Comparison and Selection of Repair and Reinforcement Plans for Songkou Bridge

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Abstract. Under the long-term action of heavy and overloaded vehicles exceeding the designed load level, the Songkou Bridge suffered serious damage. After on-site inspection, the cause analysis of the main diseases is carried out, and the corresponding reinforcement and reconstruction plan is formed. The reconstruction of the bridge needs to increase the width of the bridge deck and increase the load level by rebuilding the upper structure. Finally, three schemes are formed for comparison and selection, and the optimal scheme is selected to renovate the bridge to meet the structural safety requirements and traffic requirements.

Keywords: disease cause analysis, bridge reinforcement, plan comparison and selection, beam replacement.

1. Introduction

With the continuous increase of the operating time of bridges, existing bridges often suffer from diseases such as concrete cracking and durability [1-5]. With the rapid economic development and the rapid increase in traffic volume, in order to further protect the safety of people's lives and property, bridges need to be maintained in time when necessary [6]. Under my country's current infrastructure construction and operation conditions, it is very difficult to dismantle and rebuild diseased bridges. It is necessary to improve their service life through repair and reinforcement measures to ensure the safety of operations [7, 8]. Therefore, the reinforcement of existing bridge structures is one of the hot topics in the field of bridge engineering at home and abroad [9-11].

This article introduces the existing diseases of the Songkou Bridge, and through the analysis of the causes of the diseases, three types of reinforcement and reconstruction schemes are formed. Then take economic efficiency, construction period, traffic pressure during construction and long-term economic benefits as the main evaluation indicators, compare and select the best plan to reform the bridge to meet the requirements of structural safety and traffic.

2. Background

The Songkou Bridge is located on the national highway G534 and crosses the Dazhang River. It is the only way from Songkou Town to Changqing and Gaiyang. The central pile number of the bridge is K134+110, with a total length of 182.45m. The original upper structure of the bridge is an 8-span 22.16m reinforced concrete simply supported T-beam, and the lower structure uses reinforced concrete embedded abutments and grout masonry gravity piers. The full width of the bridge is 6.8m+2×1.0m sidewalk, and the design load is car-15. The bridge was strengthened once in 2009, using the reinforcement method of adding 4 new T-beams between the original 5 T-beams. The design load of the bridge is Highway- II. The main girder section after reinforcement is shown in Figure 1, where ②、④、⑥、⑧main beams are newly added main beams. According to the on-site investigation in 2019, the overall technical status of the bridge is grade 4, and the main components have large defects, which seriously affect the function of use, and urgently need to be repaired and reinforced.

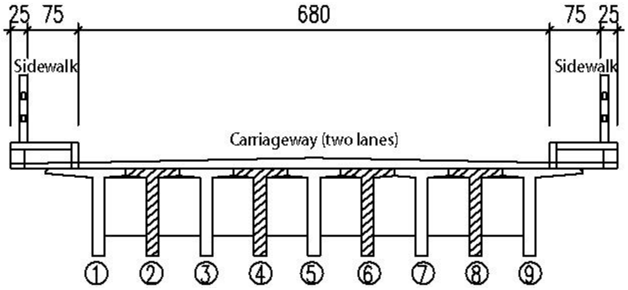


Figure 1. Cross-sectional view of the main beam after reinforcement in 2009 (unit: cm)

3. Stress monitoring of new steel members

3.1. Main girder stress monitoring results

After inspection, it was found that there were 1499 vertical and oblique cracks in the web of the main beam. The total length of the cracks reached 583.14m. Among them, 3 cracks in the web of 1-6# and 4-2# T beams exceeded the limit, and the width of the over-limit cracks was 0.26~ 0.4mm; There are 352 transverse cracks in the bottom plate of the main beam, and the total length of the cracks reaches 63.36m. Among them, one crack at the bottom of 6-1#T beam exceeds the limit, and the width of the excess crack is 0.29mm.

