THE NEW STRENGTHENING METHOD OF HOLLOW SLAB GIRDER BRIDGES BY UHPC

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Abstract

As a popular form of medium-small span bridge, prefabricated hollow slab girder bridges get hinged joints failure casually due to design defect and terrible construction quality. Hinged joints failure result in many cracks in the bridges and even much more serious situation that single slab bearing. With the accomplishment of highway systems in China, large amounts of concrete hollow slab girder bridges have a lot of diseases, and it is urgent to repair and strengthen that, but there is still no useful repair method. This paper propose UHPC thin layer strengthening method by example of repair and strengthening of Tongji overpass, and a finite element model is built by Midas FEA to analyze the failure mode of concrete hollow slab bridges, proves the superiority and feasibility of the UHPC paving layer strengthening method by studying the result of different schemes concludes: original bridge, normal strengthening scheme, UHPC strengthening scheme.

Résumé

Type courant de ponts pour les petites et moyennes portées, les ponts à poutres-dalles creuses préfabriquées souffrent de faiblesses dans les joints articulés généralement à cause d'une conception défectueuse et d'une très mauvaise qualité d'exécution. Ces faiblesses dans les joints articulés créent des fissures dans le pont et d'autres problèmes plus graves de portance des dalles. Avec la réalisation du réseau autoroutier en Chine, de nombreux ponts à poutres à dalles creuses ont beaucoup de pathologies, et il est urgent de les réparer et de les renforcer mais il n'existe aucune méthode de réparation efficace. Cet article propose une méthode de renforcement par revêtement mince de BFUP en prenant exemple sur la réparation et le renforcement de la passerelle Tongji, et un modèle aux éléments finis a été construit par Midas FEA pour analyser le mode de rupture d'un pont à dalles creuses, qui montre la supériorité et la faisabilité d'un renforcement par revêtement de BFUP en étudiant les résultats des différents cas : le pont existant, le pont renforcé selon le schéma courant, le pont renforcé par revêtement BFUP.

1. PREFERENCE

With strong competitiveness among medium-small span bridges, prefabricated hollow slab girder bridges have played an important role in the construction and upgrading of the highway system in China. However, due to unreasonable design of the concrete hollow slab girder bridge, lacking of quality control of the construction process, increase of automobile traffic, overloading vehicles and so on, a large number of hollow slab girder bridges built in early period suffer significant damages, which cause the decline of the carrying capacity and automobile ride comfort, and even endanger the traffic safety and normal operation [1]. This paper proposes a method for strengthening slab bridges by pouring a thin layer UHPC (ultra-high performance concrete) on the slab face, This technology was first adopted in Switzerland and has already completed about 10 bridges strengthening, among which a highway bridge deck was damaged by fire [2] and Fig.1 shows the new deck after strengthening. Other countries including France [3] and America [4] also applied UHPC on concrete bridge strengthening.

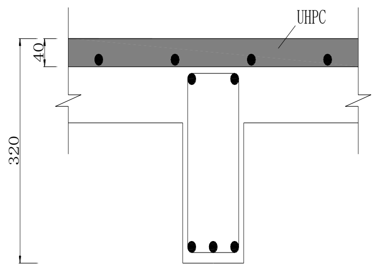

Fig.1. Strengthening scheme of bridge deck (unit: mm)

2. INTRODUCTION TO UHPC

The UHPC (commercial name is TENACAL) in this paper is developed by Tongji University and Shanghai Royang Innovative Material Technologies Co., Ltd together. UHPC is originally designed for cast in site application, so there is no need for steam curing. Table 1 shows mechanical properties of this UHPC. The measured tensile stress of UHPC is 12MPa. According to the France UHPC specification "ultra-high performance Fiber-Reinforced Recommendation" [5], the design value can be taken as 6.5MPa after calculation. The shear strength is calculated according to "Code For Design Of Highway Masonry Bridges And Culverts" (2013) [6]. The measured strength of C40 is 5MPa, the design value is 2.48MPa, the partial factor is 2.0, the measured shear strength is 22 MPa, so the design shear strength of UHPC is 11MPa.

UHPC axial tensile constitutive law can be divided into two types, namely strain-hardening fiber reinforced concrete and strain-softening fiber reinforced concrete. Stress hardening can occur when the post-cracking resistance is higher than the resistance of the matrix or else softening can occur when the post-cracking resistance remains lower than the resistance of the matrix. Fig.2 is the direct tensile mean stress-strain curve of strain-hardening UHPC.

