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Analysis of Damage Pattern of Road Bridge Landslide in Mountainous Area

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Abstract: Through on-site defect investigation, special inspection, and finite element simulation calculation of a high-speed upper-span (30 + 32 + 30) m prestressed concrete box girder bridge, the overall sliding force of the bridge on the right side of platform 0# is analyzed. In this situation, typical defects such as overall girder slippage, support dislocation, pier column deviation, and pier bottom side cracks have occurred in the overpass. At the same time, combined with simulation calculation analysis, it is interpreted that the 0# and 1# foundation has been damaged at a certain position below the ground line. The occurrence of broken piles has provided a reliable basis for the later reinforcement and maintenance of the bridge and ideas for emergency inspection and analysis of bridges damaged by the same type of landslides.

Keywords: Landslide; Overpass in mountainous area; Damage pattern; Special inspection; Simulation calculation analysis

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1. Introduction

Debris flow, water damage, and landslides are common adverse geological phenomena in mountainous areas in China. In the past, the major impacts on bridges were debris flow and water damage. Even if there are landslides, the impact or loss caused by the low road standard and small scale is not large, and the problem is not very prominent. However, in recent years, high-grade highways have continued to extend to mountainous areas or areas with complex terrain and geological conditions. There are not only bridges across valleys, but also long bridges along slopes due to difficulties in roadbed design. The application range of bridges has been greatly expanded. The number of bridge defects caused by landslides is increasing day by day, and most of them occur during construction, and the scale is relatively large, causing a lot of losses, which deserves attention of relevant parties [1].

2. Project overview

An overpass bridge in a high-speed mountainous area in Yunnan, the structural form is (30 + 32 + 30) m is a prestressed concrete constant cross-section continuous box girder, the bridge width is 8.0m, and the total length of the bridge is 99.00 m. The longitudinal surface of the bridge is located on a straight line with a longitudinal slope of -2.2%. The plane is located in a straight line, the substructure of the bridge is arranged radially, the piers are solid vase piers (pier height 19.5 m), the abutments are column abutments, and the pier abutments are pile foundations. Design load: Highway - Class I, bridge deck width: 0.5 m (anti-collision barrier) + net 7.0 m + 0.5 m (anti-collision barrier), ad oblique angle: 90°.

The standard sections of the bridge elevation, plane, and main girder are shown in **Figures 1** and **2**, respectively.

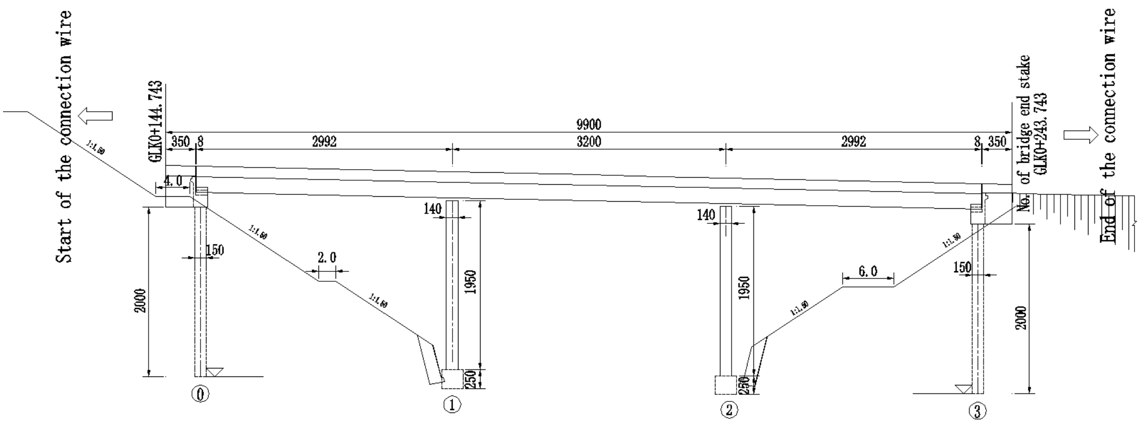

Figure 1. Layout of the sky bridge elevation (unit: 1)

