Study on the Old Girders in the Widening Hollow Slab Girder Bridge

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Abstract: Taking the bridge widening project of Shanghai-Hangzhou-Ningbo expressway widening construction project (China) as the background in this paper, the variation law of the internal force of the old bridge in the widening hollow slab girder bridge under vehicle load is studied, which is under the condition of different span lengths and different widening widths. Three different span lengths of the pre-tensioned prestressed hollow slab girder bridges are selected, the spatial finite element models of both the old bridge and the whole structure of widening bridge are established and calculated respectively by Midas/Civil software. The influences of widening and load increasing on the old bridges under the vehicle load are compared and analyzed. In addition, the authors also analyze the influences of different widening widths on the force state of old bridges under the condition of widening the same number of lane. Moreover , the effects on the old bridges that are caused by the uneven foundation settlement of widening bridge structure are also studied in this paper. This paper can provide some references for widening design of hollow slab bridges.

1 Introduction

The vast majority of expressways built last century in China are two-way four lanes expressways due to the restrictions of many factors. However, with increasing traffic volume in recent years, most of the expressways in China have been unable to meet the current traffic demands, so it is necessary to broaden and rebuild them to improve service levels. The majority of expressway widening and reconstruction projects involve the widening and reconstruction of bridges, and hollow slab bridge is the common bridge type in China, so the key technology to widen and rebuild hollow slab bridges has been a research focus.

There are currently three ways to widen the hollow slab bridges in China: neither the superstructure nor the substructure of the old and new bridges being connected; both the superstructure and the substructure of the old and new bridges being connected; the superstructure of the old and new bridges being connected while the substructure being separated 1. Considering the adverse effect of differential foundation settlement between the old and new structures on widening bridges, the third method of widening the hollow slab bridges is generally adopted in China. At present, there are many engineering practices at connection method of widening hollow slab bridges 2, and a suit of relatively mature construction technologies and processes has been formed.

Most of relevant literatures mainly focus on the effects of different connection methods on bridges, or analyze a bridge engineering example. But in this paper, it is systematically studied that the influence of widening on the main girders in old bridges which are the same type of bridge on the same line under the condition of different spans, different widening widths and load increasing.

2 General Situation of the Project

Shanghai-Hangzhou-Ningbo expressway widening construction project (China) is taken as the background in this paper, three different span lengths of the pretensioned prestressed hollow slab girder bridges are selected to be calculated and analyzed, in order to find out the variation law of the internal force of the old bridge in the widening hollow slab girder bridge under vehicle load. Three span lengths of the bridges are 10m, 13m and 16m respectively, and the heights of the main girders are 40cm, 55cm and 70cm. These old bridges are made up of 12 prestressed concrete hollow slabs, and the widening structures consist of 7 prestressed concrete hollow slabs. The cross- section of superstructure is illustrated as Figure 1 (Only half bridge is shown).

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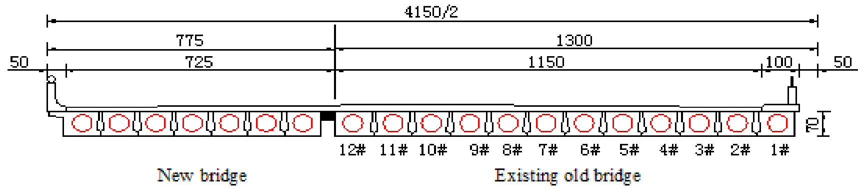

Figure 1 The Half Cross- section of Superstructure (unit = cm)

3 Calculation Mode

3.1 Design Codes

The old bridges were built on the basis of Code for Design of Highway Reinforced Concrete and Prestressed Concrete Bridges and Culverts JTJ023-85 (Old Standard for short), and the designing load of the old bridges was Truck-Load over 20. For bridge widening construction project, current Code for Design of Highway Reinforced Concrete and Prestressed Concrete Bridges and Culverts JTG D62-2004 (New Code for short) stipulates that the standard value of design load shall be the first grade loading of roadway. In this paper, the standard value of the first grade loading of roadway is determined by General Code for Design of Highway Bridges and Culverts JTG D60-2015.

The main girders of old bridges adopt C40 concrete according to the Old Standard, and the main girders of new bridges adopt C40 concrete due to the New Code.

3.2 Finite Element Modeling

Based on Grillage Theory, the spatial finite element models of old bridges and the overall bridge superstructures with span 10m, 13m, 16m are established and calculated respectively by Midas/Civil 8.32. In order to gain the vehicle load effects on these old bridges, Old Standard load and New Code load are both considered.

