The new method strengthen U-shape girders by UHPC thin layer

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Abstract

As a new type of bridge structure, prestressed concrete U-shape girders are extensively applied in urban elevated roads, railways and highways in China. However, there are problems remained for the structure of U-shape girders including large shear lag effect, poor torsional and integrity performance, which result in the emergence of various cracks on prefabricated bridge decks. Taking the strengthening of Hujia highway in Shanghai as a construction example, a strengthening method of U-shape girders by UHPC (ultra high performance concrete) is proposed in this paper. The UHPC layer was poured under the prefabricated bridge deck for repairing cracks and it has proved to improve the carrying capacity of the U-shape girders. In order to demonstrate the feasibility of UHPC layer strengthening method, a local plate finite element model is built to analyze the local effect. The UHPC plate bending experiment and in-field loading test are carried out to prove that the carrying capacity and strengthening effect of UHPC layer are remarkable.

Keywords: U-shape girder; UHPC; finite element analysis; bending capacity experiment; in-field loading test

1 Introduction

As a new form of bridge structure comparing with the box girder, T-girder and plate girder, prestressed concrete U-shape girder bridges show great advantages in lower building height, higher section utilization, better security, sound insulation and decrease of noise[1], which are especially suitable for railways, highways, urban railway transportation and overpass bridges. The U-shape girder was firstly applied on Roathy Mannerheim Bridge in 1952. From then on, Japan, France and Australia have completed a plenty of U-shape girder bridges. In 1990, Ritz U-shape girder bridge was built in Switzerland, of which the span is 143m. A preflex composite U-shape girder bridge was built in Belgium in 1995, and Australia also fulfilled a curved and skew U-shape bridge. In 2009, a 12.8km-long U-shape girder viaduct was constructed along from Dubai to Mecca, which consisted of 1170 pieces [2]. Contrary to its increasing application for the bridge structure, many defects of U-shape girders remain unsolved including the shear lag effect, the poor performance of torsion and global stability. Moreover, the concrete cracks are the main diseases of U-shape girder bridges, among which the common crack patterns can be classified as the inclined and vertical crack on the web, the transverse and longitudinal crack on the bottom plate and the visible crazing. Lap joints are adopted to connect the partial prestressed concrete U-shape girder with prefabricated plates. The joints are weak and unable to work as a unity, which result in longitudinal cracks in the prefabricated plate.

Up to now, the strengthening methods of U-shape girder mainly include: the carbon fiber paste method, the steel plate reinforcement method and etc.[3], but the actual strengthening effects are not satisfying and a more optimized method should be considered.

Based on the example of strengthening Hujia expressway, a strengthening method of U-shape girder bridges by UHPC (ultra high performance concrete) is proposed in this paper.

2 Introduction of ultra high performance composite (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" [4], the design value can be taken as 6.5MPa after calculation.

Table 1.Characteristics of UHPC

Characteristics	UHPC
28d compressive strength（MPa）	≥180
Elastic modules（GPa）	45～55
Poisson ratio	0.2
linear expansivity（$10^{-6}K^{-1}$）	11
shrink（10^{-6}）	200～600
Creep coefficient	0.8
frost resistance（Elastic modulus loss after 700 freezing-thawing cycles）	≈ 0%
slump flow（mm）	600～800
Design tensile strength (MPa)	6.5

3 Engineering examples

3.1 Engineering condition

Hujia Expressway (S5) starts from Wenshui road to the south Gate of Jiading, which is the first expressway in Shanghai and has been operating for more than 20 years. The total length is 18.35km and the design speed is 120km/h. The prefabricated deck between girders is A-Deck and the deck upon the girders is B-Deck.

The main diseases of bridge are the carbonation of the prefabricated bridge deck, water leakage on the joints of the deck, alkali aggregate reaction in the concrete of the girder and rusted reinforcements in the girder, which can be shown in Fig.1.

