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Quality Evaluation of Highway Bridges in High Altitude Areas of Qinghai-Tibet

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Abstract

Relying on the reconstruction project of Naqu to Lhasa highway of National Highway 109, the quality inspection of Dangqu Special Bridge and Cross Qinghai-Tibet Railway Special Bridge, which are two control projects of comparable scale, was carried out by combining appearance inspection and physical inspection methods, which informed the quality condition of the construction of bridges in high-altitude areas of Qinghai-Tibet and elaborated the advantages of the combination of the two quality inspection methods. The quality inspection results show that the quality of Dangqu Special Bridge is obviously better than that of the Cross Qinghai-Tibet Railway Special Bridge, and the two bridges are qualified in the overall inspection, but both of them need to be improved in quality.

Keywords

High Altitude; Special Bridge; Appearance Inspection; Physical Inspection.

1. Introduction

Due to its special geographical environment and climatic conditions, highway Bridges in high-altitude areas are faced with many challenges, such as low temperature, strong wind, hypoxia, frozen soil, etc., which have a significant impact on the quality and durability of Bridges [1, 2]. Therefore, it is crucial to establish a scientific, comprehensive and applicable highway bridge quality evaluation method in high-altitude areas [3, 4]. It can not only ensure the quality of the bridge in the construction process, but also effectively monitor the health status of the bridge in operation, timely detect potential problems, and ensure the safety and smooth traffic [5].

The traditional bridge quality evaluation methods mainly include appearance inspection, load test, material performance test and so on. Through visual inspection of the appearance of the bridge structure to check whether there are cracks, spillage, deformation and other diseases, it can directly reflect the condition of the bridge surface, but it is difficult to find the internal hidden diseases. Load test is to assess the bearing capacity of the bridge by applying different levels of loads to the bridge and measuring the response of the structure such as deformation and stress. However, this method is expensive, complicated and interferes with normal traffic to some extent. The material performance test is mainly aimed at the steel, concrete and other materials used in the bridge to detect its strength, elastic modulus and other indicators, and judge the bridge quality from the material level, but it cannot fully reflect the overall performance of the structure.

With the development of technology, non-destructive testing technology has gradually been widely used, such as ultrasonic detection, radar detection, infrared thermal image detection, etc. [6, 7]. Ultrasonic detection can be used to detect defects inside the concrete, such as holes, crack depth, etc.

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Radar detection can image the internal structure of the bridge structure, and find the problems of steel corrosion and layering. Infrared thermal image detection determines the damage inside the structure according to the temperature difference of the object surface. These non-destructive testing technologies make up for the shortcomings of traditional detection methods to a certain extent, and improve the accuracy and efficiency of detection. However, the cost of non-destructive testing technology is high, and the applicability of high altitude areas is not strong, so to learn from its strengths and weaknesses, mixed with some conventional testing methods, such as rebound method, scale, level measurement, etc., the formed method is called physical detection, which can be better applied to the quality detection of Bridges in high altitude areas. Therefore, this study relies on actual engineering cases, with physical inspection as the main appearance inspection as the assistance, to carry out bridge quality inspection and evaluation.

2. Project Overview

The third section of the National Highway 109 Naqu to Lhasa Highway reconstruction project (Naqu to Yangbajing section) is located in Dangxiong County, Lhasa City, with a total length of 77.749 kilometers. A total of 42 Bridges (excluding small Bridges) will be built in the section, of which 2 are very large Bridges, namely K3716+448.8 Dangqu Bridge and K3754+401.76 trans-Qinghai-Tibet Railway Bridge; 25 Bridges; Middle bridge 15. The main line of the project adopts the standard of bidirectional four-lane first-class highway, with the design speed of 120 km/h, the width of the integral roadbed is 26 meters, the width of the bridge is 25.5 meters, the width of the separated roadbed is 13 meters, the width of the bridge is 12.5 meters. The load standard of bridge culvert adopts the grade I design index of highway.

