Strengthen Method of the Shear Keys in Adjacent Concrete Box-beam Bridges Using High Performance Grouting Material

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Abstract. Adjacent concrete box-beam bridges are widely used in short and medium span bridges. However, this bridge system has long term durability issues caused by shear key failure and reflective cracking in the upper. This paper investigates a new maintenance method of shear key joint. High performance grouting material with good fluidity, low water-cement ratios, slight expansion, little bleeding and excellent wear ability was used in the repairing process. An adjacent box-beam bridge with 3box-beams was designed and constructed to verify this strengthen approach in the laboratory. A concentrate load was imposed in the mid-span to simulate the vehicle loading. The deformation of box-beam, concrete strain and cracks were tested, then the load-deformation curve and the relative deformation difference were obtained . It was indicated that the mechanical property of the shear key repaired by the high performance grouting material can satisfy the design requirement, and have a greater strength.

Introduction

Precast prestressed concrete box beams are widely used in short and medium span bridges. The reasons for their popularity include ease of construction, fast installation, shallow superstructures yielding hither clearance when replacing old bridges. Although the structure performance of such bridges has been successful, this bridge system has long term durability issues caused by shear key failure and reflective cracking in the topping [1]. In many cases this cracking has resulted in water leakge, which could lead to lose the integrity of the bridge [2,3].

In order to solve this problem, a series of strengthening and maintenance technology have been developed, such as bonding transverse steel plate[4] or Π-shaped plate[5,6] in the bottom flange, prestressing transverse tendons[7] etc. By the application of these technologies, the mechanical performance of shear key can be promoted, and the integral behavior of the adjacent bridge would be great improved. However, these approaches still has a few disadvantages, such as breaking prestressed strand during rebar implanting, and not easy to operate in field[8].

High performance grouting material which is composed with of special additive, macromole polymer material and low alkali ordinary portl and cement, has many advantages such as high fluidity, low water-cement ratios, slight expansion, little bleeding and good wearability etc. As the repairing work can be carried out under the bridge, this method has a smaller communication impact, and lower construction expense with short timelines. Especially for small defects in the pavement deck, this reinforce approach has a more obvious advantage, and the maintenance costs can be greatly reduced in the life cycle of the adjacent concrete box-beam bridge.

Maintenance Procedure of Shear Key

The maintenance technology of shear keys with high performance grouting material can be summarized as follow:

(1) Checking the actual quantity of the defects in shear keys, then marking them in the bridge.

(2) Picking out the gravel and debris from the joints with special brush, then cleaning with powerful water cannon.

(3) Sealing the ends of hinge joints by polyurethane foaming agent.

(4) Setting the injection tube in the joints every 5 meters. The size of the injection tube is selected according to the width of hinge joints, a measuring tube need to be installed in the other end of the box beam joint.

(5) Sealing joints under the box-beam: plug hinge joints from one end to the other end along the bottom of the box-beam by polyurethane foaming agent, and the plugging height is controlled from 3 to 5cm. prepare some wedge-shaped strips with length of 5cm wide, width of 3~5mm before grouting, height of 3cm,drive the wedge wood into slurry leakage gently to compact the crack when there is leaking under the box-beam.

(6) Checking the sealing quality after sealing operation completed, and carry out pressurized air experiment or close water experiment, If the sealing property does not meet the requirements, it is necessary to repair the leakage again.

(7) Pressure grouting: press continuous, slow and uniform speed into the grouting material through the crack with the pressure of 0.3-0.5MPa by the grouting machine, stop grouting when the paste is at the same level as the plate and there is no air bubbles. The storage time from mixing the grouting material shall not exceed 30 minutes, time out or liquidity does not meet the requirements of the grouting material shall not continue to be used, the schematic diagram of the construction is as shown in Fig. 1.