(a)Vertical cracks in the web of the beam (b)Transverse cracks in the beam bottom plate

Figure 2. Schematic diagram of the main cracks of the main beam

3.2. Stress monitoring results of steel brackets

Regular inspections of bridges showed that beam cracks and diseases increased dramatically from 2017 to 2018. During the construction of the nearby Puyan Expressway, a large number of heavy-duty construction vehicles passed through the bridge. Therefore, it can be considered that a large number of heavy-duty traffic has led to the rapid development of bridge diseases. Under long-term overload, cracks will continue to develop, affecting the safe use and durability of bridges [12]. The detailed analysis of the causes of the main diseases in various parts of the bridge is as follows:

First of all, there are transverse bending cracks at the bottom of the main beam. Most of the width of the transverse cracks at the bottom of the beam is within the limit. Only one crack at the bottom of the 6-1#T beam has a width of 0.29mm, which is mainly due to the load caused by heavy vehicles and other reasons. The effect is greater than the design load-bearing capacity of the beam, causing cracks to exceed the limit.

Secondly, the large number of vertical cracks that did not exceed the standard in the main beam web are shrinkage cracks, which are mainly due to the large difference in age between the newly poured T beam and the original T beam, and the shrinkage of the newly poured concrete is constrained by the old beam body. This results in cracks in the weak web.

Finally, the bridge deck pavement at the continuous position on the top of the pier is provided with a structure such as slitting, but it still has a certain degree of rigidity. Under the action of the vehicle load, a negative bending moment is generated and cracks are caused.

3.3. Bridge inspection conclusion.

The construction of this bridge is relatively old, the original design load is relatively low, and the crack width of some T beams has exceeded the specification limit, which will affect the safe use and durability of the bridge. In order to eliminate potential safety hazards and ensure the good traffic capacity of the G534 line, the bridge needs to be reinforced and reconstructed.

4. Bridge reinforcement plan

4.1. Design Principles

The bridge reinforcement design scheme aims at restoring the function of the components, restoring the bearing capacity to a certain extent, and ensuring the safety and durability of the structure [13]. To determine the optimal structural reinforcement plan for the existing bridge to be used, the plan is generally divided into three types: The first plan is the bridge reinforcement and utilization plan. According to the insufficient load-bearing capacity, different reinforcement methods are used for the upper structure and the lower structure to calculate and compare, mainly including pasting steel plates, carbon fiber cloth, prestressed carbon fiber boards, prestressed steel wire ropes and bridges. Surface reinforcement layer reinforcement; The second plan is the dismantling of the upper structure and the reinforcement of the lower structure; The third option is to demolish and rebuild the upper and lower structures of the bridge, and retain the pile foundation [14].

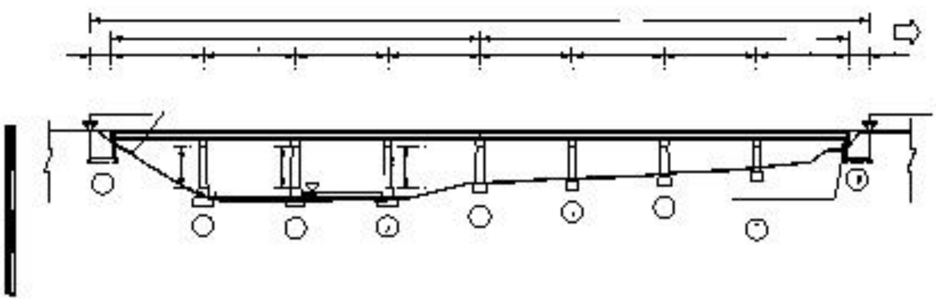
After the upper structure of the bridge was repaired and strengthened twice, the diseases continued to appear and develop. Re-repairing the upper structure would pose a greater safety hazard and the effect would be difficult to guarantee. Therefore, this design considers a repair plan of demolishing and rebuilding the upper structure, and reinforces and repairs the solid piers and abutments.

