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Field Damage Inspection and Static Load Test Analysis of Jiamusi Highway Prestressed Concrete Bridge in China

Ali Fadhil Naser[a], Zonglin Wang [b]

Ph. D Student/School of Transportation Science and Engineering, Bridge and Tunnel Engineering, Harbin Institute of Technology, Harbin City, 150090, China

[2]School of Transportation Science and Engineering, Bridge and Tunnel Engineering, Harbin Institute of Technology, Harbin City, 150090, China

[a]email: ali_hu73@yahoo.com, [b]email: wangzonglin@vip.163.com

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Abstract. The main purpose of damage inspection of the bridge components is to ensure the safety of a bridge and to identify any maintenance, repair, or strengthening which that need to be carried out. The essential damages that occur in reinforced concrete bridge include different type of cracks, scalling and spalling of concrete, corrosion of steel reinforcement, deformation, excessive deflection, and stain. The main objectives of this study are to inspect the appearance of Jiamusi highway prestressed concrete bridge and describe all the damages in the bridge structural components, and to evaluate the structural performance of the bridge structure under dead and live loads. The field tests that are adopted in this study are the depth of concrete carbonation test, compressive strength of concrete test, corrosion of steel reinforcement test, and static load test. According to inspection of the bridge structure appearance, the overall states of bridge structure in good and there are not serious damages, but there are diagonal and longitudinal cracks in the inside web of box girder within block No.8 and 9. Expansion joints suffer from serious damage such as deformation of expansion joint rubber, dislocating, shedding, and cracking. The field test results show that the concrete of the bridge structure has not carbonation; the strength of concrete in good state; there is not corrosion in steel reinforcement; The values of load test for vertical deflection, strain, and stress are less than the theoretical values and the results of cracks observation show that there is not changing in the length of diagonal cracks in the web of box girder when the load test is applied. This indicates that the working state and carrying capacity of the bridge structure in good state.

Introduction

The inspection of each bridge is important for collecting information about the bridge's structural condition and adequacy. This information must be stored as a permanent bridge record. Such a record provides a useful and accurate history. It also contains information on previous repairs and provides others with ready access to information [1].

Damage inspection and maintenance of all types of the bridges are significant to the safety of bridges users and often very important to the economy of a region. An effective bridge maintenance work must be closely associated with inspection of the bridge components. Therefore, the maintenance division should involve a permanent group of inspectors are known as inspection team. The inspection of the bridge deals with every element in bridge components to evaluate whether it is in good conditions or it needs to repair or strengthening. Inspection plan includes review reports and site conditions, necessary tools and equipment, traffic control (as necessary), site survey, and structural inspection which include inspection of deck, superstructure, and substructure [2, 3, 4].

The main damage occurring in reinforced concrete bridge include different types of cracks, scaling, spalling, delaminating, efflorescence, stains, corrosion of steel reinforcement, deformation, and excessive deflection. [3, 4, 5, 6]

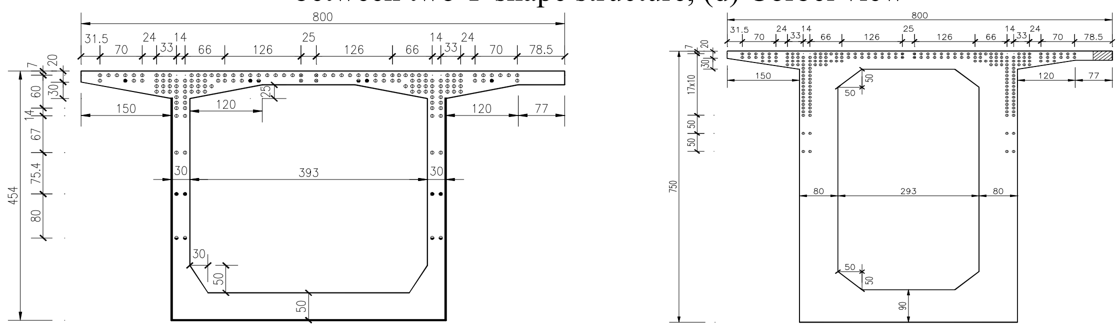
In this paper, Jiamusi highway prestressed concrete bridge is inspected by the team of inspection in School of Transportation Science and Engineering/ Bridge and Tunnel Engineering/ Harbin Institute of Technology (HIT) in China to identify damaged members and evaluate the performance of the bridge structure under dead load, live load, and environmental conditions.

