

Continuous and Jointless Transformation of Simply Supported Hollow Slab in Zhangzhou Shili Bridge

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ABSTRACT

Taking a multi-span simply supported hollow slab bridge with continuous slab-deck as an example, this paper introduces the background of Zhangzhou Shili Bridge, disease and security of the bridge are investigated and analyzed. Then the possibility and design method of the continuous and jointless transformation is put forward. Finally, the paper introduces the difficult problems on the research of the transformation.

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INTRODUCTION

Multi-span simply supported hollow slab bridge with continuous slab deck, as a common bridge type for small and medium span bridges, has the similar mechanical characteristics of simply supported girder bridge, with simple structure, convenient construction and free of expansion device, which all leads to the cost-saving in installation and repair of expansion device, and the amelioration of driving quality. Therefore, it has been applied in all parts of the world for quite a long time. With the increase of service period and the development of traffic volume, a large number of such bridges face the decrease in load carrying capacity and the inadequacy of design load. In order to improve the load-bearing capacity, safety and durability of these bridges, it is necessary to give them maintenance as well as strengthening. For that, we first need to analyze the causes of common distresses, and then accordingly give forth the scientific and reasonable solution. Taking a multi-span simply supported hollow slab bridge with continuous slab-deck as an example, this paper discusses the possibility and design method of the continuous and jointless transformation.

BACKGROUND

Shili Bridge is located in 503 County Road, Shili Village, Changtai County, Zhangzhou City. The bridge, with a length of 111.85 m and 6×16 m span arrangement, was built in 1995. It is designed as a simply supported hollow slab bridge with continuous RC deck, as shown in Fig.1. Shili Bridge, which is composed of old and new bridges, is a double deck bridge with center strip. The deck width is 1.75 m (sidewalk) + 9.5 m (lane) + 3.35 m (center strip) + 10.5 m (lane) + 1.75 m (sidewalk) = 26.85 m, where 9.5 m lane is the left old bridge (Fig.2). Original design load level for Shili Bridge is truck-load 20, trailer-load 100. The deck pavement adopts cement concrete. The superstructure uses precast or cast-in-place hollow slab of C30 grade concrete, and the substructure uses masonry gravity pier and open-cut expansion foundation. Fig.3 shows the picture of Shili Bridge after the completion.

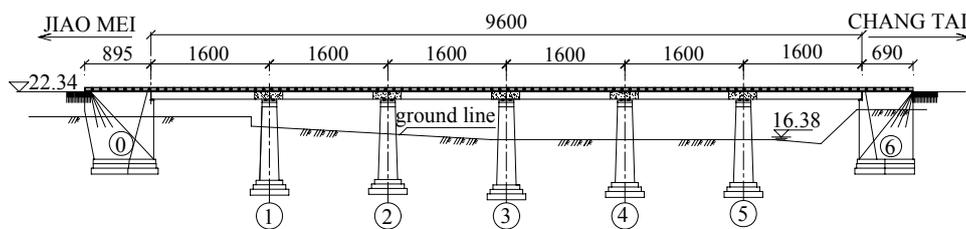


Fig.1 Elevation plans of Shili Bridge in Zhangzhou (unit:cm)

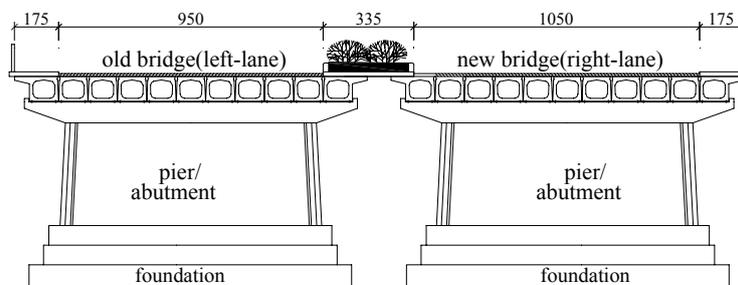


Fig.2 The standard cross-section of Shili Bridge



Fig.3 Zhangzhou Shili Bridge

BRIDGE DISEASES

Since the completion of Shili Bridge at 1995, it has been running for 18 years. During the operation, the bridge bears the heavy traffic load, and has suffered varied degrees of damage. There have been many longitudinal and transverse cracks appeared on the left deck, the maximum width of crack can be up to 1.2 mm. So we conducted a site inspection of the Shili Bridge commissioned by Zhangzhou City Road Administration.