4.2. Comparison of reinforcement schemes

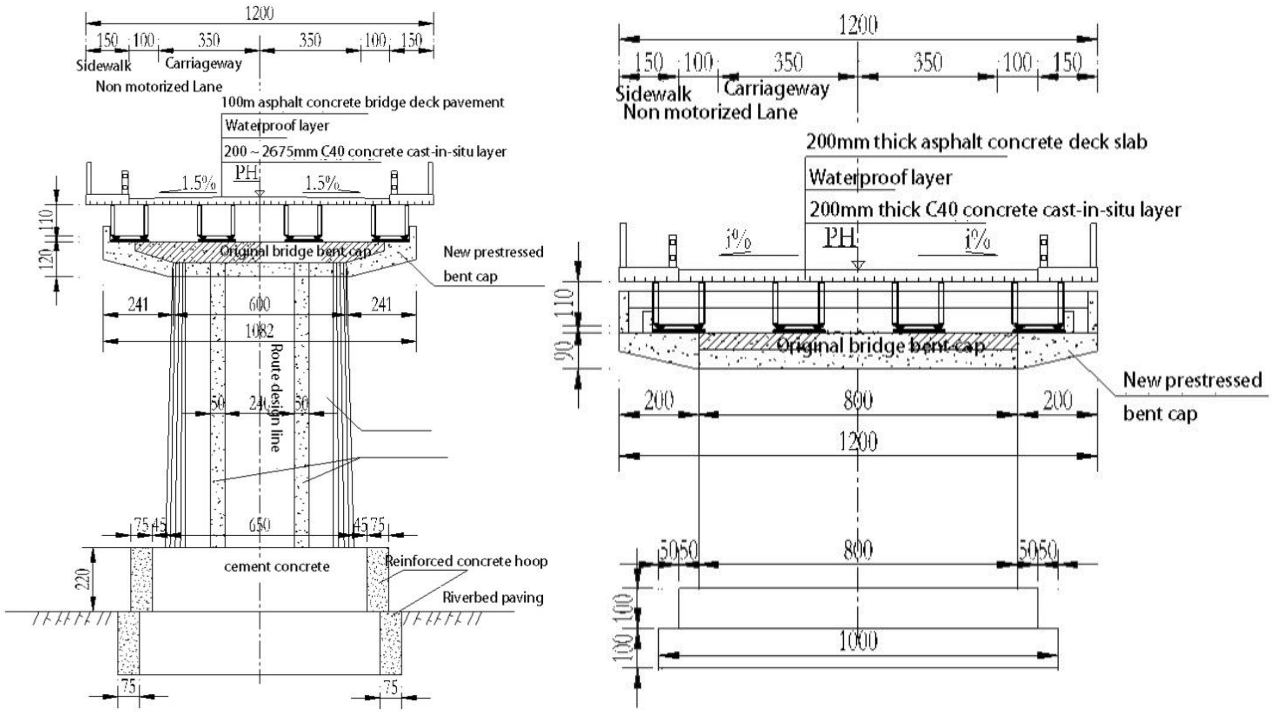
This reconstruction plan maintains the original bridge position and bridge span unchanged, and needs to increase the width of the bridge deck. According to the main girder type of the superstructure, three plans are proposed for steel-concrete composite girder, PC continuous T-beam and PC cast-in-place box girder.

4.2.1 Reinforcement plan one: steel-concrete composite beam plan

The superstructure has 4 horizontal steel-concrete composite beams with a beam height of 1.1m. The cross-section of the bridge pier is increased, the cap beam is lengthened, and the abutment cap is correspondingly increased. The bridge deck pavement is 20~26.75cm thick C40 concrete cast-in-place layer + waterproof layer + 10cm asphalt concrete. The bridge layout and section of this scheme are shown in Figure 3.



