them.

4.1.3. Meanings

The first two elements are both directly visible and easily appreciated, but the meaning is an abstract element that is hard to grasp. They may be rooted in the physical setting and objects and activities, but they are not a property of them, rather they are a property of human intentions and experiences [8]. Meanings can change and be transferred from one set of objects to another, and they possess their own qualities of complexity, obscurity, clarity, or whatever. To conclude the meaning of one place, evaluation and experience in physical settings and activities are necessary and conceivably, they differ for everyone. However, there are several criteria to assess the meaning to some extent like historical meaning, economic meaning, aesthetic meaning, and so on.

4.2. Waterfront space

In the past, the preference for waterfront locations for the industry was partly due to the ease of water transport which allowed trade between regions and even countries to take place by water. On the other hand, the high demand for water from factories dictated that building on the river was a way to reduce costs. Today, in the era of neoliberal urbanization, cities are transforming and waterfronts have become the focus of planning interventions [10]. According to Marshall, waterfronts in post-industrial cities worldwide are frontiers that reflect the complexity of contemporary urban problems, ideas, culture, and society [11]. Water is a beneficial element for human life, promoting human health in terms of physical, psychological, and social relationships [12]. The waterfront space, as a space in the city that is closely linked to the water, provides public space along the shoreline. The development of urban waterfronts in recent years has shown that urban waterfronts can help to restore or enhance the vitality of urban development [13].

5. Findings

5.1. Before waterfront renewal

The Huangpu River runs north-south through Shanghai, dividing it into two major blocks, Pudong and Puxi, and eventually joins the Yangtze River at the mouth of the Wusong River, which is an important waterway for communicating with ships.

The Hai Guan Zong Shui Wu Si Shu [14] recorded that in November 1843, under the terms of the "Treaty of Nanking," China officially opened Shanghai as a designated port of commerce for foreigners. Of the 46 ports of commerce, or centers of trade in the country, Guangzhou was in the south, Tianjin in the north, and Shanghai in the center. According to a customs survey, of the total trade volume of the above three places, Shanghai was far ahead of the other two ports of commerce with 630 million yuan [15]. This shows that Shanghai was the center of gravity of the country's trade, not only for the foreign countries' shipping routes to China, but also for the Chinese coastal and Yangtze River shipping routes.

On 29 November 1845, the Qing Government's and the British Consul George Balfour jointly published *The Shanghai Land Regulations*, which established the British Concession in Shanghai. Since then, the American and French Concessions were established one after another. Yangpu District, located on one of the western banks of the Huangpu River, was historically named after Yangtszepoo, and the term "Yangtszepoo"

first appeared in a written document in 1863 delineating the boundaries of the American Concession with China, when the English term "Yangtszepoo" was used. This refers to the name of the river and is a Latinized spelling with a Shanghai dialect accent [1].

In September of the same year, the British and American concessions were officially merged into a public concession, and the Yangtszepoo area has been part of the public concession ever since. In the Concession, foreigners invested in public utilities, set up schools and newspapers, and the Concession became a window for the Chinese to understand and learn about Western culture and institutions, and also laid the foundation for foreigners to set up industries, factories, and form a sizeable industrial base in the area.

In 1870, the Yangtszepoo Road was built, which was a result of the extension of its southern road (Broad Way), and named after the river channel Yangtszepoo near it. With China's defeat in the First Sino-Japanese War in 1895, another unequal treaty, the "Treaty of Shimonoseki," was signed, opening the way for Japan to invest in factories at China's trading ports. With its natural proximity to the Huangpu River, the low cost of land along the lower reaches of the river, and its easy access to the center of the concession, Yangshupu Road gradually became a preferred location for factories of all kinds, many of which are now recognized as historical heritage sites a century later (**Figures 2** and **3**). With the prosperity of both sides of Yangshupu Road, the whole area gradually became the birthplace of Shanghai industry and even modern Chinese industry.

The real development of industry in the Yangpu district can be traced back to the founding of the Shanghai Machine and Paper Bureau at 408 Yangtszepoo Road in 1882, which was the first national capital enterprise in Yangpu. The following year, the British Shanghai Water Company established the still famous Yangtszepoo Waterworks and opened its water supply. Its predecessor was the water supply company set up in 1875 by the Lide Foreign Company in the southern area of the present-day Yangtszepoo Waterworks, which had water purification facilities such as sedimentation and filtration ponds, and was the earliest form of industry in Yangpu [16].

In the next two or three decades, many factories were opened along the Yangtszepoo Road, including shipbuilding, paper-making, machinery, and soap-making, and although most of them were foreign-invested, national industries were also steadily advancing in a wave of rapid development. In 1913, there were already more than 20 paper, water, and yarn factories on the Yangtszepoo Road, and in the 1930s there was the first major industrial development [1]. The density of factories along the Yangpu Waterfront already far exceeded that of the surrounding areas, creating a sizeable industrial production base and an area of industrial heritage along the riverfront.

In addition to the scale of industry at the time, the extent of industrialization can also be seen in the amount of electricity generated in the city and the proportion of that electricity used by industry. From the 1910s to the 1930s, Shanghai experienced unprecedented industrialization, with the Shanghai Electric Power Company's electricity generation rising from 62 million kWh in 1915 to 770 million kWh in 1935 and still rising (**Figure 4**) [17]. Additionally, the monthly growth within each year was also significant, with total electricity consumption in Shanghai in 1935, for example, increasing stably from 32 million kWh in January to 74 million kWh by the end of the year. Moreover, the domestic electricity only accounted for one third of this and industrial electricity took up two thirds (66–69%) (**Figure 5**) and this figure continued until the outbreak of war. At the end of 1936, the Shanghai Electric Power Company's total electricity generation was as high as 813 million kWh, with industrial use still maintaining a high share of nearly 70% [18,19].

Since the start of the war (the Battle of Shanghai), Shanghai Electric Power Company's power generation decreased month by month, from 77million kWh in June 1937 to only 23 million kWh at the end of the year [20]. During this period, industrialization stalled, most factories were destroyed by artillery fire, and the remaining industrial plants were at risk of air raids at any time, to the point where the hardship of running factories was



Figure 2. Distribution of industrial heritage along Yangtszepoo Road

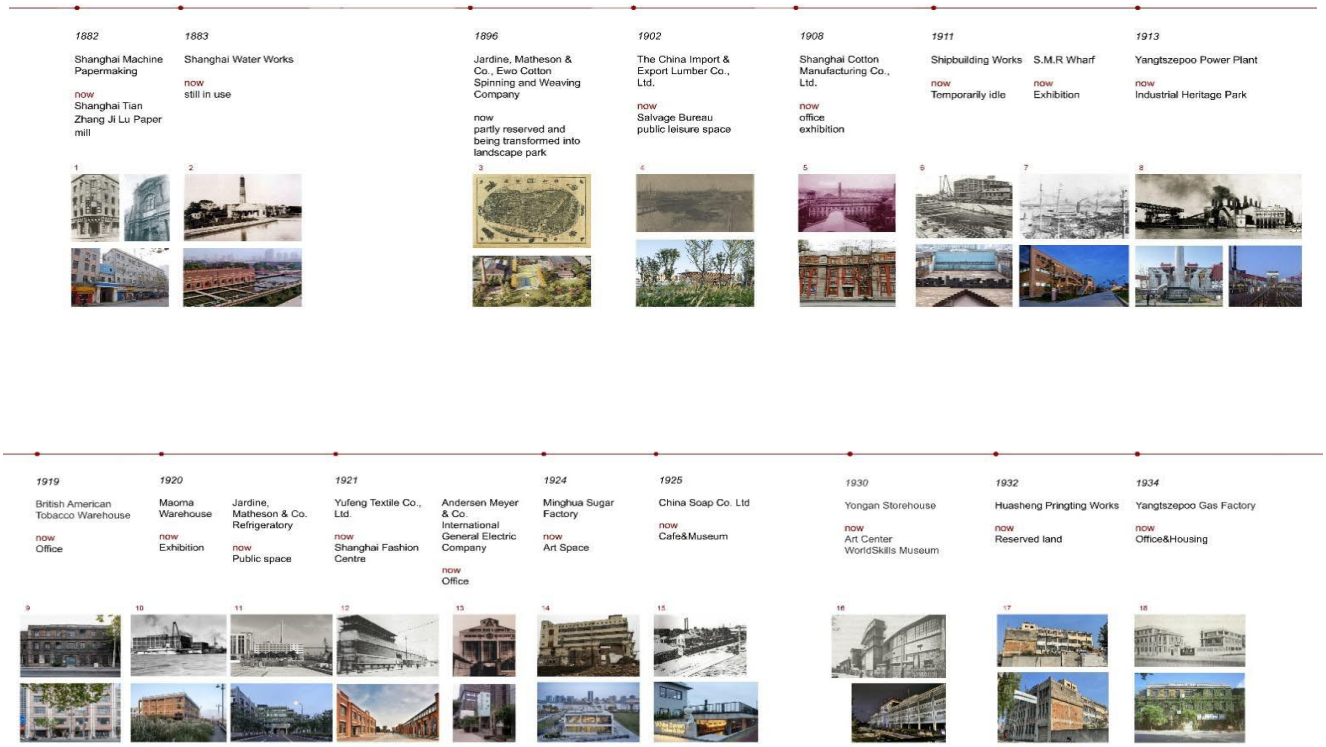


Figure 3. Timeline of factory construction along Yangtszepoo Road

ten times greater than before during the period of isolation*. Instead of being caught in a dilemma, it was better to actively plan for another way out. It was therefore essential to evacuate the industries in Shanghai, i.e., to relocate the factories to the mainland where the population was concentrated and raw materials were abundant [21].

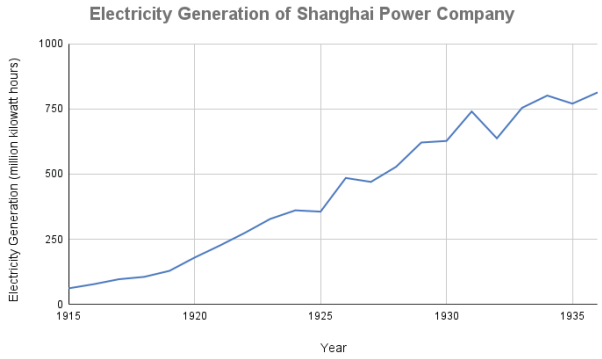


Figure 4. Electricity generation of Shanghai Power Company from 1915 to 1936

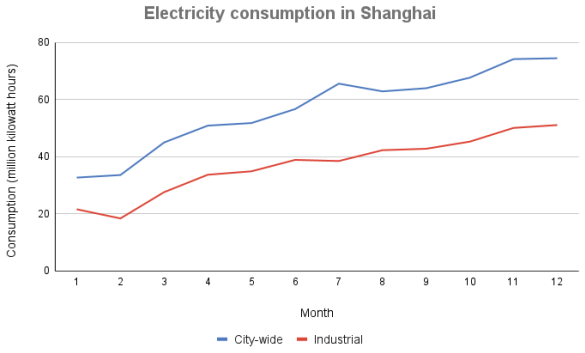


Figure 5. Monthly electricity consumption in Shanghai in 1935

***Period of isolation:** It refers to the fall of Shanghai on 12 November 1937 during the war against Japan, as the center of Shanghai was surrounded by the Central and Western Districts of the Public Concession (the Northern and Eastern Districts of the Public Concession were no longer under the jurisdiction of the Bureau of Public Works, but they were not considered to be fallen areas) and the French Concession of Shanghai, and Japan was not ready to go to war with Europe and the United States, so Japanese troops were not yet able to enter, and if they did, it was considered an act of war. The situation was like an "isolated island." This situation was maintained until 8 December 1941, when the Japanese army launched the Pacific War.