Description of Jiamusi Highway Prestressed Concrete Bridge

Jiamusi highway prestressed concrete bridge is located in the Jiamusi City within Heilongjiang province in the east north of China. The total length of the bridge is 1396.2 m and the width is 17 m. The bridge was open to traffic in September 1989. The type of the bridge is a continuous prestressed concrete T-shape rigid frame with hanging beams and simply supported T-beams. T-shape rigid frame structure consists of prestressed concrete box girders. Fig. 1 shows the layout of the bridge structure and Fig. 2 shows the pier and span prestressed box girder layout.

(a) (b) (c) (d)

Fig. 1 View of bridge structure: (a) Spans of bridge view, (b) T-shape structure, (c) Hanging beam between two T-shape structure, (d) Corbel view



(a) (b)

Fig. 2 Box girder layout: (a) Pier box girder, (b) Span box girder

Inspection of the Bridge Structural Members

In this study, problems inspection process deals with the main structural members of the bridge. These members include T-shape rigid frame cantilever, hanging beams, corbels, deck system, bearing, and piers.

Inspection of Box Girders. Inspection of box girders is carried out in the inside of box girders and the inspection include eight cantilevers in upstream, downstream, and front side of T-shape structure No.1 and No.2. There are many vents have 5 cm diameter in the inside and outside of box girders and there are also anchor holes of 20cm diameter in the bottom of box girder, making the ventilation in good state and the temperature in the inside and outside of box girders is consistence. The state of concrete is good. The concrete is dry, clean, and there is not any damage or moisture in the top, web, and bottom of box girders.

There are pieces of white substance in the outside of the web in box girders from the corbel to ½ of T-shape cantilever structure (from block No. 7 to block No.11). These pieces of white substance distribute in the surrounding of the vents. The second differential method is adopted to test the components of the white substance. The most part of the white substance is made of sodium bicarbonate (Na3H (CO3).2H2O, 72% of content), and sodium carbonate (Na2CO3.2H2O, 19%). The small part is made of potassium bisulfate (KHSO3, 8%). The white marker is the apparent feature of corrosion of concrete. The serious part can cause to crack the surface of the concrete, and also the steel can be corroded, due to invading of the chloride ions. This has a strong impact on the durability of the concrete structure. The components of white substance are listed in Table 1.

Table 1 Components of white substance materials

Composition	Content(%)	Composition	Content(%)	Composition	Content(%)
K	3.3110	Al	0.1662	Rb	0.0183
O	64.7112	Ca	0.8422	Sr	0.0223
S	2.3260	Fe	0.1584	P	0.0120
Na	27.6020	Si	0.8095	Mo	0.0210

There are leakages occur in the holes of the box girder top due to damage of deck pavement and leakage of water through pavement layer to the top of box girders. Fig. 3 shows the white substance and Fig. 4 shows the leakages of holes.

Fig. 3 White substance in the web of box girder

Fig. 4 Leakage of hole in the top of box girders

There are many diagonal cracks in the inside web of box girder in the part from the corbel to 1/3 of T-shape cantilever structure (from block No. 8 to block No.11). The oblique angles of diagonal cracks rang between 30^o to 45^o. The main causes of diagonal cracks are excessive principle stresses. The length and width of cracks rang from 2cm to 6cm and 0.1mm to 0.2mm respectively. Fig. 5 shows the diagonal cracks in the web of box girder. There are not cracks in the outside web of box girder. There are five longitudinal cracks in the inside web of box girder of block No. 9 and the maximum width of cracks is 0.06mm. Fig. 6 shows the longitudinal cracks.

