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Damage Investigation, Strengthening, and Repair of Jilin Highway Double-Curved Arch Concrete Bridge in China

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Abstract

Jilin highway concrete bridge is located in the center of Jilin City, which is positioned in the middle and southern part in Jilin province in east north of China. This bridge crosses the Songhua River. The strengthening of concrete bridge structure involves upgrading of the strength and stiffness of structural members, and the repair process involves re-establishing the strength and function of the damaged members. The main objectives of this study are to identify the damaged members of Jilin highway concrete bridge structure and to explain the application of strengthening and repair methods to improve the performance of the bridge structural members. The results of damages investigation of a bridge structure appearance show that the most components of the bridge are in good conditions with the exception arch waves, spandrel arch, deck pavement of the new arch bridge, and corbel of the old simply supported beam bridge which suffer from serious damages. In this study, jacketing method, grouting repair method, patching method, and replacement of expansion joint and drainage system had been used to strengthen and repair the damaged members of Jilin highway concrete bridge. After completing the strengthening and repair processes, the state of arch waves, spandrel arch, and deck pavement is good, but there is need to evaluate the performance of structural members which are strengthened and repaired by adopting static and dynamic load tests, and monitoring the development of cracks.

Keywords: Strengthening, repair, damages investigation, jacketing, grouting method.

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1. INTRODUCTION

Damage investigation of a bridge structure must be taken every member to evaluate weather it is in satisfactory or unsatisfactory situation. The investigation process should be careful to emphasize which damage deteriorations are in primary members, secondary members, or redundant members. Since failure of primary members usually will result in immediate collapse of a structure. (Manaf 2000; AASHTO 1986).

The strengthening of concrete structure involves upgrading of the strength and stiffness of structural members, and the repair process involves re-establishing the strength and function of the damaged members. The strengthening of the bridge structural members can be carried out by replacing poor quality or defective materials by better quality materials, attaching additional load-bearing materials, and re-distribution of the loading actions through imposed deformation on the structure system. The new load-bearing materials will usually be high quality concrete, reinforcing steel bars, thin steel plates, straps (externally bonded by epoxy), and various combination of these materials. The strengthening of reinforcement concrete bridge to required strength can be adopted by replacing of damaged reinforcement (reinforcement corrosion) and mechanically tying-in additional reinforcement in the old cross-section and replacing it in an additional concrete layer, and using epoxy-bonded steel plates. (Naser 2005; Hugenschmidt 1981).

The selection of an appropriate method for the strengthening and repair of the bridge structural members depends on a number of factors. These factors include the type and age of structure, the importance of structure, the magnitude of the strength required which is need to increase, the type and degree of damage, available materials, cost and feasibility, and aesthetics. The strengthening and repairing of the bridge structure can be provided an effective and economic solution in appropriate situation. (Daly 1997; Hai 2009).

The strategy of repair includes materials selection, method selection, support design, safety precaution, costs, and logistics. Whereas, the performance requirements of concrete repair involve protection of re-bars, aesthetics, integrity and computability, carry loads, and waterproofing. Concrete structure repair can be classified either as cosmetic-repairs or rehabilitation-repair. (Brandon 2007; Edward 2006; Raina 1996).

The objectives of this study are to identify the damaged structural members of Jilin highway concrete bridge and to explain the application of strengthening and repair methods to improve the performance of the bridge structural members. Jacketing method, grouting repair method, patching method, and replacement of expansion joint and drainage system are used to strengthen and repair the damaged members of Jilin highway concrete bridge.

2. Description of Jilin Highway Concrete Bridge

Jilin highway concrete bridge is located in the center of Jilin City, which is positioned in the middle and southern part in Jilin province in east north of China. This bridge crosses the Songhua River. The Jilin highway concrete bridge consists of two parts. The first part is the old simply supported beam bridge, which was built in 1938, and it was opened to traffic in 1940. The width of the old bridge is 9.25 m and it has 15 spans. The length of span between two furnaces spans is 23 m, but the length of span among the middle of 13 spans is not constant, and ranges between 28.59m to 31.67m. The second part is the new widen bridge which is known as a concrete new arch bridge. This part was built in 1974. The width of the new widened bridge is 13.75 m and the total length of bridge is 488.77m. There are 9 arch ribs in the transverse direction. Figure 1 shows Jilin highway concrete bridge, and figure 2 shows the transverse section of the bridge.