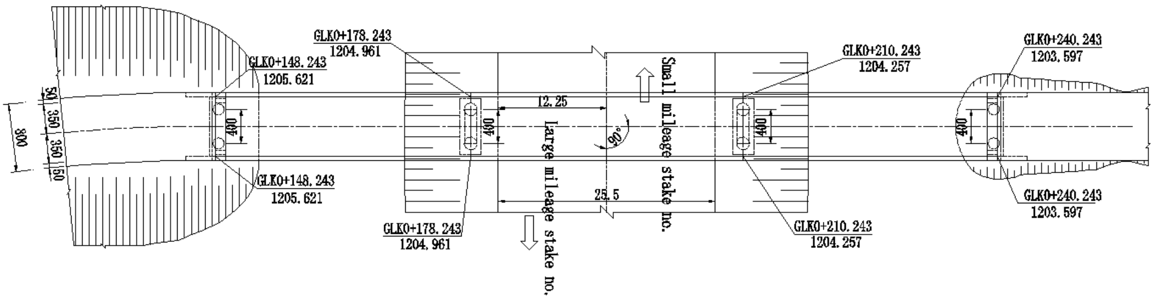

Figure 2. Layout plan of the 2- overpass (unit: cm)

3. Background of the project

Construction of the overpass began in October 2019, and it passed the third-party handover inspection on July 30, 2020, and was opened to traffic. On the morning of November 5, 2020, the construction personnel found that the support of the 1# pier of the overpass was misaligned with the steel plate at the bottom of the beam. Further inspection found that the support was damaged and the 1# pier was tilted. After the rainy season in mid-October 2020, excavation of the first-level slope on the right side of the bridge began. The third and fourth-level slopes have not been unloaded, and the first-level slope has not yet been protected. There are cracks caused by landslides on the slope, about 50 m in length and 3.0 cm in width. The overpass traffic was immediately blocked at the scene for monitoring. As of November 19, 2020, the monitoring results of the overpass by the construction unit are as follows:

(1) The accumulative displacement of the 0# platform cap towards the large mileage is 0.122 m on the left side, and 0.106 m on the right side towards the large mileage.

(2) The cumulative displacement of the left side of the 1# pier bottom towards the large mileage is 0.134 m, the cumulative displacement of the right side of the pier bottom towards the large mileage is 0.142; The cumulative displacement of the left side of the pier top to the large mileage is 0.378 m, and the cumulative displacement of the right side of the pier top to the large mileage is 0.406 m; the verticality of 1# pier deviates to the right by 0.042 m (the deviation to the right when the concrete surface of the pier body is formed is 0.019 m).

(3) The cumulative displacement of the left side of the 2# pier bottom towards the large mileage is 0.002 m, the cumulative displacement of the right side of the pier bottom towards the large mileage is 0.004 m; the cumulative displacement of the left side of the pier top towards the large mileage is 0.068 m, and the cumulative displacement of the right side of the pier top towards the large mileage is 0.057 m , the accumulative displacement of the transverse bridge is 0.004 m.

(4) The accumulative displacement of the left side of the 3# platform cap towards the maximum mileage is 0.035 m, and the cumulative displacement of the right side of the platform cap towards the maximum mileage is 0.031 m.

In order to further analyze the condition of the overpass defect and the specific cause of damage and provide a basis for the subsequent design of bridge reinforcement and treatment, a special inspection of the bridge and related theoretical simulation calculation analysis were carried out.