Inspection of Box Girders. After inspection of the bridge approach supports, it is found that the bearings are clean, the structural performance of bearings in good state, and there is not any damage in the bearings. Fig.7 shows the bearings of approach supports and Fig. 8 shows the bearing of simply supported T-beams.

Fig. 5 Diagonal cracks in web of box girder

Fig. 6 Longitudinal cracks in web of box girder.


Fig. 7 Bearings of approach supports


Fig. 8 Bearing of simply supported T-beams

There is not any damage in bearing of corbels, but there is mixed soil accumulating from the deck, influencing the normal operation of the bearing. After checking the corbels, it is found that there is not any crack in the corbel. The hanging beams are checked by using the bridge checking car. According to inspection of hanging beams, there is not any visible crack in the fulcrum of the hanging beams and the quality of concrete in good state. Fig. 9 shows bearing of corbel and Fig. 10 shows the hanging beam in the part of corbel. Fig. 11 shows the bridge checking car which is used in the inspection of bridge structural members.

Inspection of the Bridge Deck Pavement. After inspection of deck pavement, the surface layer of asphalt has serious damage, resulting the deck uneven. Deck pavement suffers from serious cracks, spalling, and exposing of the waterproof concrete. Fig. 12 shows the cracks of deck pavement and Fig. 13 shows the spalling of asphalt layer.


Fig. 9 Bearings of corbel


Fig. 10 Hanging beams in the part of corbel


Fig 11 Bridge checking car


Fig. 12 Cracks of deck pavement


(a) (b)

Fig. 13 Damage of deck pavement, (a) Spalling of asphalt, (b) Exposing of the waterproof concrete

Inspection of Expansion Joints. Expansion joints suffer from serious damage such as deformation of expansion joint rubber, dislocating, shedding, and cracking. Fig. 14 shows the damage of expansion joints.

(a) (b)

Fig. 14 Damage of expansion joints: (a) Deformation of expansion joint, (b) Losing of function of expansion

Field Tests

The field tests adopted in this study are the depth of concrete carbonation test, compressive strength of concrete test, corrosion of steel test, leveling of the bridge deck test, and static load test.

Concrete Carbonation Test. In this study, the drilling method is applied to measure the depth of concrete carbonation for the inside and outside web of the box girders and piers. For inside web of the box girders, three sections are selected to measure the depth of concrete carbonation. These sections are ends, L/4 span, and the top of T-shape cantilever structure. But, for outside web of box girders, two sections are selected to test. There are two tested areas in each section and three holes for each tested area. The test results indicate that the depth of concrete carbonation is small and range between 0.5mm to 1mm. After scattering the chemical indicator, the color changes to purplish red, it proves that the concrete has no carbonation. Fig. 15 shows the tested area and Fig. 16 shows the carbonation for inside and outside web of box girders.

Fig. 15 Tested area

(a) (b)

Fig. 16 Concrete carbonation: (a) Inside web, (b) Outside web

There are two piers are selected to measure the depth of carbonation. These piers are pier No. 1 and 2. Two tested areas are selected. From the test results it can be noted that the average depth of concrete carbonation is 0.5mm. Also After distribution the chemical indicator, the color changes to purplish red, it indicates that the concrete has no carbonation. Fig. 17 shows concrete carbonation of piers.