Although Yangtszepoo Road is close to the river, the industrial area, where production is the main objective, does not include the water as a valuable "spiritual material" in the lives of the people around it, but rather as a productive resource and a transport medium. With the rapid industrial and economic development, more and more people came to work in the industrial area of Yangshupu, where workers made up the majority of the population, but only a small proportion of the factories built housing for their workers, and even in some of the housing provided specifically for workers, the streets were in a very poor condition. After the outbreak of the civil war, more and more people fled from Hamanbei to seek refuge in the tenements, adding to the already crowded accommodation, with more than five people living in a small room. Even with the poor conditions of the workshops, there were still workers who did not have the opportunity to live in them, so they had to build shacks and straw huts in the factories and docks, creating a large-scale shanty town [22]. With the large amount of people moved in, almost all the sordid evils including disease, gambling, smoking, alcohol, fighting were concentrated here due to the lack of management [23]. Even though this was the main industrial base of Shanghai, generating most of the city's economic income and energy supply, the living conditions here resembled those of a slum.

In addition to this, the air pollution caused by the dense industrial buildings and factory operations, and the water pollution caused by the discharge of harmful substances into the rivers have left the whole area in a haze of industrial smoke, and the noise from the factories is constantly affecting the living experience of the inhabitants. There were outbreaks of plague, insomnia, and other diseases, and the people's experience of life was not enhanced by the water, but rather more miserable [24]. Even though people were aware of environmental

issues, the problem of pollution remained unresolved due to economic constraints [25].

With the workers' food and material life unsatisfied, they seldom sought the enjoyment of spiritual life. The factories in Yangshupu are like a closed barrier, completely isolating the river from the people who live there, and the water loses its landscape function, becoming a single productive resource flowing there like a symbol.

At this stage Yangpu Waterfront space was not so much a waterfront industrial area as it was a production site that made good use of water resources and happened to be close to the water's edge. The people here witnessed the beginning of industrialization in China, and even though smoke rolled from the chimneys and the water in the Huangpu River was no longer as clear as it once was, the citizens would look at the scene and think of a better future for industrialized society, as in a poem by a folk poet in a magazine [26] (translated by author):

The city is a whirlwind of metal, the pulse of the city——
It was the madness of iron, a million sinews stretching.
The head of cement is held high in the sky, looking askance.
There are no clouds in the sky, but a frenzy of misplaced electricity.
The wind, too, is only a radio stream, a coal-poisoned sick man
In the writhing of the wind, dancing black gargoyles,
…
They are representative, of the individual factory cells that
gathered in the tense space, ready for the great roar.
Please look down from the smoke burst, down into the heart of the factory.
You will see the flames of purgatory burning with indignation.
The words of the siren will declare when the sun comes.
It is a lyric of iron, a declaration of iron conviction.
…
The wires are the nerve system of the city, running with your stirring stabs.
Burning with light, spreading sound, acting mechanically.
One point, one line, the infinity of your life.
You are the wind of spring, blowing a million silver flowers.
Mercury-like, your authority rushes like a boat falling into the sea.
But thou art only a child born of labor and iron.
…
I look to you, please grasp the flag of Asia
Like an engine, guide him into the future.

The Yangpu Waterfront was the first seed planted by industrialization in China, and tens of thousands of people irrigated it and helped it to sprout, experiencing many difficulties along the way, but these industrial memories constitute a unique treasure of the city, an indelible and magnificent piece of Shanghai's modern history, writing the history of Shanghai's industrial development, and forming a cultural symbol of the city and a cultural form of urban capital. At the same time, Yangpu Waterfront is an important treasure in China's modern industrial history.

5.2. After waterfront renewal

After the end of the war, industry also gradually recovered with the restoration of social order, and in a newspaper in 1948, it was reported that Shanghai alone generated 12.08% of the country's electricity for the year [27]. After the liberation of Shanghai in 1949, the factories gradually resumed their previous state of production. With the strategic industrial layout adjustment of the central government, Shanghai assumed an important role in building the new Chinese industrial system and accelerating the industrialization of the country, and 80% of the land in the city center was occupied by factories [28].

After China's reform and opening-up in 1978, the country's economic development strategy was once again adjusted with the important goal of convergence with the international community, and in the following two or three decades, China shifted from closed internal development to external development, and its economic development increased at an astonishing rate. At the beginning of the 20th century, the government proposed to adjust the land use structure of the urban area, reducing the proportion of land for industrial enterprises, and increasing the proportion of land for service industries [29]. Some traditional industries such as textiles, shipbuilding, iron and steel, machinery, etc., have also changed from weak to strong at the end of the last century, facing restructuring and upgrading. The factories have moved away, leaving behind abandoned and unused factories, and the Huangpu River has become detached from the urban landscape and social life due to the pollution it suffered during the era of industrial mass production.

The 21st century has witnessed the identity change of the Huangpu River and its waterfront area. According to Shanghai Observer [30], in 2014, Shanghai's urban development entered an era of tight resource constraints, with the city moving from outward expansion to inward development. The next year, Shanghai Municipal Government issued the "Shanghai Urban Renewal Implementation Measures" which marked the full-scale opening of urban renewal work. This means that urban development is no longer limited to material abundance, and the demand for spirituality and quality has risen dramatically. Waterfront spaces, as a typical type of urban public space, have also gained importance in the urban regeneration segment, with people expecting more possibilities from them. Yangpu Waterfront has been transformed since 2017, when both sides of the river were opened to the public. One of the opportunities for Yangpu Waterfront to become well known is the "Shanghai Urban Space Art Season," which was held there in 2019. The "Shanghai Urban Space Art Season" (SUSAS) is a collaborative effort between the Shanghai Municipal Bureau of Planning and Resources, the Bureau of Culture and Tourism, and the district government of the main exhibition area to create an "international, public, and practical" brand of urban space art based on the concept of "culture for city, art for city." The event is held every two years since the first one in 2015, and the third edition was held in Yangpu Waterfront in 2019 with the theme of "Encounter." With the promotion of such urban events, the transformation of the waterfront space is popular among a wider audience and with the increasing visibility, the industrial history and heritage, along with the changing identity are witnessed by more people.

As for how the former Yangtszepoo Industrial Zone, which is today's Yangpu Waterfront, was transformed from an industrial wasteland into a waterfront recreational area that people enjoy participating in and experiencing, and how to understand the theme of "Encounter," Zhang Ming, the chief designer of the renovation project, said: "At that time, we saw that there were companies lined up all over the Huangpu River south of Yangshupu, and there was no space for people to meet each other. Thus, our job was to break down these barriers, to open-up these walls that were once closed to the public, so that people could really enjoy the freedom of the waterfront and 'return the river to the people,' that was the original idea" [31].

Under the architect's plan, the waterfront area is no longer a warehouse for industrial buildings, some of the dense housing has been demolished to create green spaces for strolling or staying, running tracks, lanes, and

some gaps left for people to "freely fill in." The role of the river has changed from being a medium of "isolation" to being part of the urban space in which people participate in their daily lives, with more and more amenities such as street lighting, railings, steps, and staging areas (**Figure 6**). The construction of the two sides of the river has also made the Yangpu Waterfront much more accessible to other waterfront areas.

Returning the river to the people is a way of incorporating water into people's lives in a physical sense, leading them to form various unstructured relationships with it, such as feeling, appreciating, and participating. Today, the Yangpu Waterfront has shed the haze that once hung over it and has become a popular choice for residents to walk and chat after a meal (**Figures 7** and **8**).



Figure 6. Public facilities and open space



Figure 7. Public facilities and open space

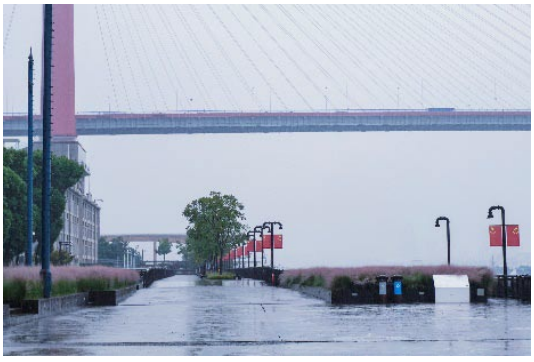


Figure 8. Public facilities and open space

At the same time, as a former industrial base, many of the industrial buildings established over a century ago are classified as national or Shanghai industrial heritage. Although the history of industrial production has passed, this heritage still has its historical significance in the leisure space along the river. In the transformation of the Yangpu Waterfront, the architects have taken into account not only the importance of the river in the public space, but also the promotion of industrial history and culture, giving everyone who comes to the space the opportunity to learn about the history of the area, creating an uninterrupted and diverse industrial exposition zone [31]. For the revival of the industrial heritage, the renovation project has taken two different approaches: the replacement of functions, such as the transformation of the former factory into a museum, preserving the architectural heritage while displaying the old production tools inside, and building a basic understanding of the history of the area. Another example is the dockyard space left over from the shipyard, which the designers not only did not demolish but also built stands on top of, so that this industrial space can be used as a stage for art [32]. People actively participate in the waterfront public space and at the same time learn about the history of the space. Another approach is to incorporate industrial elements into newly created facilities, such as the pipes that once lined the waterworks, which were cleverly used in the design of the street lamps and railings, and which have become a representative feature of the Yangpu Waterfront [33].

Either way, the transformation is reshaping the history of Yangpu's waterfront as a former industrial base. This means that the waterfront, with its cultural and ecological significance, is becoming a popular space for people. Yangpu Waterfront, with its waterfront and industrial heritage status, has truly become a symbolic waterfront space that combines a sense of modernity and history, a leisure camp and a window that speaks of the history of the area on behalf of Yangpu.

5.3. Satisfaction assessment [34]

In order to get a better idea of how satisfied people really are with the long-running riverfront renovation project, some online questionnaires were distributed randomly and 55 valid responses were obtained. Among these, 38 people had been to the Yangpu Waterfront, although most of them did not live in the vicinity (30 of them). Among the other 17 people who had not been to this area, 9 had either heard of or knew a lot about the industrial history of the area. Although this is a small sample, it can be said that Yangpu Waterfront space has a certain historical status. Out of those who had visited, 28 felt that going to the waterfront in person and doing some activities there would increase their level of knowledge about the history of the area, rather than feeling that the Yangpu Waterfront was simply a waterfront space as any common one.