After years of operating, the bridge appeared longitudinal cracks, transverse cracks, serious damage of section, concrete carbonation, steel corrosion, and other diseases, which caused a decline of its actual capacity. A detailed visual inspection was carried out. And concrete strengths of superstructure and substructure were detected by ultrasonic rebound combined method. Finally, dynamic load test was performed to check the dynamic characteristics of the bridge structure. The bridge had the following diseases:

a) Multiple longitudinal cracks appeared on the bridge deck system and hollow slab beam, most were located near the hinge joints, and the maximum crack width was 1.2 mm (Fig.4 and Fig.5); there were also multiple transverse cracks appeared on the deck above the pier, the maximum crack width was up to 1mm (Fig.4); hinge joints also appeared many concrete scaling, steel bar cropped out, and waney situations (Fig.6).



Fig.4. Cracks on the bridge deck



Fig.5. Cracks on the hollow slab beam



Fig.6. Concrete scaling at hinged joints



Fig.7. Seepage in pier and abutment

b) Abutment and pier was basically intact without deformation, subsidence, and cracking. Floor cracking, sliding, and moving were not found around foundation. Main disease of pier is the serious seepage (Fig.7).

c) Pavement concrete broke seriously (Fig.8); Beam bottom closely touched the cap beam, and caused bearings damaged (Fig.9); Expansion joint device did not run through transversely in the sidewalk slab and railing, which caused blocking and deformation; Lateral slit and pavement missing appeared on some sidewalk slab; Majority of deck drains failed to function, resulting in serious surface gathered water (Fig. 10).



Fig.8. Broken concrete pavement



Fig.9. Attached beam bottom and cap beam



Fig.10. Deck drain malfunction

d) The result of dynamic load test shows that the measured first order frequency is 5.37 Hz. The ratio of measured value with the theoretical frequency is 0.93, smaller than 1. This means the bridge was in a non-healthy state.

Based on the visual inspection results stated above, according to the “Highway bridge technical condition assessment standards” (JTG/TH-2011), the technical condition score for this bridge is 59.2. The bridge is identified as the 4th type bridge, and it means that the main components of the bridge had large defects, the bridge function was seriously influenced and the loading capacity was reduced, and the security of normal using cannot be ensured.

TRANSFORM AND UPGRADE

In view of the present bridge technology situation, in order to ensure the durability and security of the structure in the late operation, and meet the needs of the growing traffic, and improve its service level, reinforcement and reconstruction of continuous and seamless bridge structure are put forward. It is in line with the international advanced technology, and can promote the domestic development and application of seamless bridge. Detailed reinforcement plan is as follows:

The structural system was translated from simply-supported system to continuous system, thus to enhance the overall carrying capacity of the structure and improve the operational performance. After structure reinforcement, the integral rigidity of the bridge was improved, the bending moment at mid span was reduced, and the expansion joints were eliminated. These reinforcements make the driving comfortable, bring the convenience for maintenance management, and improve the durability and seismic ability of the structure. By using continuous system reinforcement, the defects of simply supported girder bridge, such as the poor continuity of bridge deck due to years of operation, large deformation, and poor durability, can be improved.

In order to form a continuous structural system, the concrete of beam end and top slab of main girder in the original bridge was chiseled at first, and the corresponding numbers of longitudinal steel bars were set up to resist negative bending moment caused by structural system transformation (shown in Fig. 11a and Fig. 11b). Then the exposed longitudinal steel bars of adjacent two beams and the negative bending moment steel bars were connected as a whole by pouring concrete. Meanwhile, the hollow portions at each end of the main girder within 1 m range were filled with micro expansive concrete of good compaction performance to ensure the integrity of pouring concrete and original main girder (Fig. 11c and Fig. 11d).