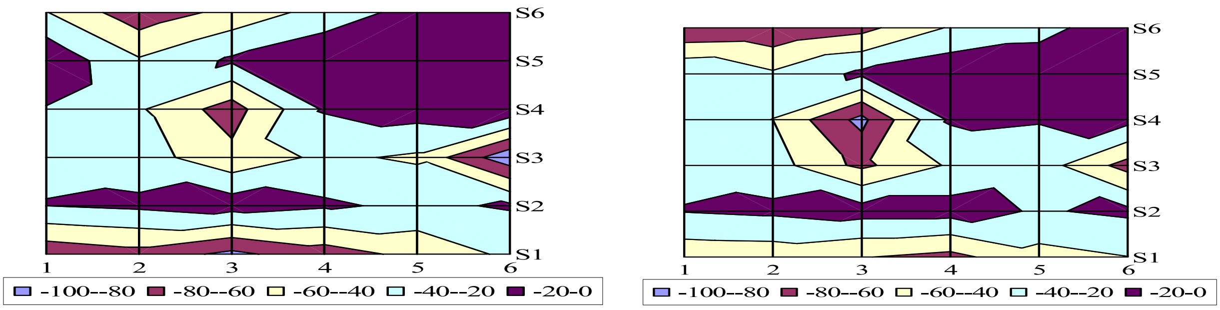
Fig. 17 Concrete carbonation of piers.

Concrete Compressive Strength Test. The compressive strength test of concrete can directly reflect the quality of the concrete. In this study, Rebound method is used to examine the quality of concrete in sampling inspection by batch. The Rebound method is applied to the pier No. 1, including four tested parts, right half of the span between piers No. 1 and 2, and left half of the span between piers No. 2 and 3, including 14 tested parts. Therefore, the total tested parts which are adopted in this test are 18 parts. The test results show that the average compressive strength is R= 45.29Mpa, reaching to the designed value of compressive strength of concrete of the bridge structure(C-40). This indicates that the compressive strength of concrete in good state. The actual value of elastic modulus (E) of concrete is 3.4146×10^{4} Mpa.

Corrosion of Steel Reinforcement Test. The corrosion of steel reinforcement is the main causes of the structural concrete deterioration. This test adopts the scribe digital reinforcement rust instrument. Two areas are selected within the top of box girder to evaluate the corrosion of steel reinforcement. The test results show that the potential of steel reinforcement corrosion range between -95mv and -34mv. This indicates that there is not corrosion. Fig. 18 shows the test results for the selected regions. Table 1 gives the standard value of potential level of corrosion state.

Table 1 Standard value of potential level of corrosion state.

Potential level	0 to -100	-100 to -200	-200 to -300	-300 to -400	>-400
Corrosion state	No corrosion	Mild corrosion	There corrosion	Corrosion >90%	Serious corrosion



(a) (b)

Fig. 18 Corrosion of steel reinforcement test results: (a) Area 1, (b) Area 2

Static Load Test. The purpose of static load test is to evaluate the existing working state of the bridge structure. According to the damages inspection of the bridge appearance, the first span of T-shape structure is selected as a tested span. For the tested span, pier box girder of cantilever, ½ of cantilever span, and corbel are used to apply static load test. Fig. 19 shows the tested structural members of bridge. Static load test includes measuring of stress, strain, deflection, and cracks. For measurement of stress and strain, 20 measuring points are arranged in the pier box girder, including 10 vibration chord strain gages and 10 concrete strain gages (0 represent vibration chord strain gages and 1 represent concrete strain gages). There are 10 strain measuring points in the box girder of 1/2 cantilever span. Fig. 20 shows the layout of measuring points of stress and strain. For corbel, there are 9 strain measuring points as a 3 groups in 45o direction. Fig. 21 shows the layout of measuring points in the section of corbel. Box girder of 1/2 cantilever span and corbel are selected to measure the deflection by using total station. This test and analysis of results are based on references [7, 8].

