Experimental Inspection of Damage and Performance Evaluation after Repair and Strengthening of Jiamusi Highway Prestressed Concrete Bridge in China

Ali Fadhil Naser and Wang Zonglin

***Abstract*—**The main objectives of this study are to inspect and identify any damage of jaimusi highway prestressed concrete bridge after repair and strengthening of damaged structural members and to evaluate the performance of the bridge structural members by adopting static load test. Inspection program after repair and strengthening includes identifying and evaluating the structural members of bridge such as T-shape cantilever structure, hanging beams, corbels, external tendons, anchor beams, sticking steel plate, and piers. The results of inspection show that the overall state of the bridge structural member after repair and strengthening is good. The results of rebound test of concrete strength show that the average strength of concrete is 46.31Mpa. Whereas, the average value of concrete strength of anchor beam is 49.82Mpa. According to the results of static load test, the experimental values are less than theoretical values of internal forces, deflection, and strain, indicating that the stiffness of the experimental structure, overall deformation and integrity satisfy the designed standard and the working performance is good, and the undertaking capacity has a certain surplus. There is not visible change in the length and width of cracks and there are not new cracks under experimental load.

***Keywords*—**Jiamusi Bridge, Damage inspection, deflection, strain.

I. Introduction

A BRIDGE can be defined as a structure including supports erected over a depression or an obstruction, such as water, highway, or railway, and having a track or passageway for carrying traffic or other moving loads. Bridge structure consists of two parts. The first part is known as superstructure which is composed of bearings, girders or beams, deck, joints, pavement layers, security barrier, and drainage system. Whereas, the second part is known as substructure which is included the foundations, piers, and pier caps. A bridge inspection can be defined as the condition inspection and evaluation of in-service bridges [1]-[2].

The purposes of damages inspection of bridge components are to sure whether a bridge structure is in safe state or not, identify any maintenance, repair, and strengthening which that need to be done, provide a basis of planning for funding of any required maintenance and strengthening, and provide information to designers and construction engineers on those features which need maintenance [3].

The main damages occurring in reinforced concrete bridge include different types of cracks, scaling, spalling, delaminating, efflorescence, stains, corrosion of steel reinforcement, deformation, and excessive deflection. Cracks play important role in the acceleration of reinforcement corrosion, deterioration of concrete, damage of bridge structure components and elements beneath of deck. Therefore, cracks can be reduced the performance and durability of bridge concrete structure [4]-[5]-[6].

The strengthening and repairing of the bridge structure can be provided an effective and economic solution in appropriate situation. The strategy of repair includes materials selection, method selection, support design, safety precaution, costs, and logistics [7]-[8].

The main objectives of this study are to inspect and identify any damage of jaimusi highway prestressed concrete bridge after repair and strengthening and to evaluate the performance of the bridge structural members by adopting static load test.

II. Description of Jiamusi Highway Prestressed Concrete Bridge

Jamusi highway prestressed concrete bridge is located in the Jiamusi City within Heilongjiang province in the east north of China. The bridge crosses a Songhua river. The overall length of the bridge is 1396.2m and the total width of transverse section of the bridge is 17m. The bridge is kind of T-shaped rigid frame structure with hanging beams and simply supported T-beams. The bridge structure is made from prestressed concrete box girder and prestressed concrete T-beams. The bridge was open to traffic in September 1989. After the bridge is operating, the bridge subjected to heavy traffic loads and environmental condition. Therefore, the bridge suffers from many problems such as vertical deflection of corbels is about 10.3cm, cracks in the top and web of box girders, and large vibration of bridge structure when the traffic loads are passing. Figs. 1(a) to 1(d) show the view of bridge structure and Figs. 2 (a) and 2(b) show the section of box girder.