2.1 Danqu Bridge

The total length of the Dangqu Bridge is 1055.08m. The bridge plane is located on the left oblique curve of R=1850m, and the transverse slope of the bridge floor is left transverse slope -3% and right transverse slope 3%. The width of the bridge is 25.5m, and the bridge floor is made of 10cm thick asphalt concrete + waterproof layer +10cm thick C50 concrete leveling layer. The upper structure of the bridge adopts 7×(6×20m)+(3×20m)+(3×30m)+(3×20m) prestressed concrete simple supported small box girder, the bridge floor is continuous; Substructure platform 0# adopts ribbed platform, platform 51# adopts column platform, bridge pier adopts column pier, pier adopts pile foundation. The design load of the bridge is highway Class I. The condition of the facade, deck and bottom of the bridge is shown in Figure 1.

(a)The left elevation of the bridge

(b)The right elevation of the bridge

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(c)Deck photo (d)Bottom view of bridge

Figure 1. Condition diagram of Danqu Bridge

2.2 Trans-Qinghai-Tibet Railway Bridge

The bridge is oblique across the Qinghai-Tibet Railway, and the national highway G109 is located near the bridge site and the traffic is very convenient. The bridge is divided into two parts, with the middle line between K3753+893.16 and K3754+197.181, the center pile number of the bridge is K3754+400.46, and the length of the bridge is 1010m. The upper structure adopts prestressed concrete (post-tensioned) simply supported small box girder and prestressed concrete (post-tensioned) simply supported T beam, and the bridge floor is continuous; Substructure 0, left width 47, right width 48 abutment adopts rib plate, pier adopts column pier, pier adopts pile foundation. Pile foundation type is friction pile. The longitudinal section of the bridge is located on the vertical curve of R=20000m, with an elevation of 4473.448m; Pier radial arrangement. The condition of the facade, deck and bottom of the bridge is shown in Figure 2.

(a)The left elevation of the bridge (b)The right elevation of the bridge

(c)Deck photo (d)Bottom view of bridge

Figure 2. Views of the Bridge Crossing the Qinghai-Tibet Railway

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3. Bridge Quality Inspection and Analysis

Based on the two large Bridges, this study conducted inspection research to explore the quality of Bridges in high-altitude areas of Tibet through the combination of appearance inspection and physical inspection.

3.1 Appearance Check

The appearance inspection is divided into the inspection of the substructure, superstructure and deck system of bridge engineering (excluding small Bridges). The appearance of each bridge component is inspected in detail according to 100% inspection frequency, and a record is formed. The basic requirements of testing are as follows: 1. The concrete surface is smooth, the formwork joint is smooth, and there is no slurry leakage. When it does not meet the requirements, 1-3 points are deducted; 2. The area of the honeycomb surface of the concrete surface shall not exceed 0.5% of the area of the part. If it does not meet the requirements, 3 points will be deducted for every 0.5%; 3. Non-stress cracks appear on the concrete surface, minus 1-3 points; When the structure is cracked by force, if the width of the joint exceeds the design requirements or is not specified in the design, it exceeds 0.15mm, each piece will be deducted 2-3 points, and the project legal person shall organize analysis and demonstration on whether it affects the bearing capacity of the structure; 4. The concrete structure has holes or exposed steel bars, each deduction of 2-5 points, and should be treated; 5. 1-2 points will be deducted when the construction of temporary embedded parts, facilities and construction waste and debris are not removed.

3.2 Entity Detection

The physical inspection will be a comprehensive inspection of the upper part of the bridge, the lower part and the bridge deck system, and the detection methods are: rebound method, ruler measurement, electromagnetic method, hammer ball method, truck-mounted laser flatness meter and level measurement. The detailed physical inspection contents of the two Bridges are shown in Table 1 and Table 2.

