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Damage inspection and performance evaluation of Jilin highway double-curved arch concrete bridge in China

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Abstract. Jilin highway concrete bridge is located in the center of Jilin City, which is positioned in the middle part in Jilin Province in the east north of China. This bridge crosses the Songhua River and connects the north and the south of Jilin City. The main purpose of damages 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 damages that occur in reinforced concrete bridges include different types 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 Jilin highway concrete bridge and describe all the damages in the bridge structural members, and to evaluate the structural performance of the bridge structure under dead and live loads. The tests adopted in this study are: (a) the depth of concrete carbonation test, (b) compressive strength of concrete test, (c) corrosion of steel test, (d) static load test, and (e) dynamic load test. According to the damages inspection of the bridge structure appearance, most components of the bridge are in good conditions with the exception arch waves, spandrel arch, deck pavement of new arch bridge, and corbel of simply supported bridge which suffer from serious damages. Load tests results show that the deflection, strain, and cracks development satisfy the requirements of the standards.

Keywords: damages; inspection; Jilin bridge; static load; dynamic load; tests; deflection; strain; cracks; spalling

1. Introduction

In general, a bridge structure can be defined as a structure that has a total length of more than 6 m. 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 includes the foundations, piers, and pier caps (Al-Rifaie and Kareem 1986, Roy 2006).

Damages inspection and maintenance of all types of the bridges are significant to the safety of the 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

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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 (IRICE 2005, Bindra and Bindra 1980, Manaf 2000).

The purposes of damages inspection of the bridge components are to: (Ministry of Transportation 2009, Robert *et al.* 2005, Fuhrman and Desens 2007).

1- Ascertain whether a bridge is safe or not.
2- Identify any maintenance, repair, and strengthening which that need to be done.
3- Provide a basis of planning for funding of any required maintenance and strengthening.
4- Provide information to designers and construction engineers on those features which need maintenance.
5- Identify the actual and potential sources of damage at the earliest possible stage.
6- Record systematically and periodically observations the state of the structures.

Depending on its conditions, a bridge structure is inspected every two or more years. Five basic types of damage inspection methods used to discover damages and evaluate the elements of bridge components. These types of methods are:

1- Initial Inspection: it is used for the new bridges or when the bridge is first observed.
2- Routine Inspection: it involves a general examination of the bridge components. It regularly scheduled once every one year or two years. This method is used for short span bridges.
3- Damage Inspection: it includes the results of collision, fire, flood, important changes in environmental conditions, and loss of supports.
4- In-depth Inspection: it contains a detailed illustrative inspection of all bridge elements. It used for old bridges and must be scheduled once every three to five yeas.
5- Special Inspection: it is used to observe a particular deficiency or change in conditions; it is also used for unusual bridge design.

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 (Bindra and Bindra 1980, Manaf 2000, Texas Department of Transportation 2002, Raina 1996).

Cracks are common demonstration of concrete deterioration that can be caused by many factors. Generally, there are two types of cracks. The first type is known as non-structural cracks which can be observed in the bridges and overpass structures. This type can be caused by thermal expansion and contraction of concrete, contraction of concrete during curing process, change in temperature, and corrosion of steel reinforcement. The second type is known as structural cracks which are caused by dead and live load stresses. Cracks play important role in the acceleration of reinforcement corrosion, deterioration of concrete, damage of the bridge structural components and elements beneath of deck. Therefore, cracks can be reduced the performance and durability of the bridge concrete structure (Raina 1996, Ahmed 2004, Yanping 2003).

In this paper, Jilin highway 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 damages and evaluate the performance of its components under dead load, live load, and environmental conditions, to measure the depth of concrete carbonation, compressive strength of concrete, and the corrosion of reinforcement steel in the main parts of the bridge components, to determine the internal forces of the bridge structure due to dead and live loads, to determine stresses, deflections, and cracks development by adopting static load test, to evaluate the dynamic performance of the bridge operation state and decide whether the bridge vibrates in a safe or unsafe manners, and to identify any strengthening and repair needing for damage structural members of the bridge. Three types of tests are done during the inspection of damages. The first test is carbonation test of concrete, the second test is compressive strength of concrete, and the third test is corrosion of reinforcement steel bars. Analysis of internal forces by using Dr. Bridge Ver. 3.1 software is adopted in this study. Static and dynamic load tests are used to evaluate the structural performance of the bridge structure components after damages inspection.