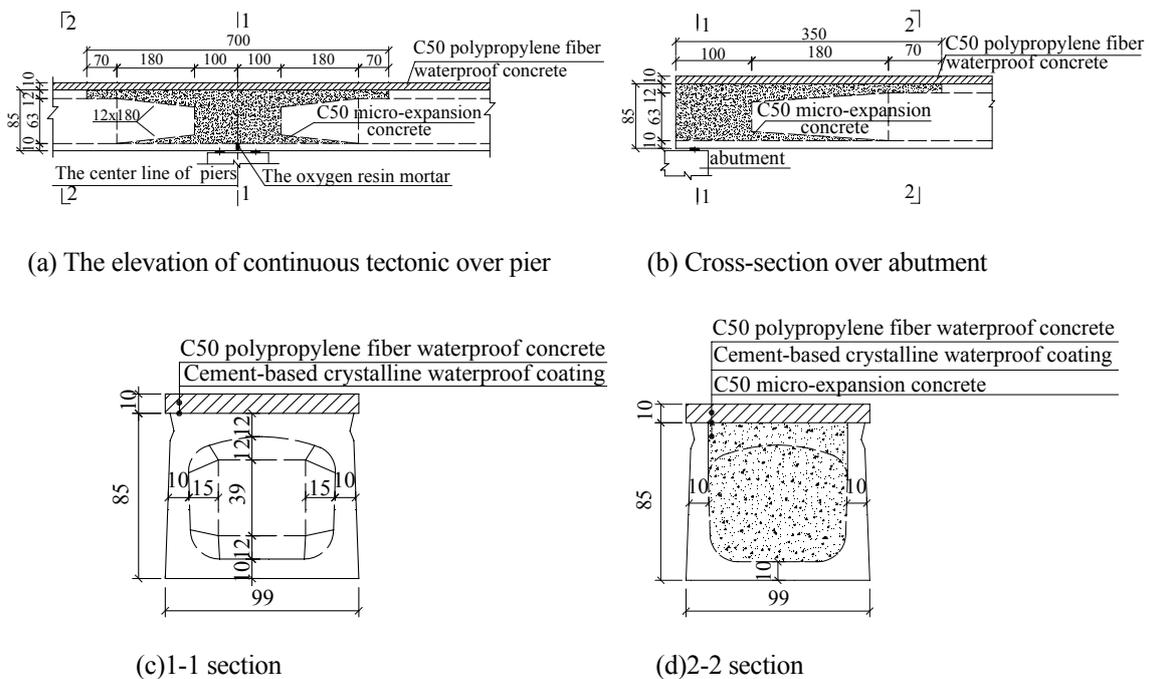


Fig. 11. Simply-supported to continuous structure system (unit: cm)

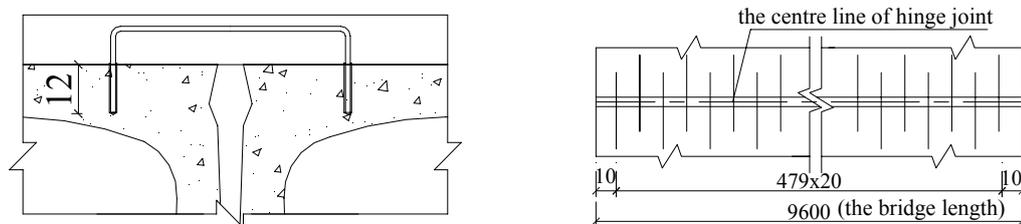
At the same time, the damaged bearings were eliminated and the new ones were reset. From theoretically analysis, single bearing and double bearing has not much difference in the influence of internal force distribution of continuous beam. Double bearing would decrease the peak of negative bending moment of continuous girder, and reduce accordingly the unloading of bending moment in the middle of the span. However, this negative impact is limited, especially for simply-supported-system to continuous-system reinforcement of commonly used 20-30 m span bridge. Therefore, from the view of the convenient construction, we adopted double bearing. All the original bearings were replaced with ordinary rubber bearings, general

laminated rubber bearing were set on the top of bridge piers, and four stainless steel PTFE laminated rubber bearings were used in the abutment to meet the deformation requirement.

The reinforcement from simply-supported-system to continuous-system can effectively improve the flexural capacity of cross section in the midspan, but has little effect on the shear capacity of inclined section near support. Therefore, it needs to make a check of the inclined section. After check, the size of cross section near support required widening (Fig. 11c). The web plate from midspan to support was thickened by 15 cm, and 12 cm for top and bottom plates (Fig. 11d). The gradient length was 1.8 m, shown in Fig.11a and Fig.11b.

Considering the crack control of on-site concrete layer in the deck (deck above piers under negative bending moment) and waterproof problems, C50 polypropylene fiber waterproof concrete with low shrinkage and good density was used in on-site concrete layer (Fig.11c). Using fiber reinforced concrete can effectively control the concrete shrinkage crack. Meanwhile, in order to control the shrinkage crack of concrete, 10 mm diameter steel mesh was placed on the top surface of after-pouring concrete layer, ϕ 20 mm steel bars were used on the top of on-site concrete layer to resist negative bending moment at the pier top caused by structural system transformation; the negative bending moment steel bars and steel mesh were tied together in the design. A ϕ 12 mm positioning steel bar parts was also embed on the top of the slab to ensure the location of negative bending moment steel bars. Finally a layer of cement base crystalline waterproof coating was paved between on-site layer and main girder to increase the waterproofing ability of bridge deck.

In the reinforcement from simply-supported-system to continuous-system, on-site concrete layer will participate with original structure in the bridge work. Therefore, reliable connection of the on-site concrete layer and the original girder is the basis for the two parts work together. In order to strengthen their reliable connection, it is needed to do careful surface roughening on the original deck and set up the necessary shear connectors. In the Shili Bridge, the shear connectors used 20 mm diameter R235 trough reinforcements, which were arranged along hinge joints at intervals of 20 cm, as shown in Fig.12.