Table 1. Danqu Bridgeg

Category of Division Project	Inspection Item	Required Number of Inspections	Actual Number of Inspections	Inspection Method
Upper structure	Concrete strength	Not less than 110 test areas	120 test areas	Rebound method
	Main structural dimension	10 - 20 points	24 points	Measurement with a ruler
	Thickness of steel bar protective layer	22 - 44 places	158 places	Electromagnetic method
Lower structure	Concrete strength of abutment and pier	Not less than 22 test areas	110 test areas	Rebound method
	Main structural dimension	Not less than 22 points	44 points	Measurement with a ruler
	Thickness of protective layer	22 - 24 places	44 places	Electromagnetic method
	Verticality of abutment and pier	44 places	92 places	Plumb bob method, total station method
Bridge deck system	Flatness of bridge deck pavement	44 test areas	44 test areas	Vehicle-mounted laser flatness meter
	Cross slope	Not less than 3 sections per 100m	32 sections	Leveling instrument measurement
	Bridge deck skid resistance (texture depth)	15 places	424 places	Vehicle-mounted laser texture depth meter

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Table 2. Bridge Crossing the Qinghai-Tibet Railway

Category of Division Project	Inspection Item	Required Number of Inspections	Actual Number of Inspections	Inspection Method
Upper structure	Concrete strength	Not less than 100 test areas	100 test areas	Rebound method
	Main structural dimension	10 - 20 points	42 points	Measurement with a ruler
	Thickness of steel bar protective layer	20 - 40 places	129 places	Electromagnetic method
Lower structure	Concrete strength of abutment and pier	Not less than 20 test areas	110 test areas	Rebound method
	Main structural dimension	Not less than 20 points	33 points	Measurement with a ruler
	Thickness of protective layer	20 - 40 places	58 places	Electromagnetic method
	Verticality of abutment and pier	40 places	48 places	Plumb bob method, total station method
Bridge deck system	Flatness of bridge deck pavement	44 test areas	48 test areas	Vehicle-mounted laser flatness meter
	Cross slope	Not less than 3 sections per 100m	32 sections	Leveling instrument measurement
	Bridge deck skid resistance (texture depth)	15 places	480 places	Vehicle-mounted laser texture depth meter

4. Detection Conclusion

4.1 Summary of Appearance Check Results

4.1.1 Upper Component

The inspection of the upper structure of each bridge is as follows: When there are transverse cracks or mesh cracks in the wet joint of the total 25 span roof of Quda Bridge, the crack width is between 0.06 and 0.26mm; The large bridge body of the trans-Qinghai-Tibet Railway has 3 places, resulting in the damage of the beam body concrete, 2 places of the beam end spacing is too small, 3 places of the wing plate concrete damage, exposed reinforcement, 2 places of the wing plate mesh crack; There is mesh cracking and crystallization in 8 roof wet joints, and mold running in 1 roof wet joint.

4.1.2 Substructure

The structural inspection of the lower part of each bridge is as follows: when the Quda Bridge is in good condition, no obvious diseases are found; The embedded steel plates at the bottom supports of some beams of the trans-Qinghai-Tibet Railway extra-large bridge have not been adjusted to the slope,

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some anti-seismic blocks are dead on the top of the beam body or the transverse partition, construction garbage is accumulated on the top of several cover beams (cap beams), one cover beam is sinking, one cover beam is running out of mold, and two columns have honeycomb phenomenon.

4.1.3 Bridge Deck System and Ancillary Facilities

When the Quda Bridge is in good condition, there is no obvious disease. A small number of anti-seismic tie rods on the trans-Qinghai-Tibet Railway bridge are not installed or not installed properly.

4.2 Summary of Physical Test Results

The sampling inspection results of the bridge engineering physical inspection are shown in Table 3 and Table 4. The concrete strength is detected according to the requirements of the "Technical Specification for Testing the Compressive Strength of Concrete by the Rebound Method" (JGJ/T 23 - 2011). The upper structures measured are precast 20m and 30m PC small box girders, and the lower structures measured include cylindrical piers and caps. The thickness of the steel bar protective layer is detected according to the "Technical Standard for Testing Steel Bars in Concrete" (JGJ/T 152 - 2019). The verticality of the abutment and pier is detected according to the requirements of the "Implementation Rules for Highway Engineering Completion (Delivery) Acceptance Methods" (Jiao Gong Lu Fa [2010] No. 65), and the detection results are evaluated according to the "Standard for Quality Inspection and Evaluation of Highway Engineering (Volume I Civil Engineering)" (JTG F80/1 - 2017). The flatness of the bridge deck pavement of this bridge is detected by the vehicle-mounted laser flatness meter in lanes according to the frequency requirements of the "Implementation Rules for Highway Engineering Completion (Delivery) Acceptance Methods" (Jiao Gong Lu Fa [2010] No. 65). The bridge deck system is detected according to the frequency requirements of the "Implementation Rules for Highway Engineering Completion (Delivery) Acceptance Methods" (Jiao Gong Lu Fa [2010] No. 65).