2. Description of Jilin highway concrete bridge

Jilin highway concrete bridge is located in the center of Jilin City, which is positioned in the middle part in Jilin province in east north of China. This bridge crosses the Songhua River and connects the north and the south of Jilin City. The Jilin highway concrete bridge consists of two parts. The first part is the old simply supported beam bridge, which was built in 1938, and was opened to traffic in 1940. The width of the old bridge is 9.25 m and it has 15 holes (spans). The length of span between two furnaces holes is 23 m, but the length of span between the 13 holes is not constant, and ranges between 28.59 m to 31.67 m. The design grade of concrete in the main beam is not detailed. The main steel reinforcement bar is equivalent to I-grade. The original designed load is equal to car-13 grade and track-60. The second part is the new widen bridge which is a concrete new arch bridge. This part was built in 1974. The width of the new widened bridge is 13.75 m and the distribution of spans length from north to the south of the bridge is $(23 + 31 + 30.59 + 31 + 31.5 + 30.59 + 31 + 31.5 + 31 + 30.59 + 4 \times 31 + 23 = 488.77$ m). There are 9 arch ribs in the transverse direction. The grade of concrete in arch ribs is grade-25 (C-25), and for arch wave

(a) (b)

Fig. 1 Jilin highway concrete bridge (a) longitudinal view of bridge holes, (b) spandrel arch and pier view

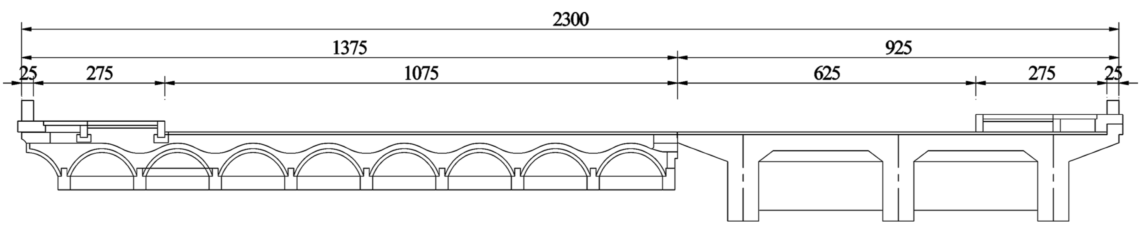

Fig. 2 Transverse section of Jilin highway bridge (dimensions in cm)

and arch plate is grade-20 (C-20). The designed standard of live load is car-15 grade, hanging car-80 grade, and crowed load is 3.5 kN/m^2. The total width of new and old bridge is 23 m. Fig. 1 shows the view of Jilin highway concrete bridge, and Fig. 2 shows a transverse section of the bridge.

3. Damage inspection of Jilin highway concrete bridge appearance

In this study, an in-depth damage inspection method is used to examine the appearance of the bridge components for all spans from hole No.1 to hole No.15. The components of the bridge which are inspected include arch ribs, arch waves, arch plates, horizontal tie beams, spandrels arch, piers of spandrels arch, pier cap beams of spandrels arch, maim beams of the old simply supported beam bridge, bearings, corbels, higher edge of fulcrum, diaphragm beams, lifting beam and deck system. The equipments used for damages inspection include inspection car, ladder, observation apparatus for cracks, rebound hammer, ultrasonic sound detector, laser total station, and steel location detector.

The results of the damages inspection process of Jilin highway concrete bridge are listed in Tables 1(a) and 1(b). From this Table it can be noted that the damages of the bridge components which include different types of crack, spalling of concrete, corrosion of steel reinforcement, corrosion of steel plates and shift of bearings, exposing of steel reinforcement, exposing of aggregate, and seepage of rain water through most of the bridge components. From Table 1 it can also be observed that the minimum value of crack width is 0.05 mm, which occurs within arch ribs, arch waves, horizontal tie beam of new arch bridge, and main beam of old simply supported beam bridge, and the maximum value of crack width is 0.4 mm (which exceeds the allowable value) for higher edge of fulcrum.

4. Tests during inspection of the bridge structural members

4.1 Concrete carbonation test

When carbon dioxide enters the concrete and reaches the steel-concrete interface, the steel loses the protection of the concrete and the steel bars will be corroded. Therefore, an increase of concrete carbonation causes a decreasing in the strength of the concrete, and results in the loss of practical effective section of the bridge. In this study, the drilling method is applied to measure the depth of concrete carbonation. The values of concrete carbonation depth are listed in Table 2. The test results indicate that there is serious concrete carbonation in both the new and the old bridge spans. From Table 2 it can be noted that the depth of concrete carbonation is more than 6 mm. For the old simply supported beam bridge, the depth of concrete carbonation range between 24 mm in the main beam and 26 mm for lifting beam, this indicates that the carbonation reaches steel bars and easily to damage steel reinforcement. The depth of concrete carbonation in abutment and pier is 50 mm and 30 mm respectively, indicating that the quality of concrete in these structures is poor, the density of concrete is loss, and the strength of concrete is low. For the new arch bridge, the average depth of concrete carbonation in the part of main arch rings is 10 mm, which indicates that the depth of carbonation does not reach steel bars. The depth of concrete carbonation of spandrel arch pier is 55 mm, indicating a poor state of concrete.