4. Appearance and special inspection results

4.1. Visual inspection results

Both the 0# platform and the 3# platform are in contact with the main beam, the concrete of the 0# platform is partially squeezed and damaged, and the back wall of the 3# platform has a horizontal crack; a total of 8 oblique cracks were found on the 0# platform (side wall, back wall, pile protection wall), with a length ranging from 90 cm to 360 cm and a width ranging from 0.20 mm to 4.00 mm; 6 horizontal through cracks were found on the longitudinal small pile surface at the bottom of the 2# pier, within a range of 0.3 m to 1.8 m from the bottom of the cap, with a spacing of 20~30 cm, length 350~466 cm, and crack width range 0.18~0.24 mm. The crack distribution diagrams are shown in **Figures 3** and **4**.

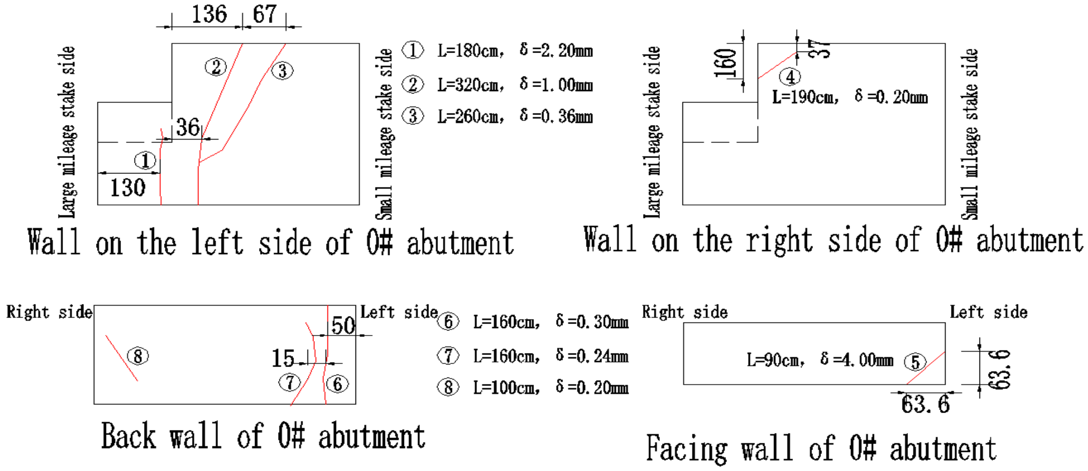

Figure 3. Distribution map of vertical and oblique fractures in platform 0# (L is fracture yield, δ is fracture width)

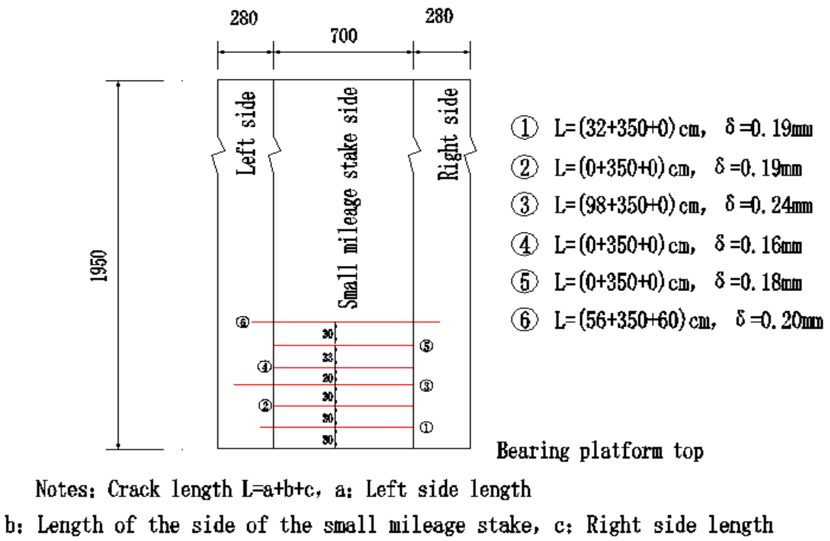

Figure 4. Distribution of horizontal cracks on the side of the bottom of 2# pier (L is the fracture rate, δ is the crack width)

4.2. Special inspection results

Test results of the verticality of the pier body

The verticality of the 1# pier-2# pier body was measured, and the verticality of each pier column was measured respectively in the longitudinal and transverse directions. The lateral deviation to the right is positive, and the opposite direction is negative [2]. The relative deviation of the pier body varies with the height of the pier, as shown in **Figures 5** and **6**.