Their most desirable activity here was walking along the river or sitting on the steps to relax, and the second thing that drew them to the Yangpu Waterfront was the transformation of some of the buildings that had become popular on the internet, such as the "Green Hill" public space adapted from the tobacco company, which was uniquely shaped to incorporate plants into the building space, without destroying all the original architecture. It is a popular place with more opportunities for people to stop and look at the gardens and river views, and it is welcomed by those who are always fond of combined sense of art and history (**Figure 9**).

Nearly 40% of people come here for study tours or history-related education. It is an effect of the rich history of the Yangpu Waterfront and its nationally renowned industrial background in this new era. People come here to experience the collision of history and reality, and to see how the barges that once served as industrial landmarks have been transformed and revitalized, which is why over 65% of people believe that what sets the Yangpu Waterfront apart from other riverfront spaces is its richer industrial heritage. This uniqueness is something that needs to be preserved, and even today, with its different functions and development orientation, the historical identity is appropriately retained within it.



Figure 9. "Green Hill" adapted from the tobacco company

When they were asked about what could be improved about the Yangpu Waterfront, around 63% chose "recreational activities to be enriched," while over 40% chose "infrastructure to be improved" and "industrial history to be gained." The renovation project has evolved so far that perhaps more thoughts are being given to how to activate the area to a greater extent in the long term, and more importantly, regardless of the identity that the users label on Yangpu Waterfront, infrastructure and accessibility are crucial in the process of transforming the waterfront industrial area into a recreational riverfront space with a historical heritage. The infrastructure and accessibility of the area will largely influence the willingness and frequency of people to visit this area. Moreover, even though many of the preserved buildings speak silently of the grand history of this old industrial base, people walking through them are expected to have easier and more active access to the history of the Yangpu riverfront.

All in all, when asked to give the Yangpu Waterfront a general satisfaction rating from 0 to 10, the average of 38 people was 7.92, which can be considered as a positive assessment of the renovation of the industrial waterfront space.

6. Conclusion

In today's rapidly developing society, any space can undergo a dramatic change of identity in a short period of time, which is closely related to macro policies, development needs, and user demands. The Yangpu Waterfront has undergone a tortuous process of industrial development, from an industrial base under economic pressure and in pursuit of productivity, to a typical recreational waterfront space of historical significance. The driving force behind this was firstly the city's development plan and secondly the specific designers who intervened in it. However, it is not enough to be a designer and planner, only when the real users are involved can the identity of a space or place be fully glimpsed. It may be grand, it may have great symbolic importance, but above all, the real identity is multifaceted and complex.

Disclosure statement

The author declares no conflict of interest.

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Literature Review on the Renovation Project of Self-Built Residential Buildings in the South Under the Low-Carbon Background

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Abstract: With the continuous exploration and research of low-carbon buildings in China, combined with foreign theories and practices, there are a few basic theoretical and practical projects for low-carbon construction in major cities of China. However, throughout the entire academic research, there is still no comprehensive and clear guidance for the green and low-carbon research and transformation of rural self-built houses. Therefore, the existing development of low-carbon technology for rural self-built houses has been summarized, and some prospects for the future development of rural self-built houses have been summarized. It is hoped that this will have positive help for future rural low-carbon transformation.

Keywords: Low-carbon transformation; Southern rural areas; Self-built houses

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1. Introduction

Since the 21st century, with the rapid development of the rural economy and the continuous expansion of the urbanization scale in China, the ecological environment problems in rural areas have become increasingly prominent. On the one hand, the extensive transformation of rural industries has led to the replacement of intensive agriculture and handicrafts by high-carbon industries such as commerce and tourism, and the blind expansion of high emissions and high energy consumption without being constrained by ecological space and natural resources. On the other hand, under the influence of nearby and on-site urbanization, the natural texture of rural areas tends to be fragmented, and the normal structure and function of green spaces are eroded to varying degrees [1]. The carbon emissions in rural areas have significantly increased. According to the "China Rural Statistical Yearbook" [2], in the past 10 years, the per capita carbon emissions in rural areas have increased by 2.4 times compared to urban areas during the same period, and the total carbon emissions have also exceeded 45% of the total value. Rural areas have become major carbon emitters. The work conference of the 19th National Congress of the Communist Party of China and the No. 1 Central Document of the Central Committee of the Communist Party of China in 2018 have successively proposed that rural revitalization should be guided by ecological civilization, and the high-quality rural development path of quality, ecological livability, and

green sustainability should be adhered to. Therefore, exploring the "low-carbon", "connotative", and "intensive" development of new rural areas under the goal of "increasing foreign exchange and reducing emissions" has become the key to smoothly promoting new urbanization, rural modernization, and creating an ecological and livable environment.

2. Research background

2.1. Concept of low-carbon buildings

At present, there is no unified definition for low-carbon buildings in the academic community. British scholar Phil Jones believes that reducing building energy consumption and fully utilizing renewable energy are necessary conditions for low-carbon buildings [3]. Gu Lijing, a scholar from Tsinghua University, expressed that low-carbon buildings reduce the use of fossil fuels and improve energy efficiency throughout the entire life cycle of buildings, thereby reducing carbon dioxide emissions. Cao and Liu from Chongqing University proposed the fundamental prerequisites for low-carbon buildings that encompass the entire building life cycle. Their approach includes the following key elements: In the architectural design stage, maximize the utilization of renewable and clean energy sources such as solar energy, geothermal energy, and wind energy. During the construction stage, employ low-carbon building materials and adopt energy-saving and low-carbon technologies. Furthermore, they advocate for a shift in consumption habits, urging people to adopt high-efficiency air conditioning systems, energy-saving lighting fixtures, and electrical equipment to conserve electricity [5]. Li Bing, a scholar from Huazhong University of Science and Technology, asserts that low-carbon buildings encompass a comprehensive approach involving scientific planning and design throughout a building's entire life cycle. This approach includes the rational use of eco-friendly building materials, energy-saving technologies, innovative processes, and other measures aimed at enhancing energy efficiency and diminishing the consumption of fossil fuels such as coal, oil, and natural gas, ultimately resulting in reduced greenhouse gas emissions [6]. Meanwhile, Yinshi Chao from the Harbin Institute of Technology defines low-carbon buildings as those with minimized carbon emissions quantified across the entire lifespan of the structure [7]. Combining these perspectives, it can be concluded that the core essence of low-carbon buildings involves reducing fossil fuel consumption, maximizing renewable energy utilization, adopting diverse energy-saving technologies, and minimizing carbon emissions over the entire lifespan of the building.

2.2. International and domestic low carbon development

The United Kingdom is the most active practitioner in advocating for a low-carbon economy and developing low-carbon buildings. In 2003, the UK took the lead in proposing the concept of a "low-carbon economy" in "The Future of Our Energy" [8]. In December 2006, the UK released the Sustainable Housing Code, which evaluated the carbon footprint of buildings from nine aspects including building use, building maintenance, and energy utilization [9].

Starting from April 2007, the UK has required new buildings to comply with the requirements of the Sustainable Housing Code, and starting from 2016, all new homes must meet the 6-star standard, which is zero carbon housing. In March 2008, the UK government proposed new requirements for new public buildings, which require all new public buildings to be zero carbon from 2019 onwards. In addition, the UK's Climate Change Act was officially passed and came into effect in 2008. In the bill, the UK proposed to reduce 20% of carbon emissions by 2020 based on 1990 levels and achieve the goal of reducing 80% of carbon emissions by 2050, which fully reflects the UK's determination to reduce carbon emissions. The Science and Technology Innovation Park of the British Institute of Building Science and Technology is a technology park dedicated to showcasing low-carbon buildings. There are 11 low-carbon demonstration buildings built in the park, which use renewable green building materials and efficient energy-saving insulation technology for the building envelope, achieving low-carbon or even zero-carbon emissions in the building. Among these 11 low-carbon

demonstration projects, the most famous is the London Beddington Zero Emission Community, which was built in 2002. Through the use of recyclable building materials, solar collectors, and photovoltaic panels, as well as the installation of rainwater harvesting devices and natural ventilation chimneys, it has achieved high standards of zero carbon emissions and is a successful example of zero carbon emission communities and low-carbon building development in the UK and even around the world [10].

Japan is one of the first countries to propose the construction of a low-carbon society, and its low-carbon development strategy was launched earlier. In April 2004, the "Japan Low-Carbon Society Scenario for 2050" research program was established by the Global Environmental Research Fund established by the Japanese Ministry of Environment. In February 2007, the project team published a research report titled "Japan's Low Carbon Society Scenario: Feasibility Study on Reducing Carbon Dioxide Emissions by 70% from 1990 Levels by 2050", fully affirming the feasibility of the low-carbon society concept. In May 2008, Japan issued the "Action Plan for a Low-Carbon Society Planning," proposing technical measures to achieve the construction of a low-carbon society. In July of the same year, the Japanese Cabinet meeting passed the "Action Plan for Building a Low-Carbon Society," proposing to vigorously promote the development and use of renewable low-carbon energy and accelerate the process of building a low-carbon society [11].

Copenhagen, Denmark is a pioneer in the construction of low-carbon cities. In August 2009, the Copenhagen Climate Plan 2009 was officially introduced, proposing carbon dioxide emission reduction targets, which were implemented in two stages. The first stage is to achieve a 20% reduction in carbon dioxide emissions by 2015 based on 2005 levels, and the second stage is to achieve zero carbon emissions by 2025, making Copenhagen the world's first carbon-neutral city. To achieve the goal of reducing 500,000 tons of carbon dioxide emissions annually, the Copenhagen Climate Plan 2009 proposes 50 action plans in six major areas: energy supply renovation, green transportation, energy-saving buildings, citizen action, urban development, and future climate adaptation. Among them, energy supply renovation, green transportation, and energy-saving buildings are key areas for achieving emission reduction goals [12]. A typical representative of low-carbon urban development in Denmark is the solar wind community in Beder, Denmark. This public residential community was spontaneously organized and built by residents, and completed in 1980, with a total of 30 households. The main forms of energy in this community are solar and wind energy, which fully utilize renewable energy and reduce carbon dioxide emissions [13].

Although the development of low-carbon buildings in China started relatively late, many efforts have also been made. In 2008, the National Development and Reform Commission and the World Wildlife Fund (WWF) selected two cities in China, Shanghai and Baoding, as low-carbon city pilots to explore low-carbon models for urban development. Among them, Shanghai focuses on developing energy-saving buildings, while Baoding focuses on the application of new and renewable energy. In January 2010, the Ministry of Housing and Urban-Rural Development of China approved Shenzhen as the first low-carbon ecological demonstration city in China. Shenzhen actively promotes the development of low-carbon buildings, playing a leading and exemplary role in the construction of low-carbon ecological cities in China. In July of the same year, the Climate Department of the National Development and Reform Commission issued a notice on carrying out pilot work in low-carbon provinces, regions, and cities, establishing the first batch of low-carbon pilot areas in China, including Guangdong, Yunnan, Hubei, Shaanxi, Liaoning provinces, and eight cities in Tianjin, Shenzhen, Xiamen, Nanchang, Guiyang, Chongqing, Hangzhou, and Baoding. In December 2012, the National Development and Reform Commission issued a notice on conducting the second batch of national low-carbon pilot projects in provinces, regions, and cities, establishing the second batch of low-carbon pilot projects in China, including 29 provinces and cities such as Beijing, Shanghai, Hainan, and Shijiazhuang. On September 19, 2014, the National

Development and Reform Commission officially issued the "National Climate Change Response Plan," which clearly stated that by 2020, China will build around 150 low-carbon industry demonstration parks, carry out around 1,000 low-carbon community pilot projects, and create around 1,000 low-carbon commercial pilot projects [14].