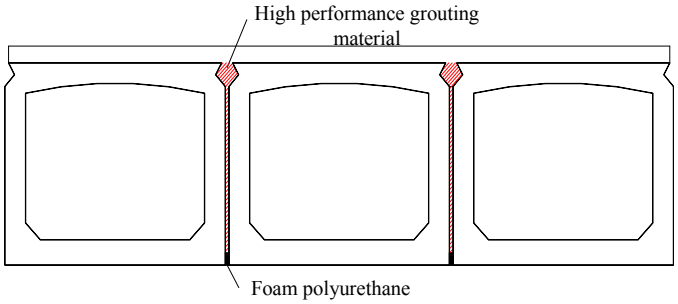


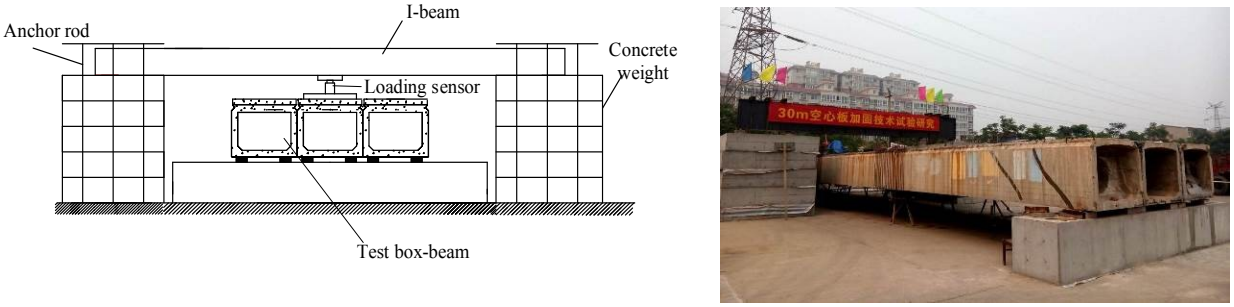
Fig. 1 Schematic diagram of the construction of high performance grouting material Layout of text

Design of the Test

The test box-beam was dismantled from a service bridge in highway road which has been in service for 10 years, as is shown in Fig. 2. The concrete's design strength is C50, and the measured strength is 54MPa. In both ends of the beam, a few of diagonal cracks have been found, and the width is no less than 0.05mm. Before the test, all the visible cracks were repaired with epoxy pouring sealant.

Fig. 2 The test void-box beam

The loading system employed for the test box-beam is shown in Fig.3, consisted of a loading sensors, a hydraulic jack, a steel I-beam, an anti-force frame, some buttress and concrete weights etc.. The loading force was applied to the cross-sectional center of the adjacent bridge through the hydraulic jack hydraulic equipped with an out-of-plane frame as well as a force transducer to record the actual vertical force.



(a) schematic plot (b) photographical side view

Fig. 3. Load applying system: (a) schematic plot; (b) photographical side view.

The deflection of specimens were tested with18 displacement sensors setted in the 1/4 、 1/2 and 3/4 cross section as shown in Fig.4. After initializing the instrumentation system, the specimen was loaded by a 5 kN incremental applied load until the substantial deflection of the beam can be observed. For each loading step, a set of reading was taken for deflections and strain of the key sections.

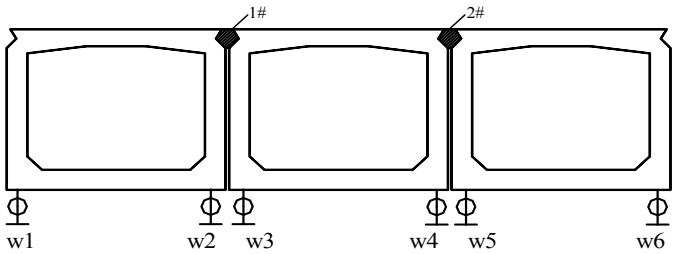


Fig. 4 displacement sensors applied to test the deflection of box-beam

Test Results

There are no abnormal in hinge joints and plate-girder in the early stage of loading, there is abnormal sound in the hinge joint when the loading reaches 80.6t, there appears cracks from 3/4 to cross of hinge joints, with the maximum crack width is 1mm and partial dislocation, as shown in Fig. 5.

Fig. 5 The crack of shear key in the topping when load reaches 80.6t

The cracks continue to increase with loading to 82.9t, and the hinge joints break completely along the interface. The failure process of the joints is very short, and the crack almost occurred at the Surface of junction, hinge joint concrete and concrete blocks completely separated along with surface, as shown in Fig.6, Failure surface is smooth, there is no breaking phenomenon of concrete aggregate.