(a) (b)

Figure 1: Jilin highway double-curved arch concrete bridge (a) side view of the old simply supported beam bridge, (b) side view of the new arch bridge

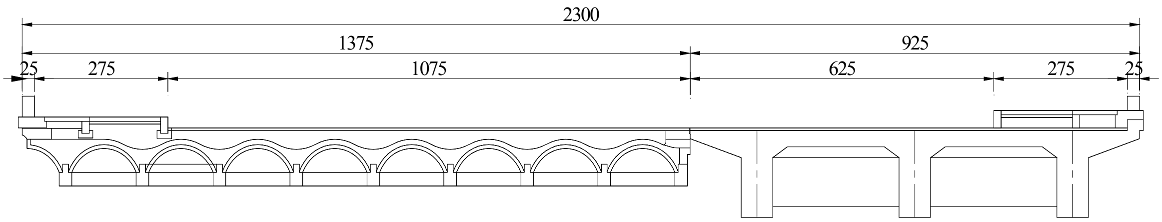

Figure 2: Transverse section of Jilin highway double-curved arch concrete bridge (dimension in cm)

3. Damage Investigation of Bridge Structure apperance

In this study, damage investigation process is used to investigate the appearance of the bridge structural members for the span No. 1 to the span No. 15. The members of the bridge structure which are investigated include arch ribs, arch waves, arch plates, horizontal tie beams, spandrels arch, piers of spandrels arch, pier caps of spandrels arch, maim beams of the old simply supported beam bridge, bearings, corbels, higher edge of fulcrum, diaphragm beams, lifting beam and deck system. The equipments of damages investigation include inspection car, ladder, observation apparatus for cracks, rebound hammer, ultrasonic sound detector, laser total station, and detector for steel location.

According to the results of damage investigation of the bridge structure appearance, the quality of main arch ring and horizontal tie beam is good. There are not series cracks for the structure. Because of the vertical cracks in the parts of arch wave, the whole mechanical performance of main arch is affected by the cracks. There are serious damages in the part of spandrel arch, resulting in larger deformation of structure. There are cracks within deck pavement. Because of these damages within the spandrel arch and damages of deck pavement, the recommendation of this study is to strengthen and repair the spandrel arch and pavement of deck. For old simply supported bridge, there are some serious cracks in the main beam and lifting beam of the simple beam bridge. The whole state is good, but there are serious corrosion and spalling of concrete in the corbel. These damages influence the strength and durability of the bridge structural members. Therefore, there is a need to repair the corbel. Figures 3, 4, 5, 6, 7, 8, 9, and. 10 show the damages of bridge structure members.

Figure 3: Damage of arch ring

Figure 4: Damage of horizontal tie beam

Figure 5: Damage of pier cap beam

Figure 6: Damage of spandrel arch piers

Figure 7: Damage of pier and pier cap

Figure 8: Damage of drainage system

Figure 9: Damage of bearing and corbel

Figure10: Damage of simply supported bridge

4. Strengthening and Repair of Damaged Bridge Members

The main causes of the bridge structures damages are lost maintenance and repair for long time and bad durability. Therefore, there is needed to strength and repair the damaged bridge structural members to get on the safety for the bridge service.

4.1. Materials of Strengthening and Repair

Different types of materials are used in the strengthening and repair process. These materials include steel bar with different diameters ($\varphi 20, \varphi 16, \varphi 12, and \varphi 10$), epoxy resin concrete (C-30), C-30 anchor spray cement concrete, C-30 cast-in-situ concrete, AFS-90 fiber sheet, glue material(adhesive material for planting steel bars), drainage pipes, grid cap, $\varphi 100$ PVC pipe, and water stop. All these materials are selected according to standard specifications of materials.

4.2. Strengthening and repair methods application

4.2.1. Strengthening of the main arch rings

In order to enhance the stiffness and carrying capacity of the main arch ring integrity, the main arch ring is strengthened by using jacketing method. This method consists of two stages. The first stage is planting steel bars, and the second stage is spraying the concrete. In this method, the materials are used in the strengthening process include steel bars, C-30 anchor spray cement concrete and glue materials. The thickness of spray concrete is 6 cm in the parts of arch ribs and arch wave, and the inserted depth of anchor bars must be more than 8 cm with weld length more than 12 cm. The difference between concave and convex of the exposed face must be less than 1.5 cm after construction completion. To improve the carrying capacity of the arch bottom, cast-in-situ C-30 concrete is used with 10 cm thickness, and the longitudinal steel bars must be inserted in arch abutment to endure the tension in the higher edge of arch bottom. Planting steel bars process includes many stages. These stages are prepare for planting steel bars, drill the holes accordance to required depth and diameter, clean the holes by compressed air, inject the glue materials by using glue guns, insert the steel bars to the bottom of the holes, weld and connect the bars after consolidation of the anchor agent, check whether the anchoring force satisfy the designed requirement by the in–situ pullout test for the bolts in the important parts, and the steel mesh is connected with planted steel bars. Spraying the C-30 concrete process adopts the mean of wet shotcrete technology. Figures 11, 12, 13, and 14 show the strengthening process of the main arch rings.