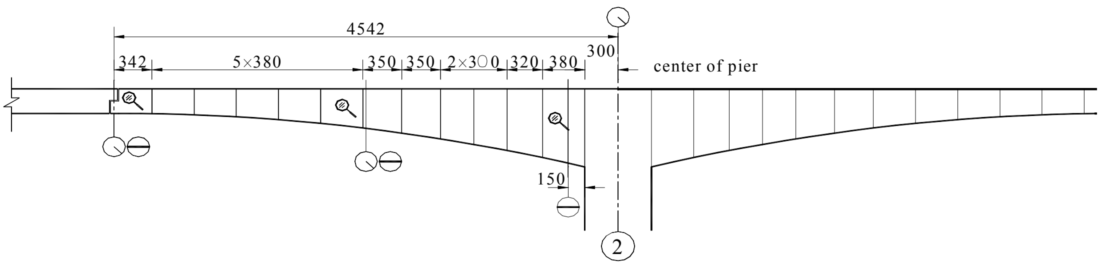
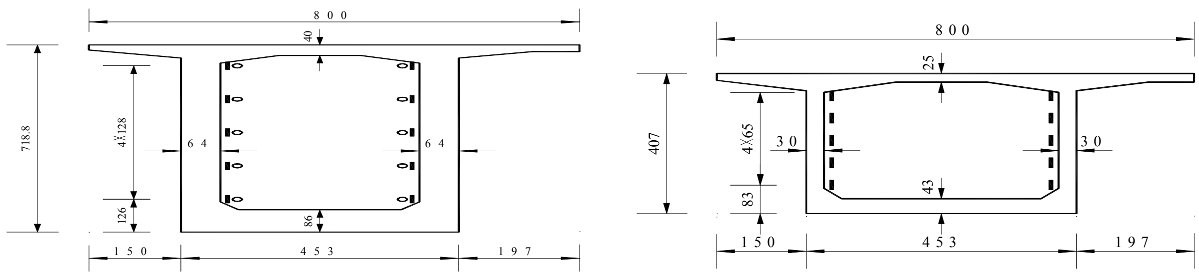


Fig. 19 First tested span of T-shape structure and measuring points



(a) (b)

Fig. 20 Layout measuring points of stress and strain: (a) Pier box girder, (b) Box girder of 1/2 cantilever span

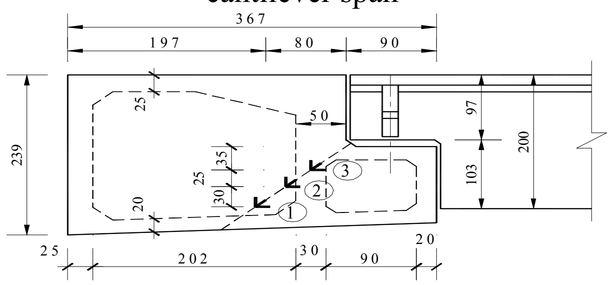


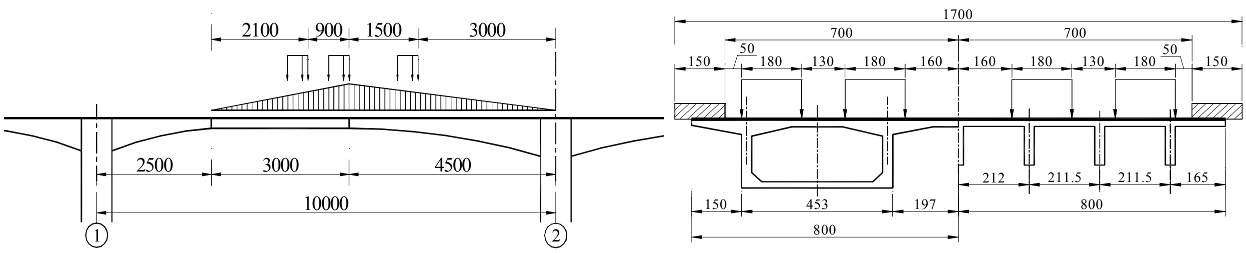
Fig.21 Layout of measuring points of stress and strain of corbel

Loading of Vehicles. In this study, 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 characteristic parameters of the vehicles for static load test are listed in Table 2.

Table 2 Characteristic parameters of the 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	55	135	135	325	325	125

Layout of Vehicles Loads. Fig. 22 shows the longitudinal and transverse layout of vehicles loads.



(a) (b)

Fig. 22 Layout of vehicles loads: (a) Longitudinal layout, (b) Transverse layout

Results of Static Load Test.