Fig. 6 Failure of the hing joint

The test load-deflection curves of every section of the box-beam are shown in Fig.7, 8, 9. It can be established that the deformation of the box-beam is coincident well, and the overall performance is in good condition at the initial stage of loading, when loading reaches 70t, the displacement of the left side plate of the cross section and the 3/4 section is not coordinated; When the loading increases to 80.6t, the deflection of 3 box-beams are 30.3mm, 29.2mm and 28.7mm respectively; the deformation is 31.5mm, 29.5mm and 29.1mm when the loading increases to 82.9t, the failure of No. 2 hinge joints appears with the load increasing slightly, the readout of Jack quickly fell to 66.5t, deflection of No. 3 slab recovery to 0.96mm, deflection of No. 1 slab increases to 35.1mm, the deflection of No. 2 increases to 31.1mm. From the general change trend of the load deflection curve, the structure is in the elastic state during the whole loading process, and the elastic and plastic stage is short. Whose failure process in brittle.

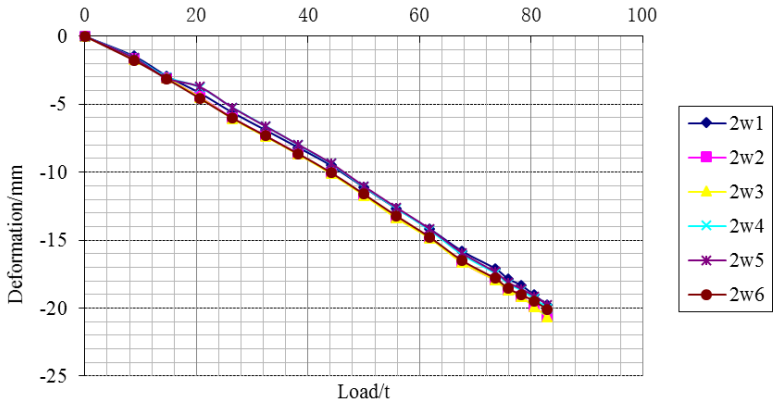


Fig. 7 Load-deflection curve of 1/4 cross section

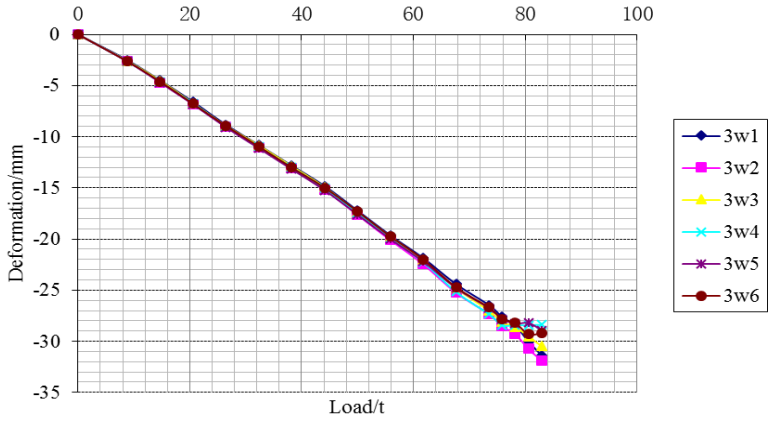


Fig. 8 Load-deflection curve of middle section

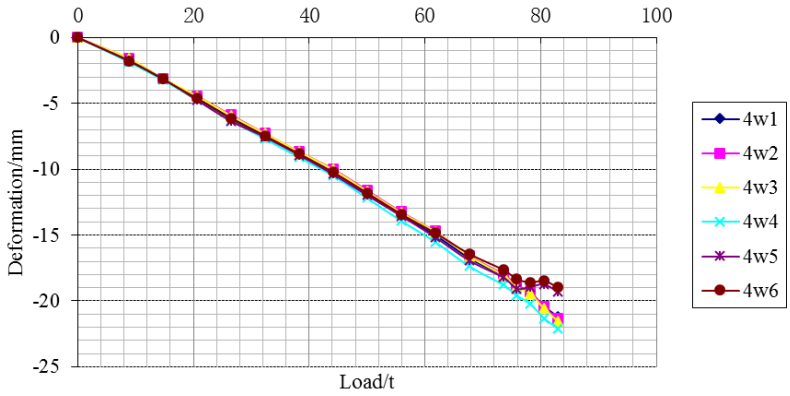


Fig. 9 Load-deflection curve of 3/4 cross section

The relative displacement curves of the box-beams on both sides of the hinge joints during the experiment are as shown in Fig10, 11, 12. From the development trend, the relative displacement of hinge joint on both sides of the box-beam are larger as the loading increases, but deformation values of No. 2 hinge joints on both sides of the box-beam are significantly greater than that of No.1 hinge joints, which presents the state of dispersing, the 2# hinge joints occurs damage first after reaching the limit state.