Each piece of prestressed hollow slab is modeled as one longitudinal beam, the transverse connections between longitudinal beams are simulated by rigid arms, which are perpendicular to the longitudinal beams. Each rigid arm between longitudinal beams is divided into two units, and the middle node is simulated by rigid joint or hinge joint according to the actual joint form between prestressed hollow slabs. The splicing joint between the new structure and the existing old bridge is rigidly connected, while the joints between the other main girders are hinged. Hinge joints are simulated by releasing beam end restraints. The space grillage model of superstructure is illustrated in Figure 2.

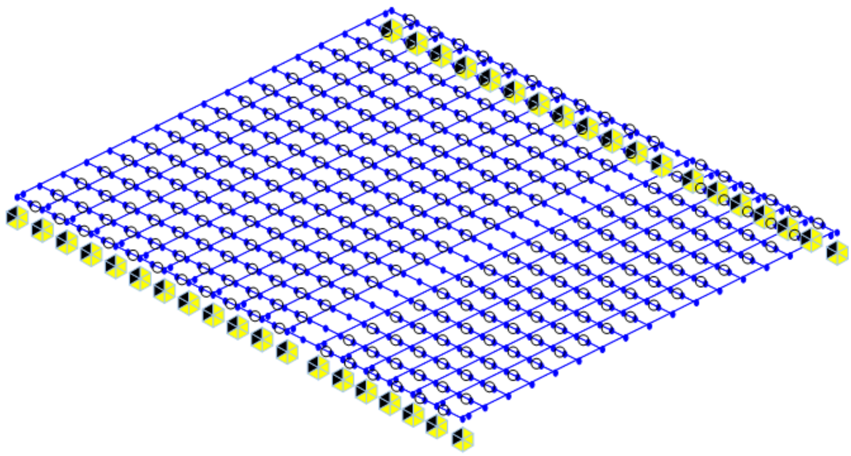

Figure 2 Space Grillage Model of Superstructure

4 Internal Force Analysis

4.1 Influence of Widening on the Old Hollow Slab Girder Bridge with Different Spans

On the basis of the articulated slab girder theory 8, the Transverse Distribution Factor of each main girder will decrease with the increase of the number of hollow slab, so the internal forces of the girders will decrease too, which shows that widening is beneficial to the main girders of the old bridges. Figure 3 shows the relationship between the load reduction rate of old bridges and the span length of bridges, in which the vehicle load on bridges before and after the broadening are both Truck-Load over 20. As shown in Figure 3, after broadening, the maximum mid-span bending moment of vehicle load effect (VMM-bending for short) of main girders in old bridges decreases, and the decrease amplitude increases with the increase of the span length. Meanwhile, it can be seen that the decrease amplitude of VMM-bending of main girders in old bridges near the broaden splicing side is more than which far from broaden splicing side.

Bridge widening and reconstruction is often accompanied with load increasing, but load increasing is unfavorable to existing old bridges. As illustrated in Table 1, the old bridges before widening are calculated on the basis of Old Standard while the whole bridge superstructures after widening are calculated based on New Code. We can find that the VMM-bending of main girders in old bridges increases after widening and load increasing. Moreover, as the span length of bridges increased, the increase amplitude has a decreasing trend.

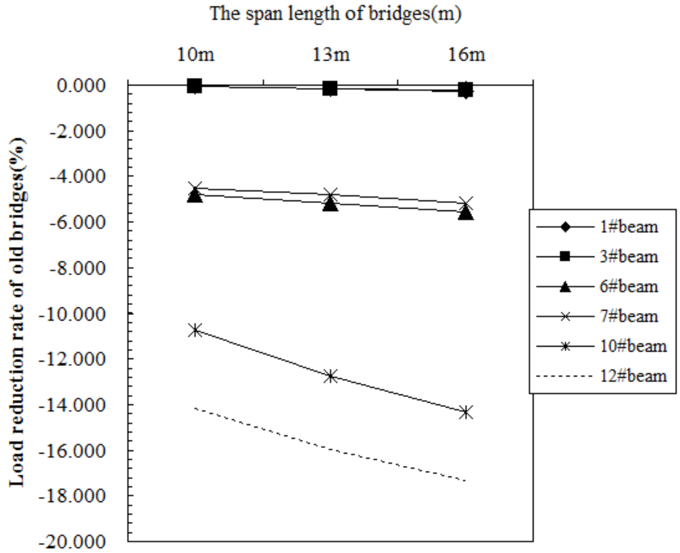

Figure 3 Relationship Between Load Reduction Rate of Old Bridges and Span Length of Bridges

Table 1 Comparison of VMM-bending of Main Girders in Old Bridge Between Existing Bridges and Whole Superstructures After Widening