Table 1.Characteristics of UHPC

Characteristics	UHPC
28d compressive strength（MPa）	⩾180
Elastic modules（GPa）	45～55
shrink（10^{-6}）	400～600
Creep coefficient	0.8
slump flow（mm）	600～800
Design tensile value(MPa)	6.5
Design shear value(MPa)	11

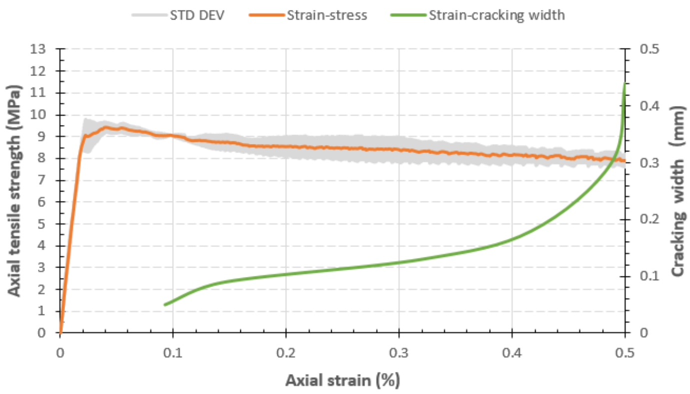

Fig. 2. Axial tensile stress-strain curves of UHPC (TENACAL)

3. CONSTRUCTION ANALYSIS

3.1 Introduction to construction

Tongji Road overpass in Baoshan District is an important transportation hub. the existing asphalt paving layer of North Tongji road has longitudinal penetration crack, hinge joints between slabs are damaged. Bridge has hidden danger. The computed span length of the bridge is 21.36m, 17 hollow slab girders in horizontal, the slab girders are connected by hinged joints.

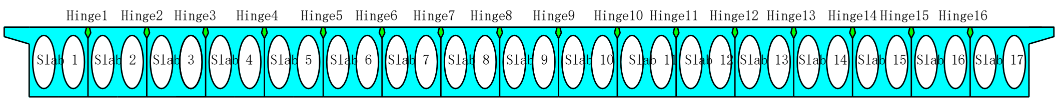

Fig. 3. Hinged number of the hollow slabs

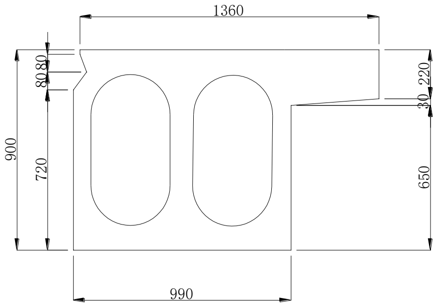

Fig. 4. Cross sections of side slab

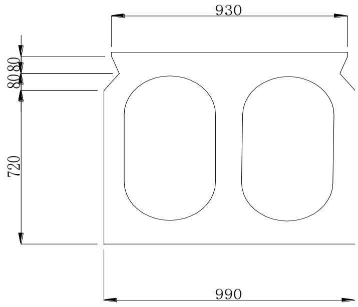

Fig. 5. Cross section of middle slab

3.2 Strengthening scheme

There are two kinds of strengthening schemes about bridge:

(1) One (conventional scheme):1. Chisel the original bridge concrete paving layer, 2. Repair damaged hinged joints, 3. Pour 11cm thickness concrete 4. Pave 5cm thickness asphalt concrete at last.

(2) Two (UHPC layer reinforcement scheme):1. Chisel deck asphalt concrete pavement, 2. Lay steel grids on the top of original concrete pavement (8cm), the diameters of longitudinal and transverse steel bars are 12mm and 8mm, 3. Pour 3cm thickness UHPC material on the top of concrete, according to the "ultra-high performance Fiber-Reinforced Recommendation" the minimum protective layer is 10mm, and it meet the requirement. 4. Finally pour 5cm asphalt concrete paving layer. The strengthening schemes are shown in Fig. 6 and Fig. 7.

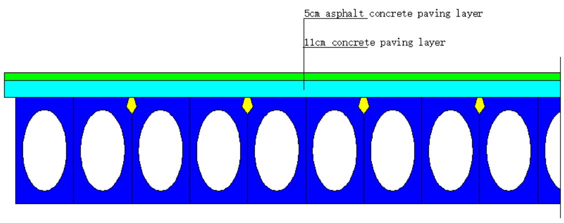

Fig. 6.Cross section of scheme one

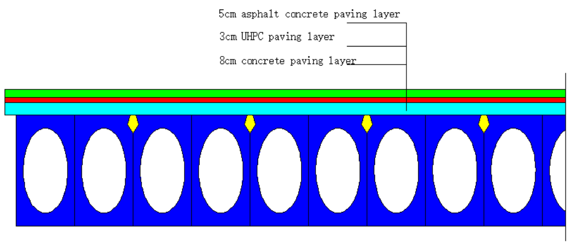

Fig. 7. Cross section of scheme two

3.3 Calculation

The original design load for the bridge is Car super-20. The calculation condition load is highway-I vehicle load of "General Code for Design of Highway Bridges and Culverts" JTJD60-2015[7] .The Fig.8 is loading model.