It can be seen from the verticality measurement results in the table below: (1) 1# pier is displaced 25.1 cm longitudinally to the large pile number, and 4.2 cm laterally to the right; (2) The 2# pier is displaced longitudinally by 5.5 cm to the large pile number, and laterally by 0.6 cm to the left.

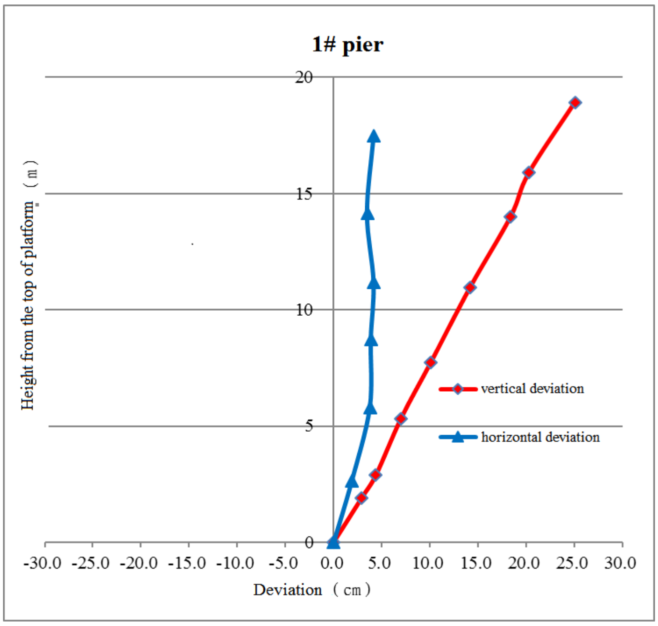

Figure 5. Measurement results of verticality of 1# pier body

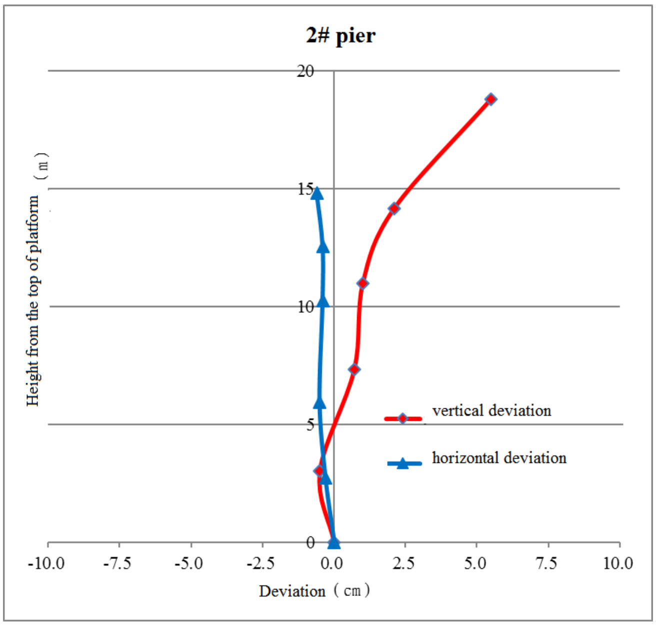

Figure 6. Measurement results of verticality of 2# pier body

4.3. Bearing appearance and displacement test results

It can be seen from the test results that the vertical displacement of the 0# platform support to the large pile number is 4.0~7.5 cm, while the longitudinal relative displacement of the 1# pier support to the large pile number is 21.5~22. The displacement is 3.5 cm, and **Figures 7–10** show the typical diseases on site.