Building low-carbon cities is a necessary path for future urban development, and the development of low-carbon buildings is also an inevitable trend. So far, China has successfully constructed many low-carbon buildings. For example, Beijing Guoao Village has integrated and applied dozens of low-carbon technologies, including green building materials, reclaimed water reuse, renewable water source heat pump systems, solar domestic hot water systems, and power generation, greatly reducing energy consumption and greenhouse gas emissions, reaching the international leading level of green residential areas. There is also Fengshang International Apartment in Nanjing, which is China's first "zero energy" residential project. It uses renewable energy such as solar energy and shallow geothermal energy to replace traditional energy, effectively reducing carbon emissions [15].

2.3. Current status of rural areas research

2.3.1. Research status of China's rural areas as compared to overseas

The energy consumption level per unit area of buildings in China was on par with that of the United States and Japan in the past but now declined to only 40% to 60% of the current levels seen in the United States and Japan. If no effective actions are taken, it is expected that China's energy consumption per unit area will naturally catch up to those higher levels in 15–20 years. To provide some context, South Korea initiated similar efforts in the early 1980s, and after about 15 years, their energy consumption per unit building area began to rise in tandem with per capita GDP. After this rapid development period, South Korea's building energy consumption currently matches that of Japan. China's urban and town construction is progressing rapidly, and if the number of urban buildings doubles and the energy consumption per unit area doubles over the next 20 years, the total energy consumption for building operations could match the current national total energy consumption. This situation poses significant challenges in terms of energy sourcing, energy transportation, and carbon emissions post-energy conversion. China's ability to handle such a substantial increase in energy consumption is constrained by factors such as its large population, limited land area, finite resources, and the impracticality of relying extensively on foreign natural resources, as the United States and Japan have done during different phases of their development. Hence, the imperative for China is to balance the demands of social and economic development with the improvement of living standards while keeping the actual operational energy consumption per unit building area at or near current levels. Alternatively, further reductions in energy consumption can be pursued based on the existing foundation [16].

2.3.2. Current situation of rural areas in China

According to 2021 data from the State Council, China's rural population totals 556 million people, and rural housing covers approximately 40% of the nation's total building area. Carbon emissions originating from rural housing contribute to about 20% of the overall carbon emissions within the construction industry [17]. Encouraging environmentally friendly and low-carbon development in rural housing offers several advantages. It not only prolongs the lifespan of rural homes but also reinforces efforts for energy conservation and emission reduction. This, in turn, helps farmers reduce expenses and boost their income. Moreover, it enhances the comfort and safety of rural dwellings, elevates the quality of rural living, and accelerates the creation of aesthetically pleasing rural areas. Additionally, it facilitates the dissemination of green technology and building materials to rural regions, contributes to regional air pollution control, supports adjustments in industrial

structures, and promotes economic transformation and upgrading.

While China has been actively promoting green rural housing in recent years, there are persistent challenges, including insufficient technical support, an incomplete management system, and inadequate promotion mechanisms. China currently stands at a critical juncture in its social and economic development. Over the past decade, the GDP has consistently grown at a rate exceeding 10% per year, urban built-up areas have expanded at a rate close to 10% per year, and annual energy consumption has continued to rise significantly, hovering around 10% [18].

Over the past three decades, developed countries like the United States and Japan have placed substantial emphasis on building energy efficiency. They have provided substantial financial support, instituted legislative oversight, and guided public opinion through various government and societal avenues. This concerted effort has spurred the emergence of a constant stream of new buildings that incorporate various energy-saving technologies. All of these experiences offer valuable guidance and serve as a reference point for the construction of energy-efficient and low-carbon self-built rural houses in China's evolving low-carbon landscape.

2.4. Countermeasures for energy consumption reduction

2.4.1. Countermeasures for reducing energy consumption in foreign countries

The concept of ultra-low energy buildings, also referred to as passive buildings, was initially introduced by German physicists [19]. These buildings are characterized by their extensive applications of energy-saving technologies in various aspects, including building envelopes, energy and equipment systems, lighting, intelligent control, and the utilization of renewable energy [20]. Ultra-low energy buildings exhibit significantly reduced energy consumption levels compared to conventional structures and prioritize the utilization of renewable energy over primary energy sources whenever feasible [21].

2.4.2. Countermeasures for reducing energy consumption in China

Ultra-low energy consumption buildings in China are typically defined based on annual calculations of energy usage as well as terminal energy consumption as key performance indicators. For newly constructed buildings, these structures exhibit a remarkable energy efficiency improvement, with heating and cooling energy consumption being over 70% more efficient compared to buildings constructed according to standard energy-saving guidelines (with residential buildings achieving a 65% energy-saving rate and public buildings achieving a 50% energy-saving rate as the baseline for improvement [22]).

Urban and rural construction represents a significant source of carbon emissions, and as urbanization continues to advance rapidly and industrial structures undergo substantial adjustments, the carbon emissions stemming from urban and rural construction are expected to rise as a proportion of total societal carbon emissions.

To expedite progress toward the "dual carbon" goals, the Ministry of Housing and Urban-Rural Development and the National Development and Reform Commission have officially unveiled the "Implementation Plan for Carbon Peak in Urban and Rural Construction." This plan introduces new requirements aimed at comprehensively enhancing the level of green and low-carbon buildings, optimizing the energy mix in urban development, and encouraging the adoption of renewable energy sources. These requirements include the ongoing implementation of green building initiatives, the target of achieving an 83% reduction in energy consumption for new residential buildings in extremely cold regions by 2030, a 75% reduction in energy consumption for new residential buildings in regions with four seasons, and a 78% reduction in energy consumption for new residential buildings in mild weather regions.

2.5. Impact of building structures and types on carbon emissions

In 2009, Ambrose and colleagues conducted a comprehensive study on the carbon emissions associated with building materials [9]. Their analysis encompassed the entire lifecycle of building materials, including mining and production, the impact of these materials on building energy consumption during use, and the potential for recycling. They specifically compared the carbon emissions of wooden and concrete structures and determined that the carbon emissions ratio between wooden and concrete structures was approximately 4:5.

Moving to 2010, Verbeeck and his team performed an exhaustive assessment of lifetime energy consumption and carbon emissions for five different types of residential buildings in Belgium [23]. They conducted a comparative analysis among buildings with distinct structural designs and found notable differences in carbon emissions throughout the entire lifespan of buildings with varying structures.

In 2011, Shang *et al.* selected three single-family building types with identical designs in the northern region, which included wooden structures, light steel structures, and reinforced concrete structures [24]. They calculated and compared their carbon emissions over the complete lifespan of these structures. The results revealed that wooden structures, in contrast to light steel and reinforced concrete structures, exhibited lower lifetime carbon emissions. In addition, all three building types shared a common feature in their carbon emissions profile, with the highest proportion occurring during the operation and maintenance phases.

In 2012, Peng conducted a study focusing on various representative cases of public and residential buildings that had received green building certifications [25]. The study involved calculations of their lifetime energy consumption and carbon emissions, facilitating a comparative analysis of energy consumption and carbon emissions among different building types. The findings indicated that public buildings, over their entire lifespan, had energy consumption and carbon emissions approximately twice as high as those of residential buildings. Green public buildings, in particular, showed a 33% reduction in lifetime energy consumption compared to standard public buildings, while green residential buildings exhibited a 13% reduction in lifetime energy consumption compared to conventional residential buildings.

3. Current challenges and development trends

3.1. Existing challenges

3.1.1. Shortage of expertise

While ultra-low energy buildings offer numerous benefits, they have not yet become a widespread housing option for the general population. Research and case studies have identified shortcomings in various aspects, including material availability, design considerations, and the availability of skilled professionals. These ultra-low energy buildings are relatively new, and as a result, there is a deficit in expertise.

3.1.2. Need for regulatory enhancements

Currently, the National Development and Reform Commission is actively promoting the establishment of a comprehensive policy framework for carbon peak and carbon neutrality. They are working on drafting high-level design documents for carbon peaking and carbon neutrality, as well as formulating action plans for carbon peaking policies related to energy conservation and emission reduction. Within these policy initiatives, the promotion of energy-saving and low-carbon development in the construction sector plays a crucial role. This involves supporting the development of ultra-low energy buildings and retrofitting existing structures for energy efficiency.

3.1.3. Acceptance among rural communities

Elevating the green and low-carbon standards of rural housing entails additional costs. Rural housing is

predominantly constructed by individual farmers in a decentralized manner, often resulting in small-scale projects. The incremental cost associated with individual construction can be substantial, posing a significant economic burden on farmers. Furthermore, there is a need to better coordinate efforts with the renovation of dilapidated rural houses and related initiatives to achieve a more synergistic approach. Therefore, it is essential to explore diverse, coordinated, and sustainable promotion mechanisms while continuously increasing efforts to promote these initiatives.

3.2. Emerging trends

In light of the national policies advocating carbon neutrality, energy conservation, and emission reduction, low-carbon energy-efficient buildings have garnered significant attention in recent years. Efforts are made to promote the use of renewable energy sources such as solar energy, geothermal energy, air thermal energy, and biomass energy in rural areas for gas supply, heating, and power supply [26]. Furthermore, there is a push to further enhance electrification in rural regions, encouraging the electrification of various energy-consuming aspects such as entertainment, heating, lighting, transportation, and hot water [27].

3.3. Progress toward low-carbon energy-efficient rural housing

Presently, national and local standards mainly focus on improving building energy efficiency and the design process but overlook other performance requirements and practical needs in construction, operation, renovation, and other phases. Consequently, there is no comprehensive guidance to enhance the green and low-carbon standards of rural housing. This results in suboptimal living conditions in rural homes, high levels of energy resource consumption, insufficient consideration of regional and historical cultural characteristics, incomplete public services and infrastructure support, and significant disparities between urban and rural areas.

4. Proposed research initiatives

4.1. Exploration of clean energy utilization in rural housing

To promote the adoption of eco-friendly and energy-efficient construction in rural areas, it is imperative to undertake energy-saving upgrades to existing rural homes. This involves enhancing the overall energy efficiency of rural residences, moving away from previous extensive building models, and fundamentally addressing the synergistic development of building energy efficiency and heating energy consumption. The goal is to establish a sustainable, long-term mechanism for development.

4.1.1. Technological advancements

(1) Solar heating and photovoltaic power generation: Achieving the organic integration of solar energy, building energy efficiency, and biomass heating offers a more comprehensive reflection of the advantages and sustainable potential of green energy-efficient heating in rural settings.