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Fig. 1 (a) View of spans

Fig. 1 (b) T-shape cantilever structure

Fig. 1 (c) Hanging beams

Fig. 1 (d) View of corbel

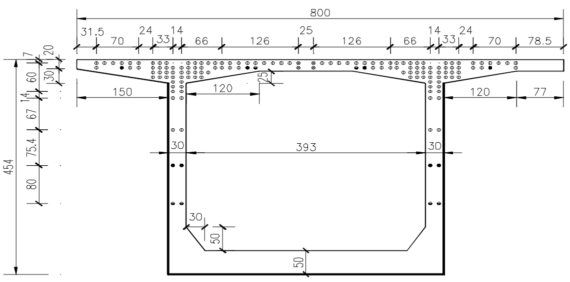
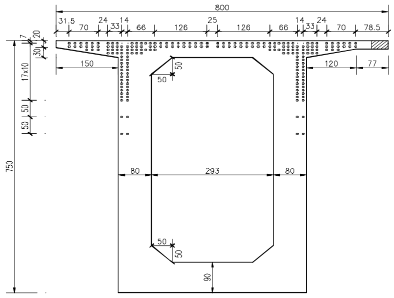


Fig. 2 (a) Pier box girder



(b)

Fig. 2 (b) Span box girder

III. REPAIR AND STRENGTHENING PROGRAM APPLICATION

According to damage inspection before repair and strengthening, the bridge structural members suffers from many damage. Therefore, there is need to repair and strengthen the damaged structural members of the bridge. The program of repair and strengthening which is applied to improve the performance of damaged structural members of the bridge includes:

- Repair the bridge deck pavement to enhance the smoothness of the bridge deck pavement by removing the old damaged layer of pavement and pouring a new asphalt concrete pavement to suitable designed thickness.
- Replacement of all expansion joints in all spans of the bridge.
- Application of chemical grouting method to plug all the visible cracks in structural members of bridge.
- Application of sticking steel plate method to strengthen the damaged parts in the top of box girders and corbels.
- Application of external prestressing tendons technology to strengthen main structural members to resist the increasing of dead load due to add leveling layer of deck pavement and vehicles load, to decrease the tensile stress in the web of box girders, positive bending moment in the section of mid span, and negative moment in the section of pier top, to increase the safety reserve of the bridge structure, and to improve the resistance for cracks to enhance the durability of structural members of the bridge.

IV. INSPECTION OF DAMAGE AFTER REPAIR AND STRENGTHENING OF BRIDGE STRUCTURE

Inspection program after repair and strengthening includes identifying and evaluating the structural members of bridge such as T-shape cantilever structure, hanging beams, corbels, external tendons, anchor beams, sticking steel plate, and piers. The time period between repair, strengthening, and inspection of the bridge structure is 11 months.

A. Sticking steel plate

Sticking steel plate method is applied to strengthen the damaged parts in the top of box girders and corbels. The results of inspection show that the color of the overflowing glue near the edge of steel plates is consistence and the hardening degree is good. The effective bonding area is more than 90%, indicating that the quality of sticking steel plate reaches to the designed requirement.

B. Cracks observation

Chemical grouting method to plug all the visible cracks in web of box girders, diaphragm beam of pier top, corbels of T-shape cantilever structure, and corbel of hanging beams. According to inspection results, the crack grouting is dens, the surface of the grouting is regular, and the appearance of grouting area is clean. There are not new cracks in the grouting area, indicating that the quality of cracks grouting in good state. For anchor beam, there are more than10 cracks before application of tension force in external prestressing tendons in the concrete of anchor beam. The length of cracks ranges between 5cm to 50cm and the width ranges from 0.01mm to 0.2mm. After strengthening, inspection results show that there are a few cracks have some development and there is some new vertical cracks appear in the structure of anchor beam. There are 7 vertical cracks. The length of cracks rang from 0.5cm to 2.5cm and the width rang between 0.1mm to 0.25mm. The new cracks are related with shrinkage of concrete. Therefore, the cracks have not influence on the mechanical properties of the bridge structure, but from the point of durability, the cracks should be sealed. Figs. 3(a) and 3(b) show cracks of anchor beam after strengthening.