Figure 7. Longitudinal large pile number displacement of 1-1# support

Figure 8. Longitudinal large pile number displacement of 1-1# support

Figure 9. PTFE slide plate warping of 1-1# support

Figure 10. Longitudinal large pile number displacement of 1-2# support

4.4. Summary of other special inspection results

Here, the distance between the expansion joints, the relative offset of the support, the relative offset of the pier top, and the coordinate offset of the main beam have been checked in detail [3].

4.5. Cause analysis of bridge defects

According to the above appearance and special inspection results, it is inferred that the main causes of bridge defects are as follows:

(1) Offset of 0# platform and 1# pier: the overall slip of the slope at 0# platform causes the displacement of the pier abutment. Due to the inconsistent displacement of the main beam and pier column, it also causes the movable support to be adjusted up and down to level the steel plate. There is a offset between them.

(2) The displacement of the main girder and the distance between the expansion joints become smaller: the displacement of the side slope at the 0# platform causes the displacement of the top of the 0# platform, which in turn causes the main beam to move to a larger pile number and the spacing of the expansion joints becomes smaller.

(3) Oblique cracks in the 0# platform body: Due to the displacement of the soil slope on the top of the 0# platform, the 0# platform received excessive earth pressure, and the concrete tensile stress of the platform body exceeded the concrete tensile stress, causing cracking.

(4) Horizontal cracks on the side of the small pile number at the bottom of the 2# pier: the main beam displaces to the side of the large pile number. Since the 2# pier is a consolidated support, the main beam drives the pier column to cause deformation, and, ultimately, the tensile stress at the bottom of the pier exceeds the limit.

5. Finite simulation calculation results

5.1. Calculation instructions

According to design specifications, design documents, geological survey data and other documents, combined with deviation monitoring, appearance inspection, entity inspection and other data, the following descriptions are made for the model:

Due to the side slope slip of the 0# and 1# pier of the bridge, the soil produces longitudinal earth pressure on the main girder, 0# abutment, 1# pier cap, etc., which, eventually, the main girder, 0# abutment, 1# pier and pile foundation will be greatly deviated. The range of earth pressure load is from the surface to the base. The force point with the bridge structure is the 0# platform and the 1# pier cap (direct contact point with the slope). The friction force of the support is applied to the pad stone position of the support on the top surface of the cover beam in the form of concentrated force. The direction of action can be judged according to the offset between the support and the main beam, and the size can be determined comprehensively according to the reaction force of the support and the coefficient of friction. The m method is used to simulate the interaction between piles, soil, and bedrock [4], and the overall model of the whole bridge, the 0# platform and pile foundation, the 1# pier and pile foundation local calculation and analysis models are established respectively. Schematic diagram of structural force analysis is shown in **Figure 11**.

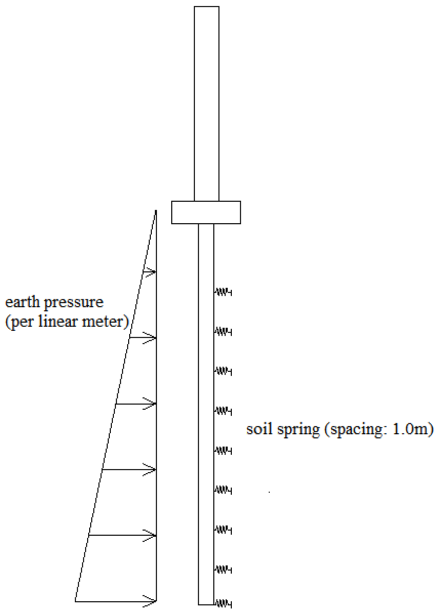

Figure 11. Schematic diagram of structural force analysis

5.2. Computational model

Using Midas finite element software, the overall calculation model, 0# pile foundation calculation model, and 1# pile foundation calculation model were respectively established for structural simulation analysis and calculation. The calculation model of the whole bridge (mainly used to calculate the reaction force of the structural support and the overall displacement of the beam) is shown **Figure 12**.