(2) Ground source heat pump systems and waste heat recovery fresh air systems: These systems can enhance energy efficiency in rural homes.

(3) Sunlight transmission for lighting and green shading: Innovative solutions for optimizing natural lighting and shading contribute to energy efficiency.

(4) Rainwater collection and on-site drainage: Implementing rainwater harvesting and localized drainage systems can improve resource utilization and reduce environmental impact.

4.1.2. Architectural design enhancements

(1) Space structure and natural ventilation: Implementing thoughtful spatial designs and natural ventilation strategies can enhance energy efficiency.

(2) Building enclosures and windows: Upgrading building enclosures and windows can significantly improve thermal performance.

4.1.3. Utilization of local crop waste

In rural areas of China, there is an abundance of straw resources and forestry residues that can be harnessed for energy production locally, demonstrating the economic and environmental advantages of biomass heating. Encouraging the exchanges of raw materials for processed particles can boost enthusiasm for waste utilization and foster the transition to biomass heating instead of relying on coal-to-gas or coal-to-electricity in rural areas.

4.2. Exploration of local construction techniques in rural housing

Designing low-carbon rural residences necessitates the active exploration of both passive and active technological approaches. Passive design strategies should be prioritized to reduce reliance on active technologies, subsequently lowering construction and operational costs. Simultaneously, active technologies should be employed to further improve energy efficiency, showcasing the pivotal role of technology in achieving energy conservation and consumption reduction [28].

Achieving the low-carbon emissions goal for rural residential buildings is contingent upon the combination of various low-impact technologies. These encompass the rational use of local environmental conditions and the cumulative impact of a series of low-impact technologies. This approach makes it feasible to reduce the carbon footprint of rural housing. Additionally, introducing appropriate low-carbon concepts, advocating a low-carbon lifestyle, cultivating a culture of low-carbon communities, and reasonably using low-carbon technologies are vital to improving the living standards and environmental quality of residents in these regions.

4.3. Preservation of rural housing heritage

The historical environment embodies the essence of urban development, serving as the backdrop for long-term human activities and encapsulating urban history and culture in tangible form. It holds profound cultural and spiritual significance [29]. Thus, the ecological construction of residential buildings must harmoniously integrate with the local historical and regional context to realize the concept of nurturing low-carbon structures within the ecological environment [30].

5. Conclusion

Based on the comprehensive review presented earlier, it becomes evident that several challenges persist in the realm of research on carbon emissions from rural buildings. Currently, most investigations primarily involve qualitative analyses, with a noticeable shortage of quantitative research. Furthermore, the bulk of existing studies predominantly concentrate on carbon emissions from residential buildings, neglecting the broader spectrum of rural construction

The findings from research on carbon emissions from self-built rural homes, especially in rural areas, often lack universal applicability. Moreover, China has yet to establish a sufficiently mature methodology and software for quantifying carbon emissions over the entire lifespan of buildings. These represent pressing issues that require resolution as China strives to develop low-carbon rural buildings and attain the objectives for energy conservation and emissions reduction.

To address these challenges, this research will involve an in-depth analysis of rural communities to discern disparities between self-built low-carbon design strategies and conventional low-carbon design approaches. By exploring optimization strategies tailored to the unique context of rural low-carbon development of villages, this paper aims to identify focal points for low-carbon development specific to southern and northern residential and non-residential structures. Additionally, an examination of the spatial transformation optimization results in self-built rural homes within communities will provide valuable insights for guiding future low-carbon optimization initiatives in the surrounding localities.

Disclosure statement

The authors declare no conflict of interest.

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Spatial Distribution and Influencing Factors of Urban Shrinkage from the Perspective of Factor Flow - A Case Study of National Urban Agglomerations

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Abstract: This paper examines national urban agglomerations by taking factor flows as the focal point as the research subject. By dividing the stages of urban agglomeration development, a comprehensive framework of urban shrinkage is constructed, encompassing economic, population, and social shrinkage. The study explores the spatial distribution characteristics of urban shrinkage during different stages of urban agglomeration and investigates the influencing factors using a geographic detector model. The findings reveal that urban shrinkage within urban agglomerations is widely spread, predominantly in peripheral areas. During the diffusion stage, urban shrinkage is scattered, with population shrinkage concentrated in peripheral regions, economic shrinkage concentrated on old industrial cities, and social shrinkage concentrated on the northeast. The outcomes of the geographic detector model indicate that traffic flow, capital flow, information flow, node importance, network connectivity, government investment, openness, and environmental regulations all play significant roles in shaping the spatial distribution of urban shrinkage.

Keywords: Urban shrinkage; Factor flow; National urban agglomeration

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1. Introduction

As the “new normal” of urban development under the interweaving effects of globalization, suburbanization, deindustrialization, local financial crisis, and social transformation, the concept definition, characteristic mode, formation mechanism, and coping strategies of urban shrinkage have sparked heated discussions [1]. As far as the definition of urban shrinkage is concerned, it shows the expansion characteristics from the single factor measurement of population size to the multi-dimensional factor [2], and gradually focuses on the accompanying problems such as economic decline, reduced fiscal revenue, vacant facilities, and increasing unemployment rate indirectly caused by population loss [3]. With the extension of the connotation of urban shrinkage, there

are diversified urban shrinkage modes in different regions. On the urban scale, there are not only the circle mode characterized by the decline of tax revenue in the city center and the deterioration of living environment promoted by suburbanization [4], but also the anti-circle mode of core prosperity and peripheral recession caused by the promotion of deindustrialization and gentrification [5], and the perforation mode represents a pattern of growth and shrinkage characterized by the disintegration of "unit compounds" and the simultaneous rapid growth of state-supported market enterprises following the social and economic transformation in East Germany [6]. On the regional scale, there are not only the shrinkage of big cities caused by the industrial transformation dilemma of the old industrial city promoted by the trend of "deindustrialization" [7], but also the small and medium-sized cities with marginal status, which are limited by the imperfect infrastructure and urban network, and are difficult to effectively participate in the international division of labor [8]. Briefly, urban shrinkage is a natural paradox between the free flow of population, capital, and many other factors, and the fixed characteristics of urban construction physical space [9]. Although not explicitly stated, there are inherent links between urban shrinkage and the flow of factors. However, there is still no direct evidence to determine whether the ability of cities to attract and distribute factors in the regional system affects the occurrence of urban shrinkage. At the same time, considering that the urban agglomeration strategy aiming at the free flow of factors will inevitably reshape the pattern of regional growth and recession by influencing the flow of factors, this paper takes national urban agglomerations as the research object, builds a framework of urban shrinkage including economic shrinkage, population shrinkage, and social shrinkage on the basis of dividing the development stages of urban agglomerations, explores the spatial distribution characteristics of urban shrinkage in different development stages, and investigates the complex relationship and differences between urban agglomeration factor flow and urban shrinkage in different stages through the geographical detector model, with a view to providing guideline for expanding the analytical perspective of urban shrinkage and promoting urban shrinkage governance.

2. Calculation method and data source

2.1. Measurement of urban shrinkage

This paper argues that urban shrinkage occurs among urban populations under market economy conditions during the transition from regional urbanization to advanced organizational forms. The migration of population, capital, industry, and other factors to high-efficiency areas in pursuit of maximum benefits leads to the restructuring of the regional urban spatial structure. Cities with strong factor aggregation capabilities experience growth, while those with weak factor aggregation capabilities shrink, resulting in the geographic reality of development opportunities being "deprived of space" [10]. Therefore, the formation of urban shrinkage is rooted in localization and embedded in globalization. Globalization influences the strengthening of regional cooperation, competition, and collaboration, which promotes factor flow and risk transmission among cities [11]. The weak "factor aggregation ability" of cities with inferior regional competitiveness causes the displacement effect of development factors [12], thus highlighting the need to discuss the formation mechanisms of factor flow and urban shrinkage from a network perspective. To comprehensively measure urban shrinkage, this paper adopts a multi-dimensional approach and constructs an index system encompassing population, economy, and society. The index system follows the principles of scientificity, systematicness, and accessibility [13]. The urban shrinkage index is calculated using the entropy method. The results are presented in **Table 1**.

Table 1. Urban shrinkage evaluation indicator system

First-level index	Second-level index	Three-level index	Weight
Population shrinkage (0.5)	Population size	Resident population in municipal districts	0.10
	Population structure	Natural growth rate	0.04
	Population density	Population density of municipal districts	0.10
	Population vitality	College students' proportion	0.26
Economic shrinkage (0.25)	Economic growth	Gross domestic product (GDP) growth rate	0.01
	Economic structure	Value added of tertiary industry/value added of secondary industry	0.03
	Economic density	GDP/area ratio of municipal districts	0.15
	Economic level	GDP per person	0.06
Social shrinkage (0.25)	Educational facilities	Middle school teacher-student ratio	0.02
	Medical facilities	Hospital beds per thousand people	0.12
	Living environment	Green coverage rate of municipal districts	0.01
	Social consumption	Total consumption of social retail goods	0.11

2.2. Analysis of urban shrinkage mechanism

2.2.1. Variable selection

The formation of urban shrinkage reflects the multi-dimensional effect of different factors, thus this paper chooses the geographical detector model to reveal the driving mechanism of factors [14]. The core driving force of urbanization lies in the improvement of urban factor aggregation ability [15], and shrinking cities are essentially the product of the outflow of urban population, industry, capital, and other factors, and the economic downturn, which affects the ability to aggregate urban factors, forming an organic unity of processes-phenomena-problems [16]. Therefore, this paper attempts to explain the formation mechanism of urban shrinkage from the perspectives of factor flow, urban network, and economic transition, as shown in **Table 2**.

Table 2. Indicator system for analysis of urban shrinkage formation mechanisms

First-level index	Second-level index	Three-level index	Code
Factor flow	Traffic stream	Number of trains between different cities in urban agglomeration	TF
	Material flow	The relative importance of 15 logistics companies in different cities of urban agglomeration	MF
	Capital flow	The relative importance of four big banks among different cities in urban agglomeration	FF
	Information flow	Measurement of Baidu users' attention intensity between different cities in urban agglomeration	IF
City network	Node importance	City grade	IN
	Node accessibility	Number of high-speed rail stations	AN
	Network connectivity	Time distance from the nearest core city	NC
Economic transition	Industrial employment	Number of manufacturing employees	IE
	Industrial structure	Change rate of secondary industry's proportion in GDP	IS
	Openness	The actual amount of foreign capital used	LO
	Environmental rules	Utilization ratio of industrial solid waste	ER
	Government investment	The total investment in fixed assets	GI

2.2.2. Data sources

Taking 10 national urban agglomerations approved by the State Council, the Central Committee of the Communist Party of China in 2020 as the empirical analysis object, the basic geographical unit is defined as cities above prefecture level. The data comes from the Statistical Yearbook of China City (2011–2021), statistical yearbooks of relevant provinces, and statistical bulletins of relevant cities. The basic data of geographic information comes from the database of National Geographic Information Center. The data of traffic flow comes from the trains between cities in the 12306 website (https://www.12306.cn/). Material flow data comes from the statistics of logistics outlets of 15 logistics companies in cities of Express Network (http://www.kuaidi.com/). The data of capital flow comes from the statistics of bank outlets in the official websites of major banks, including tier-one branches, tier-two branches, and sub-branches. The information flow data comes from Baidu users' attention among cities in Baidu Index website (https://index.baidu.com/) [17]. The time distance from the nearest core city is measured by Baidu map.