Fig. 3 (a) Actual view of anchor beam cracks

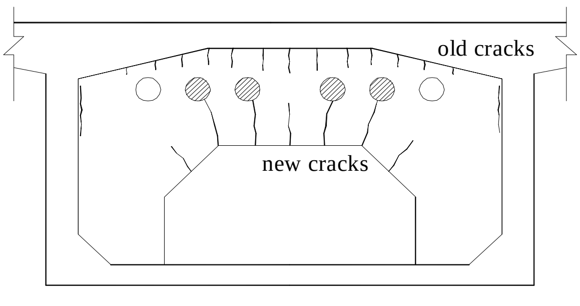


Fig. 3 (b) Drawing view of anchor beam cracks

C. Expansion joints inspection

All expansion joints are replaced but most of the expansion joints are still damaged in serious degree. Therefore, the expansion joint loss the function of the expansion, which is influenced the performance of the bridge structure. Fig. 4(a) and 4 (b) show the expansion joints device after replacement.

Fig. 4 (a) Joint fill with dust

Fig. 4 (b) Losing of joint material

D. Concrete strength test

Rebound method is used to examine the concrete as sampling inspection by batch. The Rebound method is applied to the main beam of the T-shape structure and anchor beam. For T-shape structure, the rebound test is carried out for box No. 9 to box No. 16 and the total number of tested parts is 16. The results of rebound test of concrete strength show that the average strength of concrete is 46.31Mpa, reaching to the designed value of concrete strength (C-40). The actual modulus of elasticity of concrete is 3.43x104MPa. The values of concrete strength of T-shape structure are listed in Table 1.

For anchor beam, the average value of concrete strength of anchor beam is 49.82Mpa. This value is lower than the designed value of concrete strength (C-50) which is used in the construction of anchor beam structure, indicating that the anchor beam concrete has not enough strength. The values of concrete strength of anchor beam are listed in Table 2.

E. Inspection of deck pavement

The deck pavement of the bridge suffers from serious damage such as spalling of asphalt and cracks which is caused the deck pavement unsuitable to carry the traffic load. The deck pavement is repaired by removing the old damaged layer of asphalt and the surface is poured by using asphalt concrete to required thickness. After repair, the results of inspection show that the state of the bridge deck pavement in good but there some places have cracks and bleeding. Fig. 5(a) to 5(c) shows the state of the deck pavement.

TABLE I RESULTS OF CONCRETE STRENGHT TEST OF T-SHAPED STRUCTURE

Pier No.	Upstream direction (Mpa)	Down stream direction (Mpa)
9	43.8	44.4
10	44.3	45.3
11	48.5	45.0

12	44.3	50.6
13	46.4	44.5
14	52.3	47.7
15	47.6	50.0
16	41.2	45.1

TABLE II RESULTS OF CONCRETE STRENGTH TEST OF ANCHOR BEAM

Pier No.	Upstream direction (Mpa)	Down stream direction (Mpa)
9	50.4	48.0
10	48.2	49.0
11	48.2	48.5
12	50.9	51.3
13	53.0	52.0
14	49.2	49.8
15	49.6	50.6
16	48.2	50.3

Fig. 5 (a) Spalling of pavement

Fig. 5 (b)) Bleeding of asphalt

Fig. 5 (c) Cracks

F. Measurement of external prestressing tendons vibration frequency

The relation between tension force of external tendons and vibration frequency is shown in equation (1).

$$T = \frac{4WL^2}{n^2 g} f_n^2 = K \cdot f_n^2 \tag{1}$$

Where:
T= tension force
W=unit weight of external tendons
L= external tendon length
n= order vibration
g= acceleration of gravity
fn= frequency
K= the proportional coefficient between external tendon tension force and frequency.

The results of frequency measurement are listed in Tables 3 and 4. From this table it can be noted that the maximum frequency in the upstream direction is 2.685Hz in tendon No. 1 within pier No. 16 and for downstream direction, the maximum frequency is 2.31Hz in tendon No. 2 within pier No.15, indicating that these tendons have maximum tension force.