(a)Bridge layout



(b)Cross-sectional view of bridge pier (c)Cross-sectional view of abutment

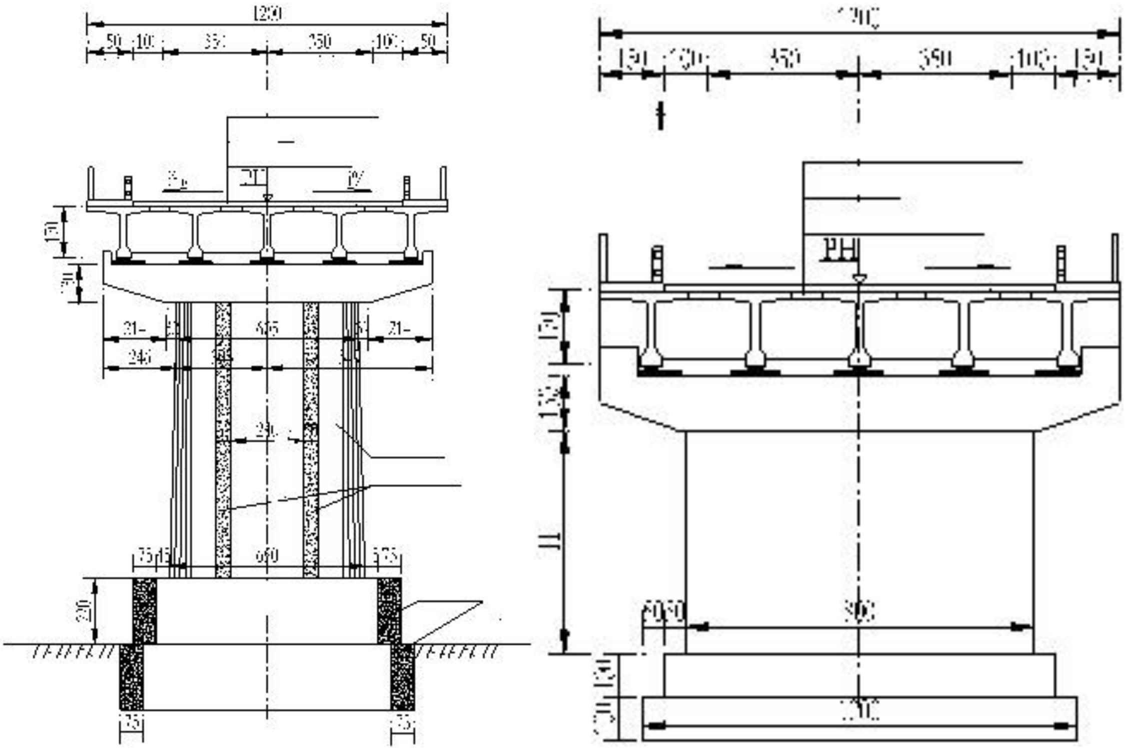
Figure 3. Plan 1 bridge layout and cross section (unit: cm)

In this plan, the construction of the superstructure requires temporary access roads on both sides of the bridge site. During the closed traffic phase, the temporary access roads and village roads near the bridge site can be used for regular vehicle traffic; the steel-concrete composite beams are processed in sections by the factory and transported to At the construction site, two 80t gantry cranes were used to assemble the entire span, and two 180t truck cranes and 200t beam trucks were used to hoist the entire span to the design position, and then the roof concrete was poured on site.

The reinforcement of the substructure mainly includes the foundation reinforced concrete hoop, the pier body is equipped with pier ribs, and the new prestressed concrete cover beam is outside. The foundation reinforcement uses the method of island cofferdam and foundation pit excavation, erecting formwork and concrete pouring; the pier body reinforcement adopts the bracket method.

4.2.2 Reinforcement plan two: PC continuous T-beam solution

The upper part of the bridge adopts 4×22.16+4×22.16mPC continuous T-beams, 5 horizontal T-beams, and the beam height is 1.7m, rebuild reinforced concrete cover beams, and strengthen bridge piers and foundations. The structure is shown in Figure 4.