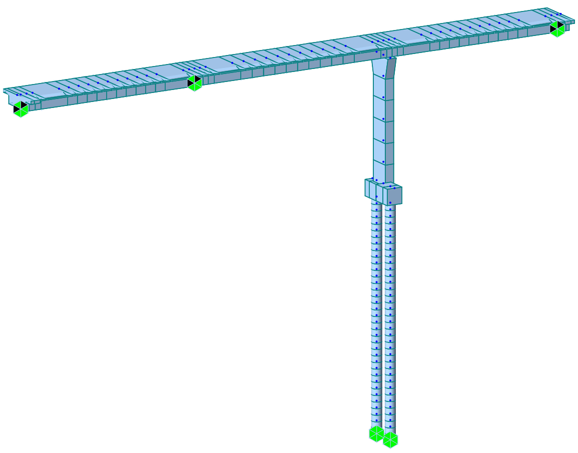

Figure 12. Calculation model of 2bridge

5.3. Calculation results

5.3.1. Calculation results of 0# pile foundation

The simulation calculation analysis is mainly divided into the calculation of the maximum crack width (0.20 mm) of the pile foundation and the yield state of the steel bar and is compared with the actual monitoring of the deflection data of the pier abutment to infer the damage status and position of the pile foundation of the 0# platform. The 0# pile foundation is controlled by the pile foundation crack limit of 0.20 mm, and the maximum displacement limit of the pile top is 63 mm; the 0# pile foundation is controlled by the pile foundation steel yield stress of 400 MPa, and the maximum displacement limit of the pile top is 107 mm; The actual monitored displacement values (0.122 m on the left side of platform 0#, and 0.106 m on the right side) all exceed the theoretically calculated displacement limit, and it is inferred that the pile foundation of platform 0# is 7.0 m away from the bottom surface of the cap, and there is a possibility of pile breakage [5].

5.3.2. Calculation results 1# pier pile foundation

The simulation calculation analysis is mainly divided into the calculation of the maximum crack width (0.20 mm) of the pile foundation and the yield state of the steel bar and compared with the actual monitoring of the deflection data of the pier abutment, inferring the damage status and position of the 1# # pile foundation. The pile foundation of 1# pier is controlled by the pile foundation crack limit of 0.20 mm, and the displacements of the pier bottom and pier top are 70 mm and 155 mm respectively; the pile foundation of 1# pier is controlled by the pile foundation steel yield stress of 400MPa, and the displacements of the pier bottom and pier top are respectively 107 mm, 235 mm; the actual monitoring displacement value (The cumulative displacement of the left side of the 1# pier bottom to the large mileage is 0.134 m, the cumulative displacement of the right side of the pier bottom to the large mileage is 0.142; the cumulative displacement of the left side of the pier top to the large mileage is 0.378 m, and the cumulative displacement of the right side of the pier top to the large mileage is 0.406 m; The verticality of 1# pier deviates to the right by 0.042 m) all exceed the theoretically calculated displacement limit, and it is inferred that the pile foundation of 1# pier is 8.0 m away from the bottom surface of the cap and there is a possibility of broken piles [5].

6. Conclusions and recommendations

Through the inspection of the defect status of the whole bridge and theoretical simulation calculation analysis, it is preliminarily concluded that the bridge 0# pile foundation and 1# pile foundation have the possibility of broken piles at the positions of 7.0 m and 8.0 m below the ground respectively. It is necessary to further verify the feasibility of broken pile reinforcement, determine the specific reinforcement plan, restore the deviation of the main beam and pier column, and replace the 1# pier support. Prior to the bridge reinforcement treatment, priority should be given to the treatment of the mountain slope at the 0# platform, and at the same time strengthen the slope stability monitoring at the bridge location and the displacement monitoring during the later bridge operation.

Disclosure statement

The authors declare no conflict of interest.

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