3. Urban agglomeration development stage and spatial characteristics of urban shrinkage

3.1. Urban agglomeration development stage

In this study, the Jaffe index |q| of rank scale rule is used to judge the development stage of urban agglomeration, so as to further explore the relationship between urban agglomeration stage and urban shrinkage. Using SPSS software, the rank-scale log regression model of national urban agglomerations is constructed. The results show that the fitting degree R^2 of the model is above 0.65, and it passes the significance test of 0.01 confidence interval. According to the analysis results in **Table 3**, national urban agglomerations are divided into two categories: agglomeration and diffusion. In the stage of agglomeration, the |q| value of urban agglomerations presents a gradually increasing change feature, including eight urban agglomerations of Hubao Eyu, Zhongyuan, Hachang, the middle reaches of the Yangtze River, Beibu Gulf, Lanxi, Guanzhong Plain, and Chengdu-Chongqing. In the stage of diffusion, the |q| value of urban agglomerations presents a gradually decreasing change feature, including the Yangtze River Delta and Guangdong, Hong Kong, and Macao.

Table 3. |q| values for the rank order size of national-level urban agglomerations

Stage	City cluster	2000	2005	2010	2015	2020
Tendency to concentration	Hohhot Baotou Erdos Yulin	0.42	0.51	0.59	0.62	0.69
	Central Plains	0.45	0.55	0.62	0.69	0.72
	Hachang	0.69	0.72	0.78	0.81	0.85
	Lanxi	1.04	1.15	1.22	1.29	1.34
	North	0.82	0.88	0.94	0.98	1.02
Trend dispersion	Middle reaches of Yangtze River	0.61	0.75	0.80	0.84	0.88
	Central Shaanxi	1.21	1.31	1.26	1.34	1.42
	Chengyu	1.11	1.23	1.28	1.31	1.39
	Yangtze River Delta	1.33	1.28	1.24	1.17	1.13
	Guangdong, Hong Kong, and Macao	1.03	1.01	0.98	0.90	0.89

3.2. Spatial distribution characteristics of urban shrinkage

On the basis of calculating the weight of each index, this paper calculates the urban shrinkage of each prefecture-level city in the national urban agglomeration and the three dimensions that constitute the urban shrinkage, namely, population shrinkage, economic shrinkage, and social shrinkage, and uses the natural fracture method to classify and visualize the grades. Based on the spatial distribution of urban shrinkage, the urban shrinkage of urban agglomerations in the trend of agglomeration is relatively scattered, and most of them are located in the peripheral areas of urban agglomerations. Among them, the urban shrinkage of Hachang urban agglomeration and Lanxi urban agglomeration is widely distributed, while the urban shrinkage of urban agglomerations in the middle reaches of the Yangtze River and the Central Plains is mainly distributed in the peripheral areas of urban agglomerations. This shows that Northeast China, as an old industrial base of the country, is under the influence of many constraints such as industrial transformation, resource depletion, and institutional environment. The trend of population outflow and industrial recession in Northeast China is obvious, and the risk of urban shrinkage continues to rise, while the living environment in the western region is harsh. Except for the regional central city, which can attract the inflow of population and industrial factors through economic agglomeration effect, the surrounding cities are facing the dilemma of factor loss, and there is a trend of urban shrinkage. Although the central region is also facing the situation of population outflow, but it benefits from the industrial transfer and the subsequent "population return" movement, the high-density and large-scale rural population provides enough resilience for urban population agglomeration, so urban shrinkage is only scattered around urban agglomerations. The shrinkage of urban agglomerations in the trend diffusion stage is characterized by scattered distribution, which shows that with the formation and stability of urban agglomeration network structure, surrounding cities gradually integrate into the urban system and achieve self-growth, thus reducing the possibility of urban shrinkage.

Based on the spatial distribution of population shrinkage, the population shrinkage of urban agglomerations in the trend of agglomeration is concentrated in the peripheral areas of urban agglomerations, among which the population shrinkage of Hachang urban agglomerations and Lanxi urban agglomerations spreads in the non-core areas of urban agglomerations, while the urban shrinkage of urban agglomerations in the middle reaches of the Yangtze River and the Central Plains is mainly distributed in the peripheral areas of urban agglomerations, and the population shrinkage of urban agglomerations in the trend of diffusion is scattered in the marginal areas of urban agglomerations. This shows that population mobility is an intuitive reflection of "voting with their feet" under the comprehensive effect of employment opportunities, public services, living environment, and many other conditions in different cities. With the function of agglomeration-diffusion mechanism of urban agglomerations, the population presents a process of mobility from rural areas to cities and from small cities to big cities, and indirectly affects the population structure and population vitality of the places where the population flows out, forming a peripheral pattern of population shrinkage in urban agglomerations.

Based on the spatial distribution of economic shrinkage, economic shrinkage is concentrated in the old industrial cities. With the transformation of energy structure and the exhaustion of resources, the old industrial cities are facing the dilemma of having to be transformed, but limited by labor structure, urban environment, management structure, and path dependence, the transformation process of the old industrial cities may face the risk of economic recession. Based on the spatial distribution of social shrinkage, social shrinkage is concentrated in Northeast China, which shows that the long-term stagnation of economic development in Northeast China leads to the decrease of local fiscal revenue and the phenomenon of social shrinkage.

4. Analysis of influencing factors of urban shrinkage from the perspective of factor flow

This paper takes prefecture-level cities in national urban agglomeration as the basic spatial analysis unit, and takes whether there is urban shrinkage as the explained variable to analyze driving factors in the process of urban shrinkage formation, as shown in **Table 4**.

From the perspective of factor flow, traffic flow, capital flow, and information flow, all of them have a significant impact on the spatial distribution of urban shrinkage, which shows that factor flow plays an important role in the formation of urban shrinkage. The flow of factors helps to change the distribution of factors in cities, enhance the complementarity of factors among cities, promote the free flow and cooperation of factors such as labor and capital among cities, achieve the coordinated development among different cities, and reduce the possibility of urban shrinkage. However, the influence of material flow on the spatial distribution of urban shrinkage is not significant, which may be because on the one hand, the flow of goods is the result of many factors such as population size, urban location, and traffic conditions, and the node position and logistics position of urban system structure are more closely related to material flow. On the other hand, due to limitation by the availability of data, this paper uses the relative importance of logistics companies to reflect the intensity of material flow, which makes it easier to amplify the influence of the node position of urban architecture on material flow. From the perspective of urban network, the importance of nodes and network connectivity has a significant impact on the spatial distribution of urban shrinkage, indicating that the higher city level can attract the surrounding population, resources, and other factors to the city through agglomeration effect and siphon effect, and promote the urban population scale and rapid economic growth. From the perspective of economic transformation, government investment, openness, and environmental regulation, all of them have significant effects on the spatial distribution of urban shrinkage. This shows that with the improvement of urban fixed assets investment and the use of foreign capital, it will promote industrial development, attract the surrounding population to concentrate in cities, raise the level of local fiscal revenue, and build a virtuous circle of urban growth. Environmental regulation plays an important role in the formation of urban shrinkage, which may be because the improvement of environmental regulation level means the upgrading of urban industries, further improving the production efficiency of cities and attracting the influx of talents, funds, and other factors.

5. Conclusion

This paper took national urban agglomerations as the research object, and on the basis of dividing the development stages of urban agglomerations, it constructed a framework of urban shrinkage including economic shrinkage, population shrinkage, and social shrinkage, explored the spatial distribution characteristics of urban shrinkage in different development stages of urban agglomerations, and investigated the influencing factors of urban shrinkage in different stages of urban agglomerations through the geographic detector model, and the following conclusions were drawn:

(1) The shrinkage of urban agglomeration is widely distributed, and most of them are in the peripheral areas of urban agglomeration. The shrinkage of urban agglomeration in the stage of diffusion presents the characteristics of scattered distribution. The population shrinkage of urban agglomerations in the trend of agglomeration is concentrated in the peripheral areas of urban agglomerations, while the population shrinkage of urban agglomerations in the trend of diffusion is scattered in the marginal areas of urban agglomerations. Economic shrinkage is concentrated in the old industrial cities. Social shrinkage is concentrated in Northeast China.

Table 4. Factors influencing urban shrinkage at different stages of development

Index	City cluster				Trend agglomeration				Trend dispersion			
	Comprehensive shrinkage	Population shrinkage	Economic shrinkage	Social shrinkage	Comprehensive shrinkage	Population shrinkage	Economic shrinkage	Social shrinkage	Comprehensive shrinkage	Population shrinkage	Economic shrinkage	Social shrinkage
IN	0.16***	0.16***	0.01	0.03*	0.11***	0.15***	0.01	0.02	0.11	0.01	0.03	0.01
AN	0.03	0.03	0.03	0.03	0.01	0.01	0.01	0.01	0.01	0.03	0.36**	0.18
NC	0.05*	0.09**	0.02	0.01	0.08**	0.12***	0.03	0.01	0.03	0.05	0.10	0.05
IE	0.01	0.01	0.05	0.01	0.01	0.01	0.06*	0.01	0.09	0.16	0.04	0.06
IS	0.03	0.04*	0.08*	0.01	0.02	0.03	0.06*	0.01	0.01	0.01	0.15	0.07
ER	0.06**	0.12***	0.02**	0.02	0.04	0.10**	0.04	0.01	0.04	0.02	0.21	0.10
GI	0.17***	0.18***	0.02	0.04*	0.12***	0.13***	0.02	0.04	0.25	0.19	0.17	0.31*
LO	0.11***	0.13***	0.04	0.03	0.09**	0.09**	0.04	0.02	0.02	0.03	0.06	0.18
TF	0.12**	0.12**	0.11	0.04	0.10**	0.17**	0.02	0.01	0.11	0.11	0.03	0.01
MF	0.06	0.05	0.05	0.03	0.03	0.02	0.04	0.02	0.04	0.01	0.02	0.01
FF	0.09***	0.08**	0.08***	0.02	0.15**	0.01	0.07**	0.01	0.14	0.01	0.02	0.01
IF	0.11**	0.09**	0.06**	0.03	0.11**	0.03*	0.02	0.03	0.17	0.02	0.01	0.01

(2) From the results of the geographical detector model, from the perspective of factor flow, traffic flow, capital flow, and information flow, all of them have significant effects on the spatial distribution of urban shrinkage. From the perspective of urban network, the importance of nodes and network connectivity has a significant impact on the spatial distribution of urban shrinkage. From the perspective of economic transformation, government investment, openness, and environmental regulation, all of them have significant effects on the spatial distribution of urban shrinkage.

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Disclosure statement

The authors declare no conflict of interest.