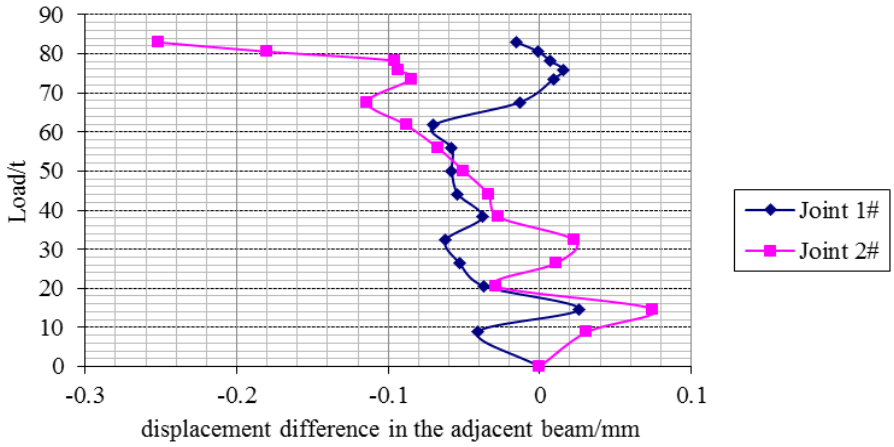


Fig. 10 The relative displacement curves of the adjacent beam in 1/4 section

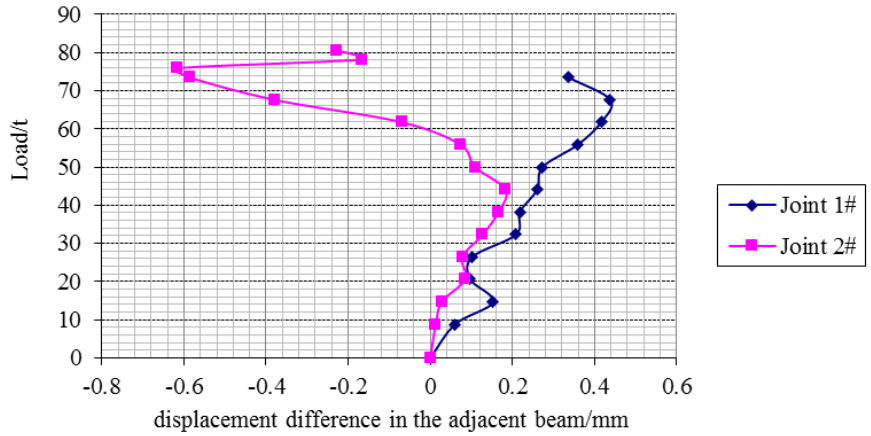


Fig. 11 The relative displacement curves of the adjacent beam in 1/2 section

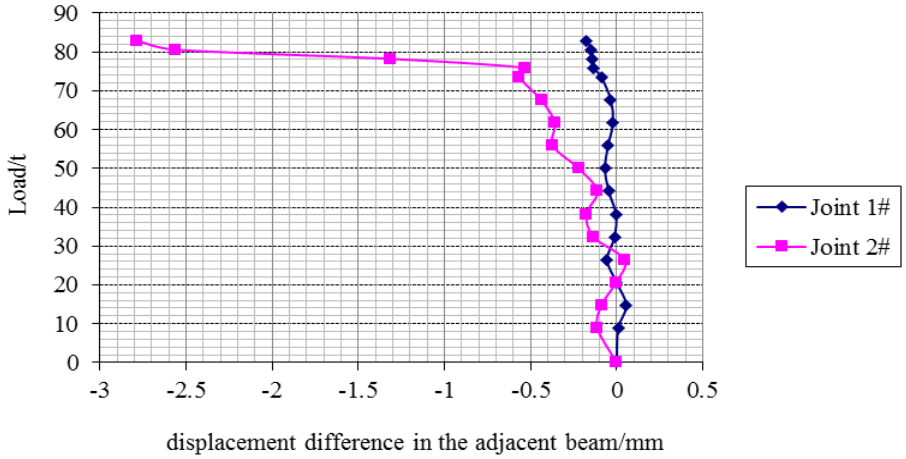


Fig. 12 The relative displacement curves of the adjacent beam in 3/4 section

Fig. 11 shows that the relative displacement of 2# hinge joints increase rapidly when the loading reaches 44t, and relative displacement load curve take on nonlinear characters. It can be conclude that the 2# hinge joints can be identified to be damaged. After that, the relative deformation continues to increase, but the slope of curve changes little, which indicates that the internal damage of the hinge joint is in the stage of stable

development. Fig. 12 shows the relative deformation of 3/4 cross section of the hinge joints on both sides of the box-beam, it can be indicated that the shear stiffness of hinge joints and rapid degrades, eventually destroys when the loading reaches 75.8t.

Conclusion

According to the experimental study on high performance grouts repairing hinge joints of box-beam, this paper obtains the following conclusions:

(1) By using the high performance grouting material in the maintenance of the joints, the ultimate load reaches 82.9t in the test, and it indicates the strengthen method can satisfy the need of design.

(2)The failure mode of repaired shear key is completely cracking of concrete joint, and it shows the characteristics of brittle failure.

(3) The relative displacement curves of hinge joints on both sides of the box-beam shows that when the loading reaches 44t, initial damage appears in the hinge joints, which leads to the degeneration of shear stiffness and increase of displacement difference. Therefore, the actual damage of shear key in the adjacent box-beam bridge can be deduced by the test of relative displacement.