Fig.1 Reinforcement of deck leak

3.2 Optimization of strengthening scheme

In order to solve existing problems and improve the traffic condition, the previous strengthening method was first considered to strengthen the A-Deck with CFRP (carbon fiber-reinforced plastics) in 2013. However, the stiffness of structure and stress condition of the bridge deck cannot be effectively improved by the CFRP. And after two years with the aging of the cohesive glue between CFRP and the concrete, the strengthening effect will sharply decrease and even lead to the dropping of the A-Deck. Therefore, considering the drawbacks of the CFRP strengthening method, a new strengthening scheme is put forward in this paper: UHPC layer strengthening scheme, which was the final implementation scheme.

UHPC layer strengthening scheme involved the following procedures: (1) the steel bars were implanted into the original girder's horseshoe, where the anchorage depth was 15cm with 10cm spacing. (2) A template for pouring UHPC was set up between A-Deck and U-shape girder. The thicknesses for the UHPC layer were 5cm of intermediate part and 10cm at the end which connects the main girder by steel bars. The following Fig.2 shows the basic scheme for strengthening.

In Fig.3, before and after strengthening were compared on site. The length of the UHPC thin layer was all bridge long, which bonded the separate bridge decks as a whole.

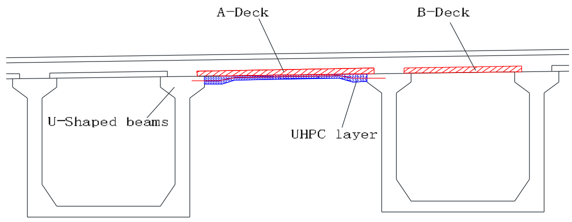

Fig.2 UHPC strengthening scheme

Fig.3 the effect drawing of UHPC

The main advantages of UHPC layer over traditional strengthening methods are: 1, convenient construction, when repairing and reinforcing U-shape girders, there is no influence on traffic or just need short close of bridge. 2, UHPC and materials of original concrete deck have good bond behavior, UHPC strengthening layer and girder can operate as a whole to cooperative bear force. 3, UHPC material has good durability, so that the durability of the whole structure will be greatly improved after being strengthened.

3.3 Local stress analysis of prefabricated A-Deck

In order to get the force distribution of the A-Deck under vehicle loads, a finite element model of A-Deck was built by Ansys Academic Release 15.0[5] for the local analysis. The dimension of the deck was 116cm×77cm with the thickness of 6cm, which was exactly the same with actual A-Deck on the bridge. The thickness of UHPC layer was 5 cm. The elements for this model were SOLID65 as the A-Deck and UHPC layer and LINK8 as the prestressing reinforcement, which the prestressing effect was applied by the cooling method. The actual boundary condition is between the hinge connection and rigid connection. In order to obtain the range of the stress, two models with one in hinge joints and the other in rigid boundary condition were established. The standard vehicle rear axle load is 70kN with an area of 0.2×0.6m. Due to the 45 degree angle of vehicle diffusion effect, the exerting area on the A-deck was 0.9×0.52m considering the 7cm thickness of asphalt paving layer and the 9cm thickness of concrete bridge deck. The FEA model is shown in Fig.4.