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Overview of Design and Construction Points Analysis for the Rotating Continuous Girder Bridge

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Abstract: With the advancement of the economy, the construction of roads and bridges has assumed a crucial role in the development of China's highway transportation system. The interplay between the design and construction technologies of road bridges is pivotal, as it directly impacts the subsequent operation and maintenance phases. Although the design and construction techniques for continuous girder transitions have been progressively improving, challenges still persist. This paper takes the example of the continuous girder design for the T-structure (75 m + 75 m) of the Xintai Highway Crossing Yanzhou-Shijiusuo Railway Separation Interchange Project and delves into an analysis of the structural design calculations for the bridge transition, the transition structure's design, and critical considerations during construction. The findings presented here can serve as a valuable reference for similar project designs.

Keywords: Bridge design; Continuous girder; Transformer bridge

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1. Project overview

The Yanzhou-Shijiusuo Railway comprises two electrified railroad tracks, and the bridge under consideration spans both the upper and lower lines of the railway. This specific section pertains to the roadbed, with a roadbed filling height of approximately 1 m, and experiences significant railway traffic.

The section of the Xintai to Taierzhuang (Lu-Su border) highway, situated between Xintai and Malantun of Taierzhuang, encompasses a design scope that extends from the starting point at milepost K45+631.0 to the endpoint at milepost K45+841.0, with a total length of 210 m. The bridge intersects with the Yanzhou-Shijiusuo Railway, with the highway's milepost at K45+743.6 and the railway's milepost at K104+700. The intersection angle is set at 50°. Following the railway department's specifications, a T-structure with an uninterrupted span is employed for the bridge crossing over the railroad. The bridge across the Yanzhou-Shijiusuo Railway is designed to incorporate the full width of a transverse T structure, ensuring that the clearance width meets the railroad's passage limit requirements, with a minimum clearance height of ≥ 8.5 m. Upon the completion of both bridges, they will be capable of accommodating double-decker container transportation beneath them.

The span arrangement consists of 2 × 75 m T-type rigid structures and 2 × 30 m simply supported small box girders, with a right deviation angle of 90°. The main bridge utilizes a 2 × 75 m T-type rigid structure transfer construction, with each transfer span measuring 2 × 70 m.

2. Structural analysis and calculations of the main bridge

2.1. Load calculation and combination

The components for load calculation are as follows:

(1) Permanent load: The permanent load in the first phase includes the self-weight of the main girder and diaphragm beam, among others. Self-weight is calculated based on the actual cross-sectional properties, with a capacity of 26 kN/m^3. The permanent load in the second phase includes the sidewalk, anti-collision guardrail, anti-throwing net, bridge deck pavement, etc., and is calculated at 218 kN/m^3.

(2) Creep and shrinkage coefficient: Determined according to the "Design Code for Highway Reinforced Concrete and Prestressed Concrete Bridges and Culverts" (JTG D62-2004) [1].

(3) Prestressing force: Controlled tension under anchoring is set at 1,395 Mpa, with a pipe resistance coefficient $\mu = 0.15$ and a pipe deviation coefficient $\kappa = 0.0015$. Additionally, the anchorage deformation and beam retraction value (at one end) $\Delta = 6$ mm.

(4) Live load: 1.3 times the highway = Class I load

(5) Temperature: The effective temperature action effect considers a concrete structure temperature difference of 34°C for heating and -10°C for cooling. The gradient temperature of the main girder is determined according to the "General Specification for the Design of Highway Bridges and Culverts" (JTG D60-2015) [2].

(6) Foundation displacement (uneven settlement): assumed to be 10 mm.

The load combinations include:

(1) Combination 1: Permanent load + Live load

(2) Combination 2: Permanent load + Live load + Heating effect + Braking force

(3) Combination 3: Permanent load + Live load + Cooling effect + Braking force

(4) Combination 4: Permanent load + Heating effect + Longitudinal wind load limit

The heating effect is the addition of a positive temperature difference system with the main beam gradient heating, whereas the cooling effect is the addition of a negative temperature difference system with the main beam gradient cooling.

2.2. Analysis and calculation

The main bridge superstructure is designed as a fully prestressed concrete member. Transverse calculations adhere to the design standards for Class A prestressed concrete and reinforced concrete members, while the substructure is designed as reinforced concrete biased members, and the pile foundation follows the column pile design approach.

3. Rotary structure

The rotary structure consists of several key components, including the lower turntable, rotary support, upper turntable, and rotary traction system (see **Figure 1**).

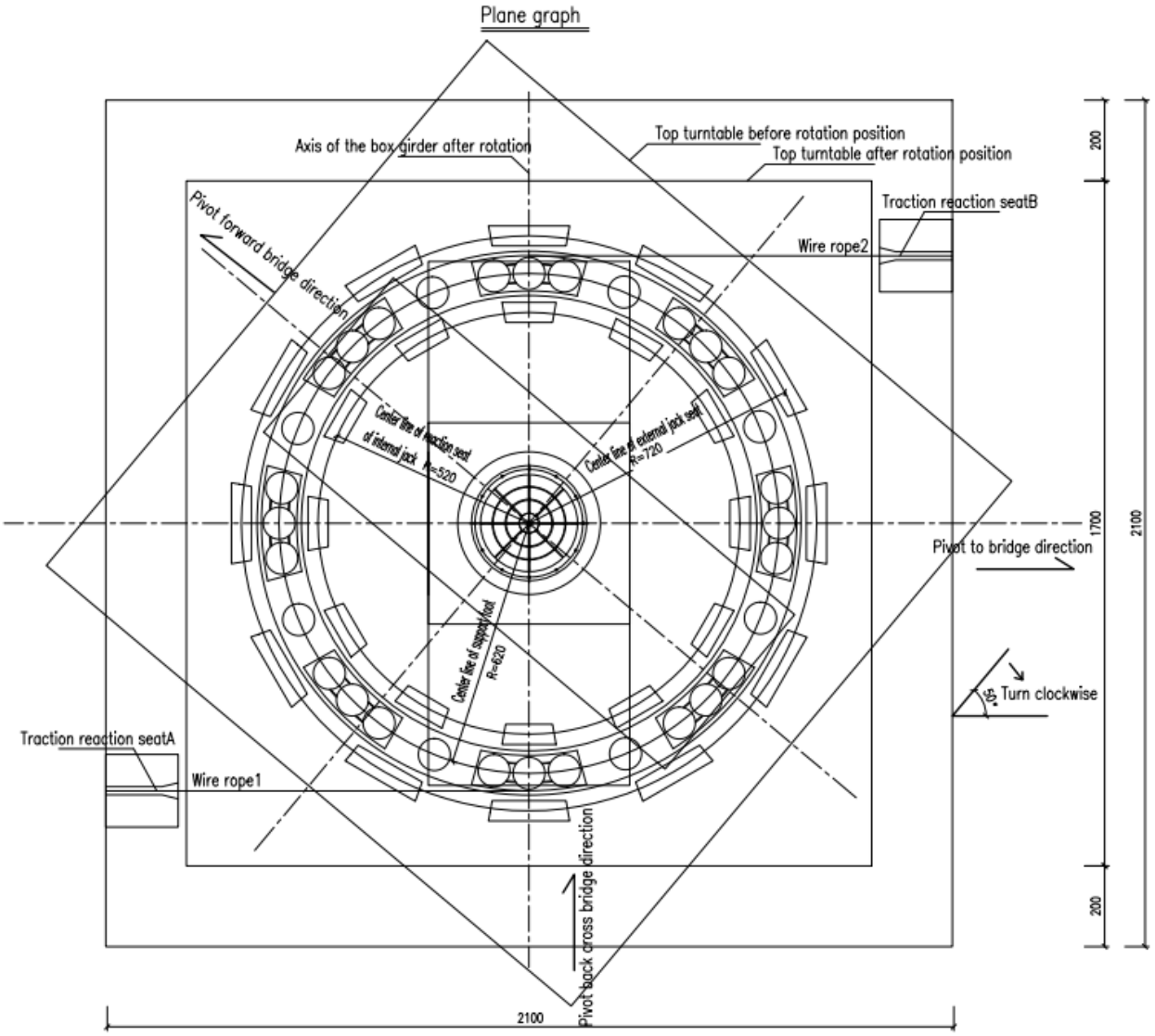


Figure 1. Plan view of the main pier turning structure

3.1. Lower turntable

The lower turntable serves as the foundation supporting the entire weight of the rotary structure. After assembly, it forms the foundation together with the upper turntable. The lower turntable is constructed using C40 concrete and incorporates various elements, including the turntable system's support, a ring slide made of steel pipe concrete support feet, and a turntable drag jack reaction seat. The clearance between the legs and the slide is set at 20 mm. To initiate, stop, and finely adjust the position of the rotary structure, a jack counterweight is employed.

3.2. Rotary support

The rotary bearing adopts a ZTQZ-190000 ball-type bearing. The concrete base's strength grade is no less than C50, with a height of 65.5 cm. The height difference among the top four corners must not exceed 5 mm. Before device installation, the top surface of the base is chiseled, and a 30 mm thick layer of M80 epoxy resin mortar is applied. The device is then installed, compacted, and leveled, ensuring that the relative height difference on the top surface does not exceed 1 mm. The connection between the rotary support and the base is achieved through

ground bolts and sleeve screws. Holes are pre-drilled on the top surface of the base, with a diameter ranging from 70 to 100 mm and a depth of 70 to 100 mm. The deviation between the center of the reserved hole and the center of the support should not exceed 5 mm.

3.3. Upper turntable legs and chutes

The upper turntable support legs function as safety supports to maintain the smooth operation of the turntable during rotation. To evenly distribute the load during rotation, the centerlines of the two symmetrical safety legs align, ensuring that all eight safety legs are symmetrically arranged on both sides of the longitudinal axis. Under each support leg (i.e., the top surface of the lower plate), there is a 1.5 m wide chute with a radius of 6.2 m at the chute's centerline. This allows the safety support legs to slide within the chute during rotation, ensuring the stability of the rotating structure. The entire sliding mechanism must maintain a horizontal plane, with a relative height difference not exceeding 2 mm. Each upper turntable is equipped with eight groups of cylindrical support feet, each featuring a 24 mm thick steel walking board. The cylinder itself is constructed from Φ 800 mm × 24 mm steel pipe, into which C50 non-shrinkage concrete is injected.

3.4. Upper turntable

The upper turntable plays a critical role in the overall structural stability during rotation, experiencing multi-directional and three-dimensional stresses. The upper plate is reinforced with longitudinal and transverse prestressing steel bars. The upper turntable is rectangular, with a height of 3.5 m. It has a diameter of 13.4 m and a height of 0.8 m. The turntable is the point of connection for the rotating body device, the supporting feet, and the upper turntable. It also directly experiences the traction force applied to the rotating body. Inside the turntable, traction cables are pre-embedded, with P-type anchorage used at the pre-embedded ends. These cable anchorages are symmetrically positioned along the same diameter line in the center of the circle. It is crucial to ensure that the pre-embedded height and traction direction of each cable are consistent. Each cable buried in the turntable must be at least 3 m in length, with exit points symmetrically arranged at the center of the turntable.