Beam Number \ Span Length		10m M (kN·m)	13m M (kN·m)	16m M (kN·m)
1#beam	$M_{before-Old}$	166.1	218.2	314.2
	$M_{after-New}$	224.6	287.9	399.5
	Change Rate (%)	35.22	31.94	27.15
3#beam	$M_{before-Old}$	191.8	247.0	339.6
	$M_{after-New}$	269.6	337.3	448.2
	Change Rate (%)	40.56	36.56	31.98
6#beam	$M_{before-Old}$	182.9	236.4	330.4
	$M_{after-New}$	242.9	301.0	403.3
	Change Rate (%)	32.81	27.33	22.01
7#beam	$M_{before-Old}$	211.6	269.4	360.2
	$M_{after-New}$	294.7	364.3	483.8
	Change Rate (%)	39.27	35.23	34.31
10#beam	$M_{before-Old}$	229.2	297.3	402.4
	$M_{after-New}$	299.0	377.6	489.7
	Change Rate (%)	30.45	27.01	21.69
12#beam	$M_{before-Old}$	221.1	292.3	401.6
	$M_{after-New}$	277.5	354.9	460.3
	Change Rate (%)	25.51	21.42	14.62

Note: 1. $M_{before-Old}$ =VMM-bending of Main Girders in Old Bridge before widening based on Old Standard
2. $M_{after-New}$ =VMM-bending of Main Girders in Old Bridge after widening based on New Code
3. Change Rate = ($M_{after-New}$ − $M_{before-Old}$) / $M_{before-Old}$ ×100%

4.2 Influence of Widening Width On Old Bridge of the Widening Hollow Slab Girder Bridge

The hollow slab girder bridge with span 16m is taken as an analysis object in this paper, which consists of 12 main girders. To widen the old bridge from two lanes to four lanes, there are five kinds of widening width as follows:

1) Widening width is 5.75m: consisting of 5 main girders;

2) Widening width is 6.75m: consisting of 6 main girders;

3) Widening width is 7.75m: consisting of 7 main girders;

4) Widening width is 8.75m: consisting of 8 main girders;

5) Widening width is 9.75m: consisting of 9 main girders.

The splicing joint between the new structure and the existing old bridge is rigidly connected, while the joints between the other main girders are hinged. According to the most dangerous state of the old bridge, the distribution method of vehicle load is to asymmetrically load four lanes near the original inner side beam of old bridge as shown in Figure 4. The finite element models are established by Midas/Civil, and the vehicle load on bridge is Truck-Load over 20. The VMM-bending of main girders in old bridge under the condition of different widening widths is shown in Table 2.

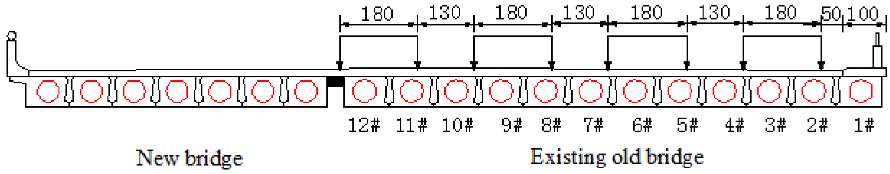

Figure 4 Distribution Method of Vehicle Load (unit = cm)

Table 2 The VMM-bending of Main Girders in Old Bridge under The Condition of Different Widening Widths

Widening Width	Beam Number	VMM-bending of Main Girders in Old Bridge（M/kN·m）			
		1#beam	6#beam	10#beam	12#beam
0m	$M_{before\text{-}Old}$	314.2	330.4	402.4	407.6
Widening width: 5.75m	$M_{after\text{-}Old}$	313.4	312.2	345.7	334.6
	Change Rate (%)	-0.25	-5.51	-14.09	-17.91
Widening width: 6.75m	$M_{after\text{-}Old}$	313.4	312.1	345.0	332.9
	Change Rate (%)	-0.25	-5.54	-14.26	-18.33
Widening width: 7.75m	$M_{after\text{-}Old}$	313.3	312.1	344.7	332.1
	Change Rate (%)	-0.29	-5.54	-14.34	-18.52
Widening width:8.75m	$M_{after\text{-}Old}$	313.3	312.1	344.5	331.8
	Change Rate (%)	-0.29	-5.54	-14.39	-18.60
Widening width: 9.75m	$M_{after\text{-}Old}$	313.3	312.0	344.2	331.6
	Change Rate (%)	-0.29	-5.57	-14.46	-18.65

Note: 1. $M_{before\text{-}Old}$ =VMM-bending of Main Girders in Old Bridge before widening based on Old Standard

2. $M_{after\text{-}Old}$ =VMM-bending of Main Girders in Old Bridge after widening based on Old Standard

3. Change Rate = $(M_{after\text{-}Old} - M_{before\text{-}Old}) / M_{before\text{-}Old} \times 100\%$

As shown in Table 2, the decrease amplitude of the VMM-bending of main girders in old bridge has a slow increasing trend with the increase of widening width with the condition of broadening the old bridge to four lanes. Moreover, the increase of widening width has almost no influence on the main girders far from the broaden splicing side.