Acknowledgement

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References

[1] Peng HE, Zhenfeng XIA, Huanan GUO. 30m hollow slab airbag Reinforced by Increasing Section Construction, The road, 2016,05:82-85. (In Chinese)

Improved Connection Details for Adjacent Prestressed Bridge Beams

[2] Guobin TANG, Tongning WANG, Yiqiang XIANG. Couple Effect of Loading and Corrosion of Concrete Bridge in Service Life. Journal of Highway and Transportation Research and Development, 30(2013) 62-67. (In Chinese)

[3] Russell, H. G.. Adjacent Precast Concrete Box Beam Bridges: Connection Details. A Synthesis of Highway Practice. United States, (2009): 86.

[4] Qingxiong WU, Yuechi CHEN, Kangming CHEN. Combined with the bottom surface of the hollow hinge failure mode analysis with door Reinforcement. Journal of Traffic and Transportation Engineering, 2015, 05:15-25. (In Chinese)

[5] Yudong LIN, Zhouhong ZONG, Honglei CHEN. Experimental study on shear performance of concrete beams strengthened with steel plates. Journal of Building Structures, 2011, 08:90-98. (In Chinese)

[6] Tongning BO. Study of the Mechanical Principle and Engineering Application of the Hollow Slab Bridges with Beam-reduction and Rib-addition Strengthening Method. Changan University, 2012. (In Chinese)

[7] F. Elgabbas, A.A. El-Ghandour, A.A. Abdelrahman, A.S. El-Dieb. Different CFRP strengthening techniques for prestressed hollow core concrete slabs: Experimental study and analytical investigation. Composite Structures, 92(2010): 401-411.

[8] Hua HUANG, Boquan LIU, Tao WU. Analysis of stiffness and cracks of shear strengthened beam with stainless steel wire mesh and polymer mortar. China civil engineering journal, (2011):32-38. (In Chinese)