TABLE III VALUES OF VIBRATING FREQUANCY OF EXTERNAL TENDONS FOR DOWN STREAM DIRECTION (Hz)

Pier No.	Tendon No. 1	Tendon No. 2	Tendon No. 3	Tendon No. 4
16	1.330	1.008	-	-
15	1.067	2.31	0.774	1.078
14	0.788	1.386	1.049	0.778
13	1.103	1.168	1.001	0.945
12	2.070	2.081	0.872	0.704
11	2.059	2.092	0.683	1.612
10	0.791	0.790	1.289	2.046
9	1.864	2.309	-	-

TABLE IV VALUES OF VIBRATING FREQUANCY OF EXTERNAL TENDONS FOR UPSTREAM DIRECTION

Pier No.	Tendon No. 1	Tendon No. 2	Tendon No. 3	Tendon No. 4
16	2.685	1.035	-	-
15	0.851	0.846	0.707	0.784
14	1.791	0.856	1.531	1.376
13	0.861	1.587	0.691	1.147
12	0.712	0.709	0.978	0.718
11	1.205	1.050	0.870	0.792
10	1.332	0.770	0.771	0.762
9	3.914	1.611	-	-

V.STATIC LOAD TEST

The purpose of static load test is to evaluate the existing working state of the bridge structural members and to measure the forces under the maximum values of bending moment. According to the damages inspection of the bridge appearance, the span No. 15 of T-shape cantilever structure as an experimental span. Fig.6 shows the experimental span with measuring points. The static load test includes four stages. These stages are measurement of strain, measurement vertical deflection of corbel, measurement of external prestressing tendons tension force, and observation of cracks development.

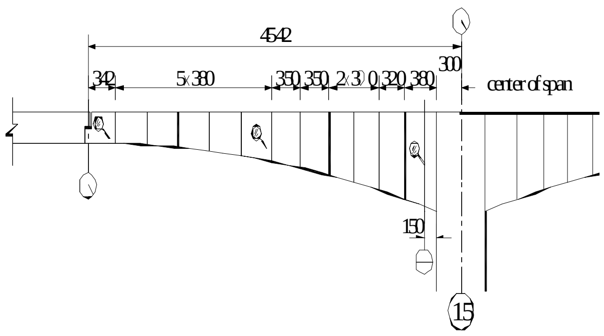


Fig. 6 Experimental span with measuring points

A. Arrangement of strain and vertical deflection measuring points

For strain measurement, there are 8 strain measuring points are arranged in the section of pier box girder within pier No. 2, including 4 vibration chord strain gauges and 4 concrete strain gauges. For anchor beam, 3 front type strain gauges are arranged in the middle of top edge of anchor beam hole and there are 3 vibration chord strain gauges are arranged along the width direction of anchor beam hole. Fig. 7 shows the measuring points of strain in the pier box girder and Fig. 8 shows the measuring point of strain in anchor beams. The measuring points of vertical deflection of corbel are arranged in the deck, pier top, and corbel.

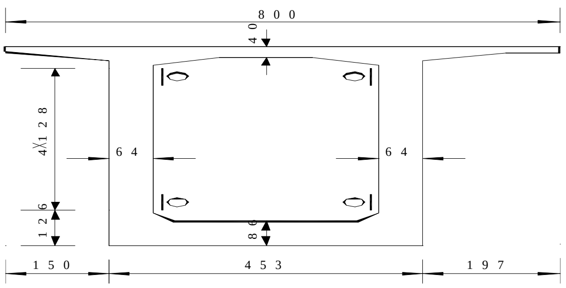


Fig. 7 Strain measuring points of pier box girder

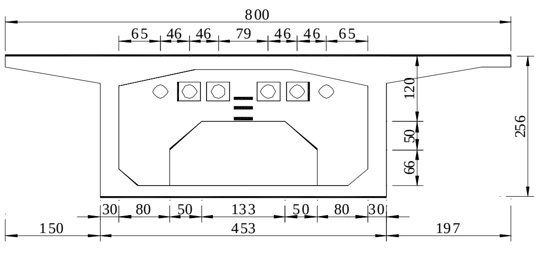


Fig. 8 Strain measuring points of anchor beam

B. Loading of Vehicles

In this test, the load test is determined by using method of equivalent load. The efficiency coefficient (η) of load test ranges from 0.85 to 1.05. In practical loading process, there are 12 automobiles FAW produced by the heavy-duty factory in Changchun City in China. The overall weight is 325 kN. The total numbers of vehicles which are used in static load test are 12 vehicles. The characteristic parameters of the vehicles for static load test are listed in Table 5.