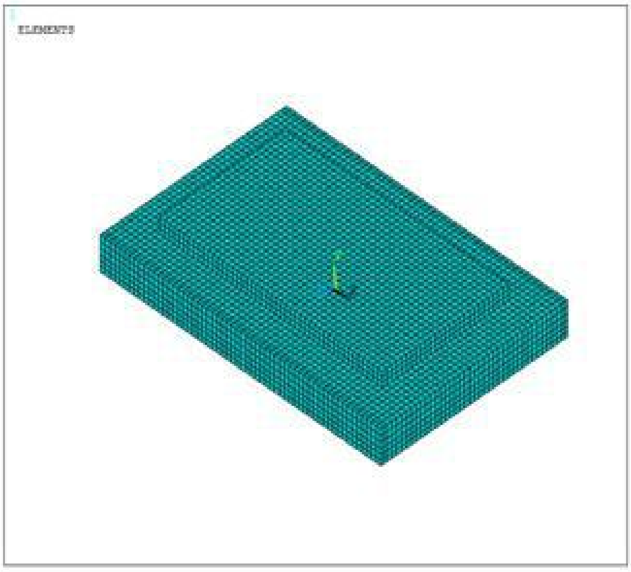

Fig.4 Finite element model of A-Deck and UHPC layer

The distributions of the transverse stress under two boundary conditions for the A-deck before strengthening are shown in Fig.5 and Fig.6. The maximum transverse stress was 7 MPa for hinge constraints and 3.1MPa for rigid conditions. Therefore, the maximum transverse stress for actual conditions was between 3.1 and 7 MPa.

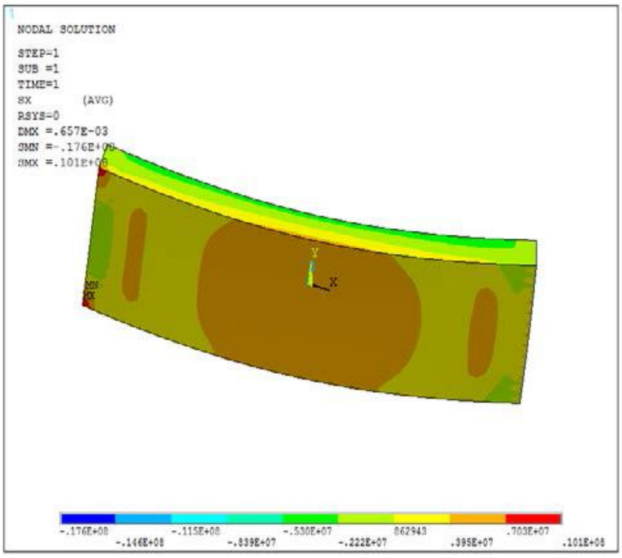

Fig.5 Transverse stress of the A-Deck before strengthening under hinged constraint

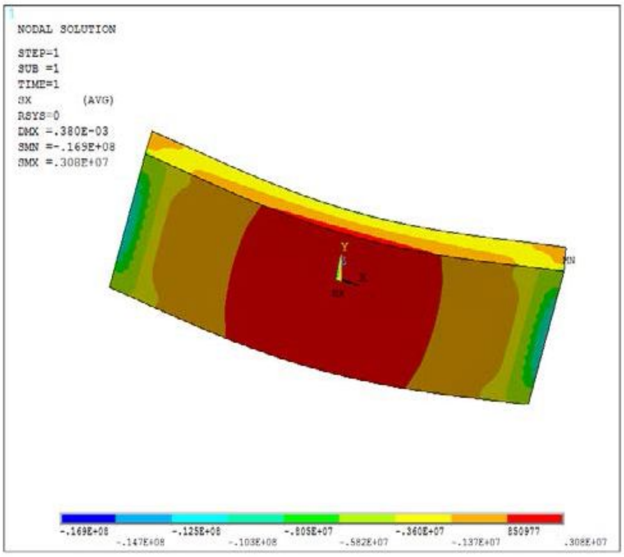

Fig.6 Transverse stress of the A-Deck before strengthening under consolidation constraint

The distributions of transverse stress of A-Deck after strengthening are shown in Fig.7 and Fig.8, in which the dead weight of the UHPC layer was included as well. The maximum transverse tension stress of A-Deck ranged from -0.44MPa to 0.44MPa, the maximum transverse tension stress of UHPC plate is 2.47MPa.