Deflection Results. Table 3 lists the tested load and theoretical values of bending moment and shear force. From this table it can be noted that the efficiency coefficient (η) of load test range from 0.866 to 0.903. These values are more than standard value =0.80. This indicates that the performance working of the bridge in a good condition and has enough stiffness to resist the external and internal loads. Table 4 lists the tested load and theoretical values of vertical deflection for 1/2 cantilever span and corbel sections. From this table it can be seen that the efficiency coefficient (η) of load test is 0.815 and 0.887 for corbel and 1/2 cantilever span respectively. These values more than standard value =0.8, indicating that the whole deflection and integrity of the bridge meet the requirements and the state of elastic working is fine.

Table 3 Tested and theoretical values of bending moment and shear force (kN)

Section	Location	Theoretical value	Test load value	Test coefficient (η)
1	Bending moment of pier box girder(kN·m)	70005.1	60621.1	0.866
2	Bending moment of1/2 cantilever span(kN·m)	32393.4	29180.5	0.901
3	Corbel shear(kN)	1161.5	1049.0	0.903

Table 4 Tested and theoretical values of vertical deflection (mm)

location	Tested value of deflection (mm)	Theoretical value of deflection (mm)	efficiency coefficient (η)
1/2 cantilever span	12.35	13.92	0.887
Corbel section	40.10	49.21	0.815

Strain and Stress Results. Table 5 lists the load test and theoretical values of longitudinal concrete strain for the pier box girder and box girder of 1/2 cantilever span sections. This table shows that the tested values are less than the theoretical values, indicating that the working performance of the structure is good and the undertaking capacity has a certain surplus and safety reservation.

Table 5 Load test and theoretical values of longitudinal concrete strain (με)

location	Distance to the bottom section	Load test value ($\mu\varepsilon$)			Theoretical values ($\mu\varepsilon$)		Testing coefficient (λ)	
		Internal	External	Internal / external	Internal	External	Internal	External
Pier box girder	1.260	-35.0	-31.5	1.111	-45.7	-38.4	0.765	0.821
	2.540	-14.0	-12.5	1.120	-20.8	-17.5	**0.673**	0.716
	3.820	4.5	3.5	1.286	4.1	3.4	**1.097**	1.017
	5.100	25.5	22.5	1.133	29.0	24.4	0.878	0.924
	6.380	46.0	41.5	**1.108**	53.9	45.3	0.853	0.917
box girder of 1/2 cantilever span	0.830	-58.0	-50.0	1.160	-75.5	-63.4	0.768	0.789
	1.478	-30.5	-26.5	1.151	-41.1	-34.5	0.743	0.769
	2.125	-6.5	-5.5	1.182	-6.6	-5.5	0.985	0.993
	2.773	30.0	16.0	**1.875**	27.9	23.4	1.077	0.684
	3.420	52.5	42.0	1.250	62.3	52.3	0.842	0.803
Average				1.238			0.868	0.843

The stress of concrete can be determined by adopting the longitudinal strain and modulus of elasticity of concrete. Table 6 gives the load test and theoretical values of stress. From this table it can be noted that the load test coefficient values of top edge section rang from 0.77 to 0.897 and load test coefficient values of lower edge section rang from 0.779 to 0.837. All load test values less than theoretical values, indicating that the bridge structure has enough stiffness, carrying capacity, and ability to resist the external loads

Table 6 Load test and theoretical values of stress (Mpa)

Location of section		Stress of top edge section(Mpa)			Stress of lower edge section(Mpa)		
		Load test value	Theoretical value	Tested coefficient	Load test value	Theoretical value	Tested coefficient
Pier box girder	Intern-al	-1.986	-2.363	0.840	1.860	2.386	0.779
	Extern-al	-1.778	-1.983	0.897	1.676	2.002	0.837
box girder of 1/2 cantilever span	Intern-al	-2.791	-3.296	0.847	3.227	4.070	0.793
	Extern-al	-2.149	-2.765	0.777	2.689	3.415	0.787

For corbel sections, table 7 lists the load test values of strain, principle stress, and shear stress. From this table, the values of compressive stress ranges from -0.204 Mpa to 0.664Mpa and the values of tensile stress ranges from 0.035 Mpa to 0.582 Mpa. The maximum shear stress value is 0.623 Mpa and the angle between the main stress and horizontal direction is about 300Mpa.