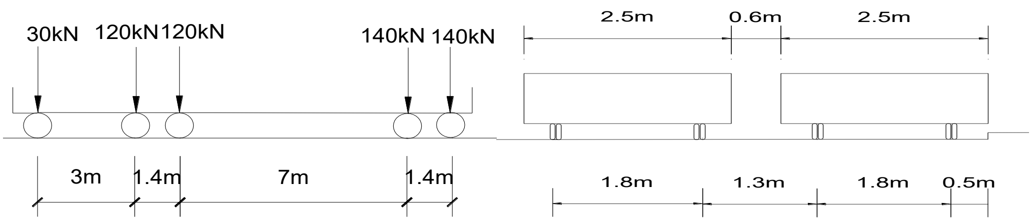

Fig. 8. Loading model (unit: m; kN)

4. ANALYSIS AND CALCULATE

4.1 Failure model

A Midas FEA [8] model was established for iterative calculation, from which the failure modes of the hollow slab bridge were obtained before and after strengthening, respectively. Four slab girders were connected by hinge joints and the load was a single automobile axis-weight which considered the overload ratio 0.3 and impact coefficient 0.3. The load was applied at mid-span, no other load was considered including the self-weight. The calculation model is shown in Fig.9. Scheme 1 (conventional scheme) the failure mode and the original bridge failure mode are basically the same, every stage of failure mode is shown in Table 2 and Fig. 10.

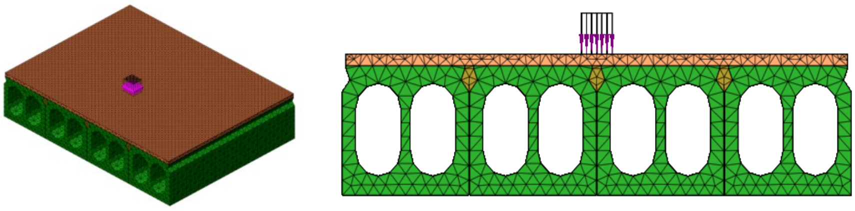

Fig. 9. Ansys calculation model

Table 2. The destruction mode of the original bridge

Stage	Axle load（kN）	3D unit status	Maximum crack width（mm）	Joints Shear stress（MPa）	Explanation
From one to two	80～160	Elastic	0	0.64	No crack
From three to four	240～320	Local crack	0.00641	1.31	The middle hinged joint in the contact interface of the hinged joint and the slab girder cracks, with the load increasing, the transverse crack at the bottom of the hinged joint extends upwards ,then the bottom of the paving layer and the edge of the hollow slab crack
From five to seven	400～560	Crack penetrate hinged joint	0.115	2.34	
Eight	640	Middle hinged joints damaged, paving layer crack	0.213	2.78	The middle hinged joints are damaged, the cracks penetrate the paving layer, and the other two joints crack.
From nine to ten	720～800	Structure failure	—	—	Hinged joint damage, crack penetrate paving layer, hollow slab girder web and bottom plate crack, overall structure failure