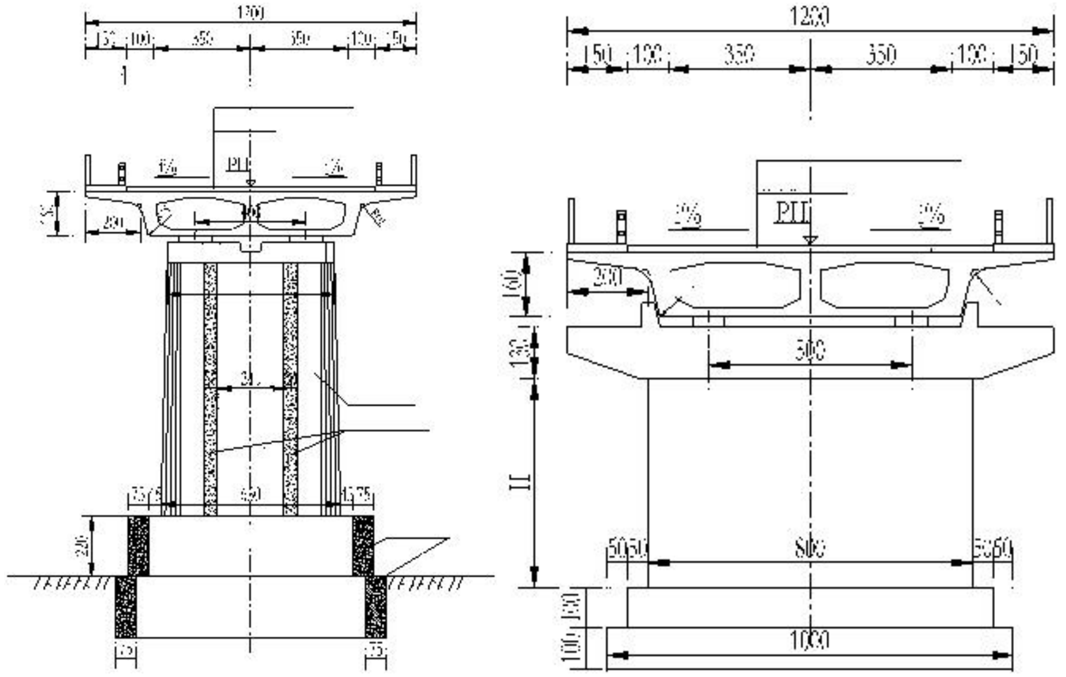
(a)Cross-sectional view of bridge pier (b)Cross-sectional view of abutment

Figure 4. Cross-sectional view of the main beam of Scheme 2 (unit: cm)

In this plan, the construction of T-beam prefabricated beam yard, installation of gantry cranes, water and electricity, and construction of Baotong temporary trestle bridge are required. The bridge deck system, upper reinforced concrete T-beam, pier cap beam and part of the pier body, abutment cap beam and part of the abutment body of the existing bridge need to be removed; Newly built bridge pier cap beam, abutment cap beam and abutment body. The installation of the T beam uses a bridge erecting machine.

4.2.3 Reinforcement plan three:PC cast-in-place box girder construction plan

The third option is to use 4×22.16+4×22.16mPC cast-in-place box girder on the upper part of the bridge, using uniform cross-section oblique web box girder, single box and double chamber, beam height 1.6m, cantilever 2m, and web slope 4:1. The deck pavement is 8cm thick C40 concrete + waterproof layer + 10cm asphalt concrete. The structure is shown in Figure5.



(a)Cross-sectional view of bridge pier (b)Cross-sectional view of abutment

Figure 5. Cross-sectional view of the main beam of Scheme 3 (unit: cm)

In option three, a trestle bridge needs to be installed downstream of the Songkou Bridge to ensure traffic along the route. The deck system, reinforced concrete T-beams, pier cover beams and part of the pier body shall be removed, and scaffolding shall be installed at the same time to build new pier cover beams and pier ribs.