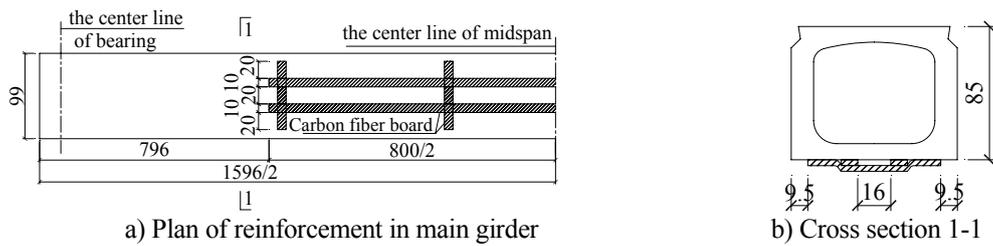


a) Details of planting steel bars

b) Arrangement plan of planting steel bar

Fig.12 Connection of on-site concrete layer and original structure (unit: cm)

In order to improve the bearing capacity of the cross section of the main girder, the carbon fiber plate was adopted for its high strength, high elastic modulus, good corrosion resistance and durability, without increasing weight and volume, wide application, and convenient construction. Two 1.4 mm thick carbon fiber plates were laid at the bottom of main girders of midspan within the range of 8 m, as shown in Fig.13, to improve the ultimate bearing capacity of the main girder and safety margin of the bridge.



a) Plan of reinforcement in main girder
 b) Cross section 1-1
 Fig.13 Sketch of reinforcement in main girder with carbon fiber plates (unit: cm)

Materials and structural stiffness varies greatly in phase at the abutment and bridge. The expansion joint are much more easily damaged here than those placed on the pier top. The vehicle bump at bridge approach, which causes a great damage on the bridge, is also a common problem accompanied with the settlement of abutment backfill. Therefore, we eliminated the expansion joints and expansion device at the abutments and piers, and achieved the seamless transformation of the whole bridge by taking effective measures. By eliminating the expansion joints of the whole bridge, the occurrence of vehicle bump was avoided or reduced, and driving smoothness was improved; maintenance and replacement costs of the bridge expansion joints were reduced, and consequent impact on traffic disruption was eliminated; noise caused by the expansion joints and environmental impacts due to structural vibration were also eliminated; joint water leakage was reduced; In a word, the structural integrity, durability, seismic resistant capacity and the service function of the bridge were improved.

Jointless transformation at the abutment was carried out on the basis of original design. In order to eliminate the expansion joints at both ends, the concrete within the range of 1 m in the girder at the ends of bridge was chiseled; the height of back wall of the old abutment was lowered, and re-poured concrete between the girder and slab to make slab cross the back wall and closely connect with main girder (Fig. 14).

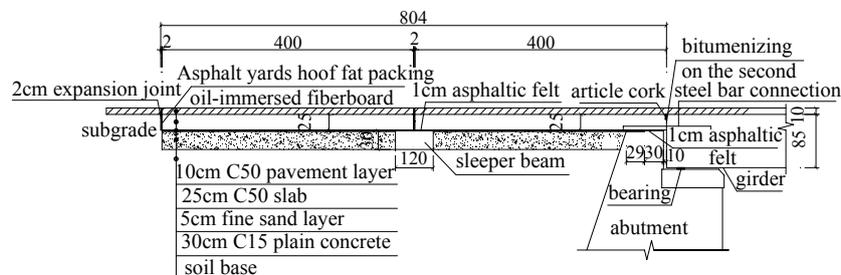


Fig.14. Elevation of jointless abutment (unit:cm)

Superstructure still retained the original abutments and bearings. A sliding surface (1 cm layer of asphaltic felt) was set on the top of back wall to make the deck system extend longitudinally under temperature deformation. The slab behind abutment should be placed on the backfill layer with smooth surface and low friction. Therefore, 5 cm thick layer of silver sand was laid under the slab to reduce the friction between slab and foundation for transmitting the stretching deformation from main girder. A construction joint (spline filled in the upper edge of joint) was set up between the beam ends and slab, aligned with the inside of the back wall, to establish a connection hinge to prevent the transmission of bending moment and control cracks. Meanwhile, the lower-part-transfixion-reinforcement connection was adopted to transmit the axial force at the joints between main girder and slab.

Two 4 m long slabs were set up behind the abutment. A 2 cm wide expansion joint was each set up between the slabs and slab and subgrade to absorb various deformations from bridge superstructure and slab system, and also alleviate the longitudinal pressure caused by expansion constraint of rigid pavement. To prevent the subsidence of slab at far end of abutment caused by stiffness mutation of subgrade, sleeper beam was set up between two slabs for achieving rigidity transition.

To ensure the carrying capacity requirement of the slab bottom, after excavation of foundation pit, a 30 cm thick concrete layer was laid under the slab for enhancing the strength of slab foundation.

DIFFICULT PROBLEMS

To make the old bridge jointless and continuous is an international hot spot. There are several difficulties existing in the jointless and continuous transformation of the hollow slab (small box girder) such as: the interaction of post-poured solid concrete and existing concrete structures, the interaction of new concrete and existing concrete and so on.

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