The upper turntable is constructed using C50 concrete. Once the concrete on the upper plate reaches its design strength, the entire turntable system is converted into a support system. The cushion plate is removed, allowing the turntable to be supported by the rotating body device. Rotating torque is applied to initiate the turntable's rotation along the center axis of the rotating body device. A thorough assessment is conducted to verify the proper operation of the rotating body device, determine its friction coefficient, and provide the basis for further construction of the rotating body.

The friction coefficient is calculated using the following formula:

$$\mu = 3 \times M \div (2 \times R \times G)$$

Here, represents the friction coefficient, represents the torque of the rotating body (in Newton-meter), represents the radius of the plane of the rotating device (in meters), and represents the total weight of the turntable (in tons).

The design static friction coefficient is 0.1, while the kinetic friction coefficient is 0.06. If the measured actual friction coefficient significantly deviates from the design value, a thorough analysis is conducted to identify the causes and implement appropriate adjustments.

4. Guiding construction plan

4.1. Substructure construction

The substructure of this bridge utilized drilled pile foundations, employing conventional construction methods to complete the construction of the side pier section of the pier body, as well as the main pier rotary support and bearing platform. Once the bearing construction is completed, support structures are placed on the pallet framework to secure the pre-embedded parts of the slipway. It is crucial to note that the entire bearing platform and slipway must ensure the flatness of the entire T structure while also withstanding the substantial load of up to 19,000 tons imposed by the pier and the main girder. As such, the concrete compactness and slipway smoothness requirements are exceptionally high. The design specification mandates that the slipway's levelness must not exceed 2 mm. To address potential temperature-induced deformation cracks in the large-volume concrete of the bearing platform, construction guidelines for relevant content are referred to.

4.2. Pier column and main beam construction

The pier is constructed using the full-tower bracket method. For the box girder construction, a bowl buckle-type steel pipe scaffolding is erected on the solidified foundation, and the girder is cast in sections using the bracket method.

4.3. Weighing

The T-structure relies on a self-balancing system, necessitating the assurance of a balanced moment between the transverse bridge and the center of the turntable. Before the rotation, the body must undergo weighing to verify this balance. If the rotating body is found to be unbalanced, adjustments are made using counterweights on the girder. The weighing process involves:

(1) Installing counterweights, jacks, and sensors at the beam's end.

(2) Applying an upward load to one end to lift the beam, simultaneously monitoring the moment of rotation using a displacement meter set between the turntable and the bearing platform. The jacking force from the sensor is recorded.

(3) Calculating the moment from the jacking force and the force arm.

(4) Applying the moment equilibrium equation for the center of the bearing to calculate the bearing resistance.

Under normal circumstances, the moment resistance of the rotating support exceeds the unbalanced moment of the rotating body. However, if significant construction errors are present, the moment resistance of the rotating support may fall short of the unbalanced moment of the rotating body.

4.4. Flat turn traction system

The flat-turn traction system comprises the traction counterweight, the upper turntable, and traction ropes. The installation steps are as follows:

(1) Cleaning the tensioning groove on the counterweight and the periphery of the upper turntable, removing any rust or impurities on the hauling rope's surface [3].

(2) Placing the platform behind the counter-force seat, adding a padding plate in the stressed area behind the counter-force seat, and ensuring that the jack is correctly installed.

(3) Straightening the traction cable steel hinges, winding them around the upper turntable about 3/4 of the way, and inserting the free end into the jack counter-force seat tensioning slot. The strands must remain straight, without twisting or kinking.

(4) Introducing the steel hinged line sequentially into the jack anchor ring, clip sheet, support foot, jack, anchor ring, and clip sheet to assemble the LSD200-type continuous tensioning jack.
(5) Installing the oil pipe and distribution cabinet.
(6) Conducting adjustments to the jack, traction cable, anchorage, and pump station.

4.5. Boosting system

The boosting system is used to overcome the difference between static and dynamic friction torque, enabling the initiation of the entire rotating body. The system consists of the boosting distribution beam and the boosting jack, which is placed between the steel pipe support foot of the turntable and the boosting counter-force seat.

4.6. Fine adjustment system

To correct any offset that may occur during the rotation of the rotating body, four YCW6000 jacks are placed under the turntable. These jacks are used to fine-tune the orientation of the rotating body in both the bridge's longitudinal and transverse directions. The positioning is carried out symmetrically.

4.7. Limit system

To prevent the girder from continuing to move forward after rotating into position, a limiting system is installed by placing the booster jack and the counter-force seat in the reverse direction under the booster counter-force seat before the rotating body reaches its final position.

4.8. Measurement and monitoring markers

Before the transfer, corresponding line monitoring points should be established on the beam and turntable. This mainly includes the following points:

S/N	Type of measurement point	Measurement point location	Requirements and uses of measurement points
1	Girder linear measurement points	Centerline of girder face and end of girder	Monitor changes in girder alignment by taking one section every 5 meters
2	Level observation point	Middle and sides of girder top	Monitor the change of girder elevation (deflection and lateral inclination)W
3	Limit observation point	Girder end of closing opening, side of turntable	Rotary body leveling and positioning control
4	Rotation speed observation point	Between footing and chute	Control the linear speed of the rotating body
5	Cross-bridge inclination measurement point	Upper turntable and bearing platform	On the same horizontal plane, observe the inclination of the rotating body in the transverse direction

4.9. T-structure turn

The transformation process is a critical phase in the entire T-construction project and involves the following steps:

(1) Cleaning both the inside and outside of the box girder, removing any debris and excess load. A thorough review of key components is conducted, including pier and beam consolidation points, upper turntable, ball hinge, and other elements, with confirmation and verification.
(2) Ensuring that monitoring personnel and instruments are in position.
(3) Removing the weighing bracket and the supports in front of the girder's bottom, allows it to stand for 24 hours. Subsequently, stress and line monitoring is performed to confirm equilibrium.
(4) Conducting an on-site technical briefing and assigning specific tasks to each observation point,

controlling signals, communication links, and other personnel, with a clear and comprehensive division of labor.

(5) Closing off each traffic intersection and initiating the formal rotation of the body.

(6) Tensioning the flat-turn traction cable and maintaining tension until the cable force reaches the designated traction force, while also maintaining the oil pressure.

(7) Activating the booster jack and applying a graded load of 100 kN symmetrically to the center of the turntable according to the design booster.

(8) Continuously applying traction force to the jack until the structure initiates movement, ensuring a uniform and controlled flat rotation of the turntable, with an angular velocity not exceeding 0.02 rad/min.

(9) While maintaining a constant-speed rotation, monitoring personnel continuously observe and survey the axial deviation of the bridge piers and the elevation changes at the girder's ends.

(10) When the rotating body approaches the edge of the girder body close to the side pier, a limit system is installed simultaneously between the upper and lower turntables.

(11) When the centerline of the girder's end of the rotating body is approximately 1 m away from the designated position, the oil supply to the traction cable jack is reduced to decelerate the rotating body.

(12) Continuous monitoring of the beam end's centerline, commanding the oil pump station to move to the beam center axis aligns with the axis of the beam. A coping pad is placed between the limit distribution beam and support foot to prevent the rotating body from sliding further and ensuring it reaches its intended position.

4.10. Fine positioning

After the rotating body reaches its final position, comprehensive measurements are taken to assess deviations in the axis and elevation of the beam body. The boosting system, fine-tuning system, and leveling traction system collaborate to precisely align the ends of the girder through the displacement of the entire rigid body and local deformations at the girder's end.

4.11. Other

The turning gear is removed, and the top support of the side pier is promptly installed, enabling progress to the joint section construction phase.

5. Technical requirements and precautions for the installation of the rotational device [4]

(1) During the assembly of the turning device in the factory, meticulous attention should be paid to ensuring proper leveling. The upper and lower seat plates must be precisely centered, and temporary connecting devices should be employed to assemble the components into a single structure, securely locking them in place. These temporary connecting devices should not be dismantled or loosened before the final bridge rotation. When transporting and lifting the device, it should be handled carefully to avoid any violent impacts that could alter the device's alignment.

(2) Before installing the rotational device, a thorough inspection of the device's connections should be conducted to ensure they are in proper working order. However, the temporary connecting devices should not be arbitrarily loosened.

(3) On-site installation of the rotational device should include the fitting of upper and lower ground bolts

and socket screws. It is advisable to install these components in a position where epoxy mortar is not yet applied, confirming the correct positioning of the reserved holes.

(4) The areas of the base surface where the device will be placed should be chiseled as necessary. Debris within the holes should be removed, and three support pads should be positioned along the edges of the device's placement area, ensuring that the top surface of these pads has a height difference of no more than 1 mm.

(5) Prior to grouting, an initial calculation should be made to determine the required volume of slurry. The amount of slurry used in the grouting process should closely align with the calculated value, avoiding excessive slurry or insufficient coverage in the middle. The compressive strength of epoxy resin mortar should not be less than 80 MPa.

(6) Following the calculation of the required amount of epoxy resin mortar, the components should be proportioned and thoroughly mixed. The entire batch of mixed mortar should be centrally piled up within the device's placement area. The rotational device should then be slowly lowered into place, relying on its own weight to compress the mortar effectively. Care should be taken to ensure that the epoxy resin mortar does not enter the sleeve screw in the reserved hole. Prior to the solidification of the mortar, the height difference between the upper seat plate of the device should not exceed 1 mm.

(7) In line with the calculated quantity, a high-strength non-shrinkage grout should be proportioned and stirred. The gravity grouting method should be used to fill the reserved holes in the base and thoroughly compact the grout until it is observed to fill the gap between the edge of the device and the hole's edge.

(8) After the grout beneath the device has solidified, protective measures should be implemented at the gap between the upper and lower seat plates of the device. This prevents debris from entering the device prior to the bridge's rotation and safeguards the sensors and sliding surface of the device.

6. Conclusion

The Yanzhou-Shijiusuo Railway Bridge stands as the sole railway bridge along the Xintai Expressway, representing one of the most challenging engineering endeavors. This bridge construction project entailed a substantial scale, a tight construction schedule, elevated safety risks, advanced technical complexities, and intricate process methodologies. This paper documents the successful execution and subsequent opening of this vital infrastructure, delivering commendable social and economic advantages. It serves as a valuable reference for similar projects in the future.

Disclosure statement

The author declares no conflict of interest.

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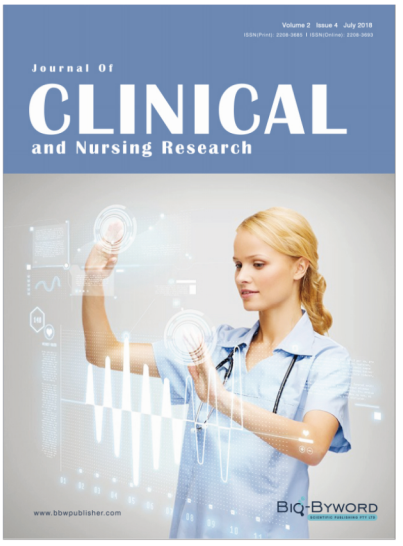
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