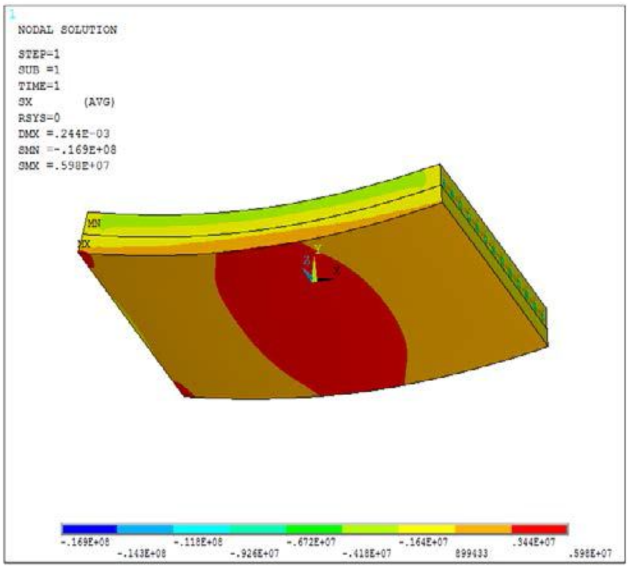

Fig.7 Transverse stress of A-Deck after reinforcement under hinged constraint

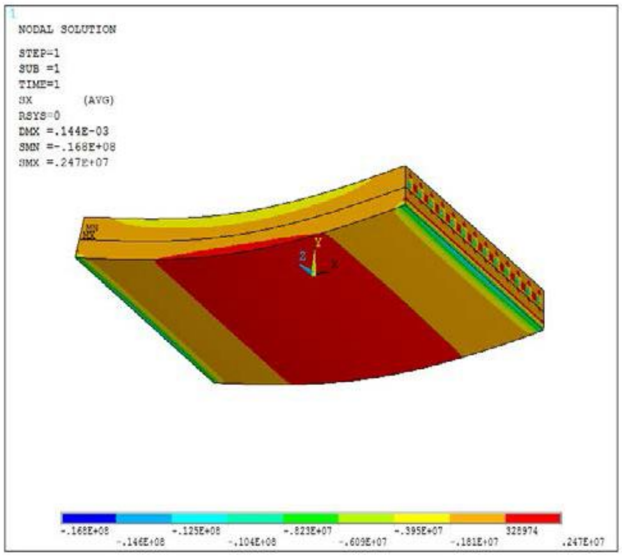

Fig.8 Transverse stress of A-Deck after reinforcement under consolidation constraint

Table 2 is a summary of the Ansys calculation results mentioned above. The maximum transverse stress was greatly decreased by UHPC strengthening method, which decreased from 3.1MPa and 7 MPa to -0.44MPa and 0.44MPa. The maximum stress for UHPC was 2.47MPa, which was far below the tension strength of UHPC

Table 2. Maximum normal stress of eachplate under vehicle load（MPa）

	A-DECK	UHPC
Before strengthening	3.1~7	—
After strengthening	-0.44~0.44	2.47

It can be concluded that the normal stress of A-deck decreased sharply, and the normal stress of UHPC layer is far less than the design value of UHPC 6.5MPa. Meanwhile, if the temperature and other factors are concluded the normal stress is more than 5MPa, and it is also meet the requirement, the strengthening effect is ideal.

4 Conclusion

A new method is proposed in this paper for reinforcing U-shape girder bridges by UHPC layer. Through the example of Hujia Expressway Wenzaobang Bridge repair and strengthening, a local model of Hujia Expressway Wenzaobang Bridge was established by Ansys to analyze the effects before and after strengthening. Based on the analysis, several conclusions were obtained as follows:

(1)The UHPC layer and the original bridge were able to form as an entity to bear the load.

(2) The partial model results by Ansys have shown that the stress of the UHPC under vehicle load and

load combination were less than its tensile strength and the stress condition of the prefabricated plate was highly improved by the UHPC strengthening

(3)The UHPC strengthening method shows many advantages over traditional methods. Therefore, it has wide applications and broad prospects in strengthening and structure fields.

5 References

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