Figure11: Planting steel bars in arch rings

Figure12: Planting steel bars in arch rib

Figure13: Spraying the concrete

Figure 14: The first layer of sprayed concrete

4.2.2. Strengthening of spandrel arch

There are serious damages in the parts of spandrel arch, especially in the piers. These damages include the spalling of concrete and corrosion of steel reinforcement. The strength of concrete is low. Therefore, there is need to improve the carrying capacity of spandrel arch piers. Two methods are used to strengthen the spandrel arch parts. The first method is known as patching method which is used to strengthen the pier cap by using the epoxy resin concrete after removing the corroded concrete surface and clean the steel reinforcement. The second method is used to strengthen the pier of spandrel arch by using double layers of AFS-90 (Aramid Fiber Sheets). This method consists of five stages. These stages are: preparing the base surface of concrete, brush the glue material, repair the lower parts on the surface by using the glue to get suitable level and ensure the smooth of the pasting surface, and pasting the aramid fiber sheet (AFS-90), Protection of overlay.

The construction must be stopped when the temperature is below 5℃ or the weather is rainy. The amount of the types of adhesives is limited in the range of one-time application, and the mix proportion of the glue must be obeyed the instruction of the product. Figures 15, 16, 17, and 18, show the strengthening and repair of spandrel arch of the new arch bridge.

Figure15: Repair the piers of spandrel arch

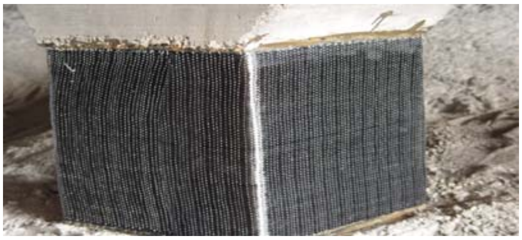

Figure16: Spandrel arch pier strengthening

Figure 17: Spandrel arch piers strengthening

Figure18: Pier cap repair

4.2.3. Repair of the old simply supported beam bridge

Repair process of the old simply supported beam bridge damaged parts include repair of corbel roller supports by using derusting and covering oil, re-install the expansion joints in every corbel, repair the sidewalk which that contains on electrical line, repair the concrete of lifting beam and bottom of the box beam by removing the corroded concrete and applying the epoxy resin concrete, and re-set the drainage system of the bridge deck by using the new drainage pipes and $\varphi 100$ PVC pipes.

4.2.4. Grouting method for cracks repair

The method of grouting repair is adopted to repair the cracks in the parts of horizontal tie beam, arch wave, the higher edge of arch bottom, the interior edge of arch top, mid-span of the main beam, and the higher edge of pier top of the old simply supported beam bridge. For cracks width less than 0.15mm, the grouting method stages include clean and remove the laitance and dust; dig a V-shape groove by using chisel; adhesive sealing the cracks by using the mixed epoxy resin No. 6101. The cracks are leveled by using scraper. The compressive strength of mixed adhesive is more than of concrete. For cracks width more than 0.15, the grouting method is used to repair the cracks by using the grouting machine and the grouting pressure is about 0.4MPa.

5. CONCLUSIONS

The main conclusions that can be drawn from this study are:

1. The results of damages investigation of a bridge structure appearance show that the most components of bridge are in good conditions with the exception arch waves, spandrel arch, deck pavement of the new arch bridge, and corbel of the old simply supported beam bridge which suffer from serious damages
2. Jacketing method, grouting repair method, patching method and replacement of expansion joint and drainage system are used to strengthen and repair the damaged members of Jilin highway concrete bridge.
3. After completing the strengthening and repair processes, the state of arch waves, spandrel arch, and deck pavement is in good conditions, but there is need to evaluate the performance of structural members which are strengthened and repaired by adopting static and dynamic load tests, and monitoring the development of cracks.

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