TABLE V CHARACTERISTIC PARAMETERS OF VEHICLES FOR STATIC LOAD TEST

Model	Axle load(kN)				Wheel distance(cm)	
	Front axle load	Middle axle	Rear axle	Total weight	Between front and middle axles	Between middle and rear axle
FAW	50	125	125	300	325	125

C. Layout of Vehicles Loads

The longitudinal and transverse layout of vehicles loads can be shown in Figs. 9(a) and 9(b)

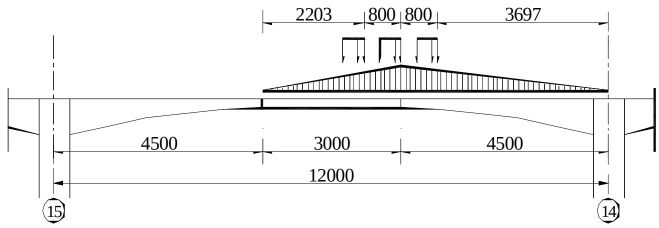


Fig. 9 (a)) Longitudinal layout of vehicles loads

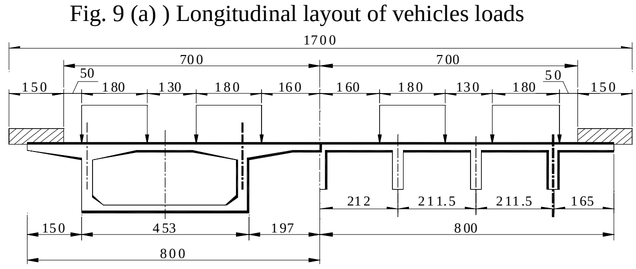


Fig. 9 (b) Transverse layout of vehicles loads

D. Results of Static Load Test

1. Internal Forces Results

According to the results of static load test, Table 6 gives the experimental values and theoretical values of internal forces. From this table it can be noted that the efficiency coefficient (η) of load test is 0.906 for bending moment and 0.934 for deflection. These values are more than standard value =0.85. Therefore, the experimental results satisfy the designed values.

TABLE VI EXPERMENTAL AND THEORETICAL VALUES OF INTERNAL FORCES

section	Location	Theoretical value	Experimental value	efficiency coefficient (η)
1	Bending moment of pier box girder(kN·m)	70005.1	63400.0	0.906
2	Deflection of corbel(mm)	56.30	52.6	0.934

2. Deflection Results

The deflection is measured in the section of corbel within the span No. 15 and L/2 of T-shape cantilever structure. The results of deflection are listed in Table 7. From this table it can be noted that the maximum residual deflection is 1.34% and smaller than 20%, indicating that the overall deflection and integrity of the structure satisfy the designed requirement and the structure is in good elastic state. The comparison between experimental and theoretical values of deflection is listed in Table 8. From this table it can be shown that the efficiency coefficient (η) of load test is 0.838 and 0.844. These values within designed values of =0.60 to 0.85. [9]-[10]-[11], indicating that the stiffness of structure, deflection, and integrity of the bridge satisfy the designed values, and the working performance and undertaking capacity is in good state.

TABLE VII RESULTS OF EXPERMENTAL DEFLECTION (MM)

Location	Initial load			Final load		
	Loaded state	Unloaded state	Residu-al deflecti-on%	Loaded state	Unloaded state	Residu-al deflecti-on %
Upper stream	44.0	43.5	-1.23	44.1	44.7	1.34
Down stream	43.9	44.2	0.64	44.7	44.8	0.23

TABLE VIII EXPERIMENTAL AND THEORETICAL VALUES OF DEFLECTION (MM)

Location	Experimental value(mm)	Theoretical value(mm)	efficiency coefficient (η)
Upper stream	44.1	52.6	0.838
Down stream	44.4	52.6	0.844

3. Strain Results

The results of longitudinal strain are listed in Tables 9, 10, and 11. From these table, the average ratio between medial and lateral strains for experimental load are 1.90 which is less than the ratio of non-uniform coefficient 1.959, and the efficiency coefficient (λ) of tested load ranges between 0.878 and 0.937.indicating that all experimental values are less than theoretical values. Therefore, the working performance of the bridge tested members is in good state, and the undertaking capacity has a certain surplus. For anchor beam, the results of strain are listed in Table 12. From this table it can be noted that the strain in the transversal direction of concrete in the anchoring transversal beam is small. This indicates that the small effect of vehicle load isn't the main reason for stress cracking of anchoring transversal beam.