Table 3. Dangqu Grand Bridge

Division Project	Inspection Item	Number of Inspections	Number of Qualified Items	Qualified Rate
Upper structure	Concrete strength	120 test areas	120 test areas	100%
	Thickness of steel bar protective layer	790 points	757 points	95.8%
	Structural dimension	24 points	24 points	100%
Lower structure	Concrete strength	110 test areas	110 test areas	100%
	Thickness of steel bar protective layer	220 points	210 points	95.5%
	Structural dimension	44 points	44 points	100%
	Verticality of pier	92 places	83 places	90.2%
Bridge deck system	Flatness of bridge deck pavement	44 places	44 places	100%
	Bridge deck skid resistance (texture depth)	424 points	424 points	100%
	Bridge deck cross slope	32 sections	29 sections	90.6%

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Table 4. Bridge Crossing the Qinghai-Tibet Railway

Division Project	Inspection Item	Number of Inspections	Number of Qualified Items	Qualified Rate
Upper structure	Concrete strength	100 test areas	100 test areas	100%
	Thickness of steel bar protective layer	645 points	540 points	83.7%
	Structural dimension	24 points	24 points	100%
Lower structure	Concrete strength	110 test areas	110 test areas	100%
	Thickness of steel bar protective layer	220 points	210 points	95.5%
	Structural dimension	42 points	41 points	97.6%
	Verticality of pier	48 places	46 places	95.8%
Bridge deck system	Flatness of bridge deck pavement	48 places	48 places	100%
	Bridge deck skid resistance (texture depth)	480points	480 points	100%
	Bridge deck cross slope	32 sections	31 sections	96.9%

In general, except for the test results of the protective layer of steel bars on the upper part of the trans-Qinghai-Tibet Bridge, the pass rate of the remaining parts is above 90%, and the overall pass rate is good.

5. Conclusion

The appearance inspection results show that there are a few quality problems in the upper part of the Qujiang Bridge, the substructure, deck system and ancillary facilities are in good condition and no obvious diseases are found, while the quality problems exist in various parts of the trans-Qinghai-Tibet Railway Bridge, but they are all within the scope of repair. The physical test results show that the pass rate of all tests of Dangqu Bridge is more than 90%, the pass rate of the steel protective layer thickness of trans-Qinghai-Tibet Railway bridge is only 83.7%, and the other tests are more than 90%. In summary, when the quality of Quqiao is higher than that of the Trans-Qinghai-Tibet Railway Bridge, when the Quqiao Bridge needs proper repair, and the Trans-Qinghai-Tibet Railway Bridge needs to focus on quality improvement, the two Bridges are generally qualified.

The results of appearance inspection can more directly reflect the quality problems existing in the appearance of the bridge, but cannot reflect the quality defects inside the bridge. Only the results of physical inspection cannot reflect the quality defects existing outside the bridge. Only the combination of appearance inspection and physical inspection can fully reflect the overall quality of the bridge, especially in high altitude areas. This method can provide reference for other bridge engineering quality inspection.

Data Availability

The datasets used and/or analysed during the current study available from the corresponding author on reasonable request.

Author Contributions

Zhang Xin-Feng: Conceptualization, Methodology, Visualization, Funding acquisition, Writing-Original Draft. Honggang Wu: Investigation, Funding acquisition, Writing-Review & Editing.Wu Xiaon-Feng: Funding acquisition, Data Curation, Writing-Review & Editing.Zhu Zhao-Rong: Data Curation, Investigation, Resources.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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