5. Design scheme comparison

5.1. The impact of each plan on the substructure

In order to consider the impact of changes in the upper structure on the lower structure, this design did not consider the increase in load level. The comparison of the design schemes with the dead load before the reinforcement in 2009 is shown in Table 1.

Table 1. Checking results of substructure pier top

Serial number	Bridge plan	Dead load	
		Axial force(KN)	Load multiples
1	Steel concrete composite beam	3006.9	1.44
2	T beam scheme	4791.8	2.30
3	Concrete box girder	6620.9	3.17
4	After reinforcement in 2009	2577.8	1.23
5	Before reinforcement in 2009	2087.8	1.00

It can be seen from Table 1 that the minimum load increase of the steel-concrete composite beam scheme under the dead load is 1.44 times that before the reinforcement in 2009, and the T-beam and box girder schemes are 2.30 and 3.17 times in turn. It can be seen that the steel-concrete composite beam scheme (Scheme 1) has the least impact on the substructure.

5.2. Comprehensive comparison conclusion

Table 2 shows the comparison and selection of various reinforcement design schemes. It can be seen from the table that the construction period of the steel-concrete composite beam scheme is shorter, the closed traffic time is shorter, and the social impact is small. It can be used with a convenient construction scheme with a lower cost, and the dead load increase is less compared with the original structure bridge. The load level can be upgraded to highway I, and the safety of the original old bridge piers can be more effectively guaranteed. Therefore, after comprehensively considering the construction period, social impact, and project cost, the first option-steel-concrete composite beam option is recommended.

Table 2. Comparison and selection of various reinforcement design schemes

plan	plan one	Plan two	Plan three
Superstructure form	Steel concrete composite beam	PC continuous T beam	PC cast-in-place box girder
Beam height	1.1m	1.7m	1.6m
Load level after reinforcement	Can meet the highway-I level	Highway- II	Highway- II
Impact on current traffic	Need to close traffic for a short time	Traffic must be closed	Traffic must be closed
Construction characteristics	Low requirements for lifting capacity, fast construction speed	Need to build a new prefabrication plant, construction is relatively fast, but high requirements for hoisting capacity	Cast-in-place construction with scaffolding, slow construction speed
Construction period	65 days, short construction period	122 days, long construction period	162 days, long construction period
Structural features	Strong spanning ability, lightest structural weight, 0.44 times increase in dead load compared to the original structure, and the bridge cross section is not compressed	The dead load is increased by 1.3 times compared with the original bridge, the force of the substructure is increased greatly, and the integrity is poor; the existing pier and abutment need to be removed during construction	The dead load is increased by 2.17 times compared with the original bridge, and the force on the substructure is increased greatly, and the integrity is better; the existing pier and abutment need to be removed during construction
Features of transport and nutrition	Appropriate maintenance can be taken during operation	Good durability, low maintenance and maintenance requirements	Good durability, low maintenance and maintenance requirements
Project Cost	17.284 million yuan	12.643 million yuan	16.879 million yuan
Comparison conclusion	Optimal		

6. Conclusion

(1) The cause analysis of the structural defects of the old bridge of Songkou Bridge shows that the bridge defects are mainly caused by a large number of heavy-duty traffic operations.

(2) Based on the problems that the diseases continue to appear and develop after the superstructure is repaired and strengthened, the repair and reconstruction plan for replacing the main girder of the old bridge and strengthening the original pier and abutment foundations is preliminarily determined.

(3) Three reinforcement schemes for steel-concrete composite beams, PC continuous T-beams and PC cast-in-place box girder were proposed. The comparisons and selections were made in terms of

economy, construction period, traffic pressure during construction, and long-term economic benefits. The results showed that steel-concrete composite beams The beam scheme has a shorter construction period, shorter closed traffic time, and less social impact. It can be used with a convenient construction and lower cost guarantee scheme, and compared with the original structure of the bridge, the dead load increase is less, and the load level can be upgraded to highway I , The safety of the original old bridge piers can be more effectively guaranteed, which can be used as a priority recommendation.

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