TABLE IX RESULTS OF EXPERMENTAL LOGITUDENAL STRAIN ($\mu\varepsilon$)

Measuring point	Medial	Lateral	Ratio
Inside of box girder	-59	-30	Ratio
Outside of box girder	51	28	1.96
Average	-	-	1.83 1.90

TABLE X RESULTS OF THEORITICAL LOGITUDENAL STRAIN ($\mu\varepsilon$)

Measuring point	Medial	Lateral	Ratio
Inside of box girder	-65.9	-33.7	1.95
Outside of box girder	58.5	29.9	1.95
Average	-	-	1.95

TABLE XI RESULTS OF EFFECIANCY COEFFECIENT OF TESTED LOAD

Measuring point	Medial	Lateral
Inside of box girder	0.899	0.897
Outside of box girder	0.878	0.937
Average	0.889	0.917

TABLE XII RESULTS OF STRAIN OF ANCHOR BEAM ($\mu\varepsilon$)

Condition	1	2	3	4	5	6
Initial load	3	2	3	-1	2	0
Final load	-1	-3	4	2	1	-2

4. Results of External Pretesting Tendons Vibration Frequency

The results of external prestressing tendons vibration frequency under experimental load are listed in Table 13. From this table, the vibration frequency of external cable increases under the experimental load, and the change is small and ranges from 0.8% to 9.0%. This indicates that the increasing of tension of external cable is small.

TABLE XIII RESULTS OF VIBRATING FREQUANCY OF EXTERNAL TENDONS UNDER EXPERMENTAL LOAD

Item	Condition	External tendon No.1	External tendon No. 2	External tendon No. 3	External tendon No. 4
Frequen-cy (Hz)	Theoretic-al frequency	0.851	0.846	0.707	0.784
	Initial load	0.927	0.909	0.756	0.846
	Final load	0.916	0.882	0.712	0.836
Frequen-cy ratio	Initial load	1.090	1.075	1.069	1.079
	Final load	1.077	1.043	1.008	1.066

5. Cracks Observation

Before strengthening of the bridge structure, there are many cracks within anchor beam. But after strengthening process is completed, there is not visible change in the length and width of cracks and there are not new cracks under experimental load. Therefore, the reason of cracks is not vehicles load, but the cracks are due to concrete shrinkage.

VI. CONCLUSIONS

According to the damage inspection of the bridge structure appearance and experimental results of static load test, the main conclusions of this study are:

1) Inspection program after repair and strengthening includes identifying and evaluating the structural members of bridge such as T-shape cantilever structure, hanging beams, corbels, external tendons, anchor beams, sticking steel plate, and piers. The results of inspection show that the color of the overflowing glue near the edge of steel plates is consistence and the hardening degree is good. There are not new cracks in the grouting area, indicating that the quality of cracks grouting in good state. For anchor beam, there are more than10 cracks before application of tension force in external prestressing tendons in the concrete of anchor beam. The length of cracks ranges between 5cm to 50cm and the width ranges from 0.01mm to 0.2mm. All expansion joints are replaced but most of the expansion joints are still damaged in serious degree. Therefore, the expansion joint loss the function of the expansion, which is influenced the performance of the bridge structure. The state of the bridge deck pavement in good but there some places have cracks and bleeding. The results of rebound test of concrete strength show that the average strength of concrete is 46.31Mpa, reaching to the designed value of concrete strength (C-40). The average value of concrete strength of anchor beam is 49.82Mpa. This value is lower than the designed value of concrete strength(C-50) which is used in the construction of anchor beam structure, indicating that the anchor beam concrete has not enough strength.
2) The results of static load test show that the experimental values are less than theoretical values of internal forces, deflection, and strain, indicating that the stiffness of the experimental structure, overall deformation and integrity satisfy the designed demand. The working performance is good, and the undertaking capacity has a certain surplus. There is not visible change in the length and width of cracks and there are not new cracks under experimental load. Therefore, the reason of cracks is not vehicles load, but the cracks are due to concrete shrinkage.

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