4.3. Influence of Foundation Settlement of Widening Structure on Old Bridge

In general, when the old bridge was built and used for many years, its foundation settlement has been basically completed, but the foundation settlement of the new bridge has not been completed. So there is an uneven vertical foundation settlement between the old and new bridges 7. To analyze the influence of foundation settlement of widening structure on old bridge, the foundation settlement of widening structure is illustrated in Figure 5. Considering the engineering practice and the restriction of old bridge on widening structure, the foundation of the old bridge is considered having no settlement, and the foundation settlement of the main girder of the new bridge near the old bridge is adopted as 2mm, the foundation settlement of the outside girder of the widening bridge structure is adopted as 5mm, the foundation settlement of the other main girders of the widening bridge structure is calculated by linear interpolation simultaneously. The distribution method of vehicle load is shown in Figure 4, and the vehicle load on bridge is Truck-Load over 20. The VMM-bending of main girders in old bridge with the influence of uneven foundation settlement of widening structure is shown in Table 3.

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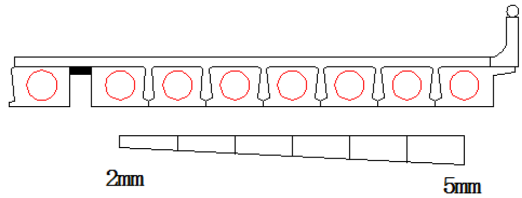

Figure 5 Foundation Settlement of Widening Structure

Table 3 The VMM-bending of Main Girders in Old Bridge with the Influence of Foundation Settlement of Widening Structure

Span length / Beam Number		VMM-bending of Main Girders in Old Bridge（M/kN·m）		
		10m	13m	16m
8#beam	M (without settlement)	204.5	261.4	347.9
	M (with settlement)	204.5	261.4	347.9
	Change Rate (%)	0.000	0.000	0.000
9#beam	M (without settlement)	173.9	221.5	306.3
	M (with settlement)	173.9	221.5	306.3
	Change Rate (%)	0.000	0.000	0.033
10#beam	M (without settlement)	204.6	259.4	344.7
	M (with settlement)	204.6	259.5	344.8
	Change Rate (%)	0.000	0.039	0.029
11#beam	M (without settlement)	211.9	271.5	358.3
	M (with settlement)	212.1	271.6	358.5
	Change Rate (%)	0.094	0.037	0.056
12#beam	M (without settlement)	189.8	245.6	332.1
	M (with settlement)	190.1	245.8	332.4
	Change Rate (%)	0.158	0.081	0.090

Note: Change Rate = (M (with settlement) — M (without settlement)) / M (without settlement)×100%

As shown in Table 3, the VMM-bending of main girders in old bridge near the broaden splicing side increases with the influence of the foundation settlement of widening structure, but the changes are very small (The change rates of the VMM-bending of main girders in old bridge are less than o.2%). Besides, the foundation settlement of widening structure has almost no influence on the main girders of old bridge which are far from the broaden splicing side.

5 Conclusion

Through tabular approaches to the study of the old girders in the widening hollow slab girder bridge, we can come to the following conclusions:

When the vehicle load on bridges before and after the broadening are both Truck-Load over 20, the VMM-bending of main girders in old bridge reduces, and the reduction of main girders of old bridge near the broaden splicing side can reach about 18%, which shows that widening can play an obvious unloading effect on the old bridges. Meanwhile, we can find that the decrease amplitude has an increasing trend with the increase of the span length of bridges, and decrease amplitude of VMM-bending of main girders in old bridge near the broaden splicing side is more than which far from broaden splicing side.

Besides, when the vehicle load on bridges after the broadening is the first grade loading of roadway, the VMM-bending of main girders in old bridge is greatly improved than which before widening. It indicates that load increasing is unfavourable for the old bridge. Therefore, it is necessary to check and analyze the state of old bridges during bridge widening design, and the old bridges should be reinforced if necessary. What's more, according to analysis, the influence of the widening width on the old bridge can be be neglected under the condition of widening the same number of lane because the changes are very small. And the foundation settlement of widening structure has little influence on the old bridge under vehicle load.

Acknowledgments

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