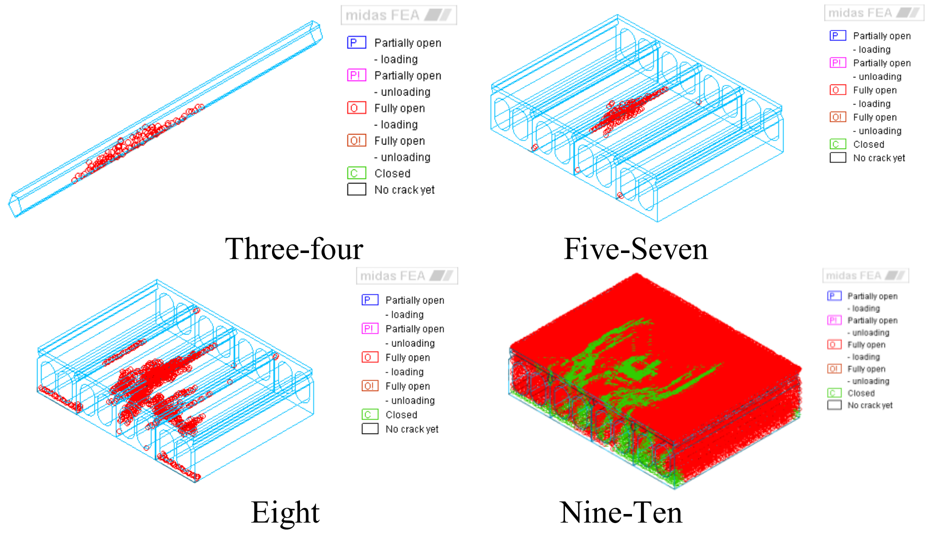

Fig. 10. Each destruction mode of the scheme two

From Table 2, the damage of the concrete hollow slab girder bridge began from the most vulnerable hinge joint and cracks on the bottom of hinge joints extended upwards till penetrating the paving layer. With failure of the adjacent hinge joints, slabs started to bear loads separately which resulted in cracks on the bottom slabs. Finally, the whole bridge structure was completely destroyed. Compared with the traditional scheme, UHPC strengthening scheme has shown similar phenomenon at the beginning of damages. However, cracks did not penetrate the UHPC layer until the failure of the whole bridge. The UHPC layer was able to transfer shear force during the whole loading process. Therefore, under the situation of damaged hinge joints, UHPC layer is efficient in bonding the whole bridge together, which avoids the single slab bearing.

4.2 Paving layer calculation

The tensile stress and shear stress of different schemes are shown in Table 3. According to the influence line, test report and filed situation, three conditions are determined: (1) hinged joints are not damaged; (2) No. 5 joint is damaged; (3) No.4, No.5, No.6 joints are damage.

The design shear strength and tension strength of UHPC are 11 MPa and 6.5 MPa respectively while for ordinary concrete C40, the design shear strength is 2.48MPa and the design tension strength is 1.65 MPa. Under the conditions that the middle or all hinge joints are damaged, the paving layers of original bridge and the conventional strengthening scheme would crack while tension stress and shear stress of UHPC layer did not surpass the design value under any conditions. That means the conventional paving layer would crack as long as one hinge joint cracked. To be compared, UHPC layer was able to bear loads even under damages of all the hinge joints. The whole bridge was at the integrated loading status by UHPC strengthening. Therefore, without damaged hinge joints repairs, 3cm UHPC paving layer enabled the whole bridge to bear sufficient loads, which also shortened the construction period and simplified the construction process.

Table 3: Paving layer stress of different schemes (unit: MPa)

Load condition	Maximum stress of pavement layer	Original bridge	Normal reinforcement scheme	UHPC scheme
one	Tensile stress	0.33	0.35	0.33
	Shear stress	0.21	0.37	0.21
two	Tensile stress	2.99	3.08	2.63
	Shear stress	6.32	6.02	4.56
three	Tensile stress	3.27	3.56	2.98
	Shear stress	4.57	4.88	3.06

4.3 In-field construction

Now, the UHPC thin layer strengthening scheme has been completed, and UHPC has excellent self-leveling property, achieves early strength without high temperature curing strength is about 30 MPa after 2 hours curing). The construction photos are shown in Fig. 11. The bridge paving layer was divided into two longitudinal parts in the whole span long, the strengthening scheme is carried out one by one.

Fig. 11. Construction photo

5. CONCLUSIONS

This paper proposes a new method for strengthening the hollow slab girder bridges by UHPC layer, and the following conclusions are obtained based on comparative analysis:

1. The failure modes of hinge joints on hollow slab girder bridges are analyzed. The damage begins from the bottom of the most unfavorable hinge joints, cracks extend upward to the paving layer with the adjacent hinge joints failure and finally the whole bridge structure is destroyed. This analysis is consistent with the actual situation, and provides the theory reference for disease analysis of hollow slab girder bridges.
2. Comparing with the conventional methods, UHPC layer strengthening scheme has shown great feasibility and superiority. Under the circumstances of one or more hinge joints failure, the UHPC layer can still transfer shear force effectively to maintain integrity of the whole bridge. It is obviously superior to the traditional strengthening scheme.
3. UHPC has excellent construction performance. The ultra-high performance can be achieved under ambient temperature curing. The early strength is high and the strain-hardening behavior shows similar properties with steel. Little effects on daily traffic by only removing asphalt, there is no need to chisel the existing concrete paving layer which greatly reduces the construction difficulty and period.
4. Considering the open traffic during strengthening, only 3cm UHPC layer was paved on the original concrete layer without repairing joints, but it also provided enough bearing capacity. Furthermore, the mechanical behavior of hollow slab girders will be largely improved if repairing joints is available as well.
5. Since UHPC material has superior properties, it has a wider application both on new bridges and strengthening fields of different structures.

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