Cracks Observation. Two tested points are selected in block No.8 within the cantilever span in the web of box girder to observe the development of diagonal cracks. For longitudinal cracks, one tested point adopted. The results of cracks observation show that there is not change in the length of diagonal cracks in the web of box girder when the load test is applied, and the maximum width of crack has a little changing. The increasing of crack width is about 0.01mm, indicating that the direct reason of the diagonal cracks producing in the web of box girder are not due to live load, but due to the combination of prestress forces, dead load, shrinkage, and creep of concrete.

Table 7 Load test values of strain, principle stress, and shear stress of corbel

Corbel number	Load test Strain ($\mu\varepsilon$)			Principle stress(Mpa)		Shear stress τmax(Mpa)	Max $\varepsilon_1$degree φ (angle)
	ε1(0°)	ε2(45°)	ε3(90°)	Tensile stress	Compressive stress		
No. 1	-10.5	-20	8.5	0.582	-0.664	0.623	31.717
No. 2	-11.5	-13.5	-2	-0.035	-0.519	0.242	27.433
No. 3	-3	-5.5	-4	-0.083	-0.204	0.060	-37.982

The longitudinal cracks in the top of box girder web are developed. The width of crack increases about 0.04mm and the maximum crack width is about 0.11mm. The length of crack increases about 2.7mm. It indicates that the cracks in the box girder top are produced from bending moment. However, the width of cracks is less than the allowable value (0.2mm). There are not visible cracks near corbel.

Conclusions

According to the damage inspection of the bridge structure appearance and tests results, the conclusions of this study are:

1. The temperature in the inside and outside of box girders is consistence and the ventilation in good state and the state of concrete is good. The concrete is dry, clean, and there is not any damage or moisture in the top, web, and bottom of box girders. There are pieces of white substance in the outside of the web in box girders from the corbel to ½ of T-shape cantilever structure (from block No. 7 to block No.11). There are many diagonal cracks in the inside web of box girder in the part from the corbel to 1/3 of T-shape cantilever structure (from block No. 8 to block No.11). After checking the corbels, it is found that there is not any crack in the corbel. Deck pavement suffers from serious cracks, spalling, and exposing of the waterproof concrete. Expansion joints suffer from serious damage such as deformation of expansion joint rubber, dislocating, shedding, and cracking.

2. The results of tests show that the concrete has not carbonation in the inside and outside web of the box girders and piers. The average compressive strength is R= 45.29Mpa, reaching to the designed value of compressive strength of concrete of the bridge structure (C-40). This indicates that the compressive strength of concrete in good state. The actual value of elastic modulus (E) of concrete is 3.4146×10^4 Mpa. The potential of steel reinforcement corrosion ranges between -95mv and -34mv. This indicates that there is not corrosion. The maximum down deflection of corbel is 102.8 and it occurs within pier No. 5, and the up deflection occurs within piers No. 1 and 8. These values are 5.9mm and 30.9mm respectively. The values of load test for vertical deflection, strain, and stress are less than the theoretical values and the results of cracks observation show that there is not changing in the length of diagonal cracks in the web of box girder when the load test is applied, and the maximum width of crack has a little changing. The increasing of crack width is about 0.01mm, indicating that the direct reason of the diagonal cracks producing in the web of box girder are not due to live load, but due to the combination of prestress forces, dead load, shrinkage, and creep of concrete. There are not visible cracks near corbel.

3. Because of there are diagonal and longitudinal cracks in the web of box girders and there is down deflection in the corbels, there is need to strengthen the main span of the bridge by using external prestressing tendons and repair other damage structural members.

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