Table 1(a) Results of damages inspection of Jilin highway concrete bridge

Bridge part	Bridge components	Types of damages	Cracks			Damage location	Figure number
			Crack width (mm)	Crack length (cm)	Crack type		
New arch bridge	Arch ribs	1-transveres cracks	0.05-0.3	5-10	flexural	Rib No.4 of holes No.2 and holes No.14	Fig. 3
		2-exposing of steel reinforcement 3-corrosion of steel reinforcement				Rib No.2 and rib No.3 of hole No.2 and rib No.4 of hole No.14.	
		4-spalling of concrete 5-different degree of rain water seepage.				Internal edge of the arch rib bottom	
	Arch waves	1-Longitudinal cracks	0.05-0.03	250-300	flexural	Rib No.3 to rib No.9	Fig. 4.
		2-seepage of rain water				Joints between parts of arch waves	
	Horizontal tie beams	1-horizantal cracks	0.05	60	fracture	Rib No.2 and rib No.3 of hole No.9	Fig. 5
		2-spalling of concrete 3-corrosion of steel reinforcement				Rib No.4 and rib 9 of hole No.1	
	Arch plate	1-horizantal cracks	0.1-0.2	100	fracture	Back and side near arch bottom within hole No.2	
	Spandrel arch	1-corrosion of steel reinforcement 2-spalling of concrete 3-exposing of steel reinforcement 4-exposing of concrete aggregates				Piers of spandrel arch	Fig. 6
		5-seriouse cracks	1-Shear and bending	0.3	15-25	Pier caps and pier of spandrel arch	Fig. 7
			2-flexural	0.5-1.5	10-30	The higher edge of pier cap and along the length of pier cap direction	Fig. 8
		6-corrosion of steel reinforcement 7-spalling of concrete				Pier caps and pier of spandrel arch	Fig. 9
	Expansion joints	In good conditions					

Table 1(b) Results of damages inspection of Jilin highway concrete bridge

Bridge part	Bridge components	Types of damages	Cracks			Damage location	Figure number
			Crack width (mm)	Crack length (cm)	Crack type		
Old simply supported beam bridge	Main beam	1-vertical cracks	Max 0.4	20-70	flexural	Higher edge of fulcrum.	
		2-inclined cracks	0.1-0.35 0.05-0.35	50-100 2-105	Shear	In the 7 m mid-span of rib No.1 and rib No.3 of hole No.2	Fig. 10
		3-transvers cracks			Flexure and thermal	The interior edge of the main beam	Fig. 11
		4-spalling of concrete 5-different degree of rain water seepage 6-corrosion of steel reinforcement 7-exposingof concrete aggregates				Weep hole, joints between old and new bridge, corbel of end beams in all holes, lateral side of rib No.1 and rib No.3 in all holes	Fig. 12
	diaphragms	In good condition					
	lifting beams	1-vertical cracks	0.05-0.15	10-30	Flexure, thermal	Mid-span of lifting beam	
	corbel	1-corrosion of steel reinforcement 2-spalling and shedding of concrete 3-exposing of steel reinforcement				Within parts of lifting beam and box beam	Fig. 13
Pier and abutment of new and old bridge	pier	1-map cracking 2-spalling of concrete 3-pier of old bridge in good state				Pier and abutment caps	
	abutment	1-spalling of concrete 2-exposing of concrete aggregates				Most abutment structure	
Deck system	Deck pavement	1-seriouse cracks and depression 2-destroy all the continuous structure in the part of all corbels. 3-seepage of pavement 4-corrosion of corbels				From rib No.3 to rib No.4 near pier top of old arch bridge and pavement of pier top and near expansion joint	Fig. 14

Fig. 3 Arch ribs damages

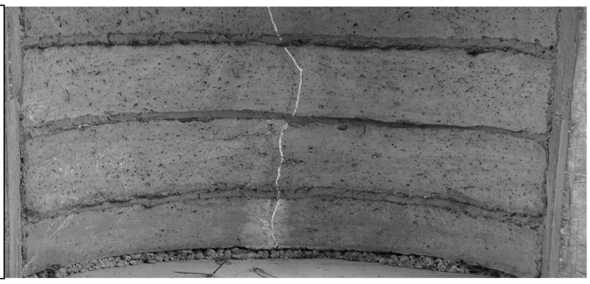

Fig. 4 Longitudinal crack in arch wave

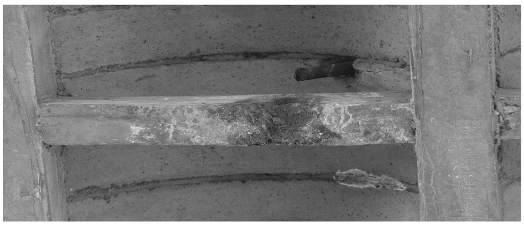

Fig. 5 Horizontal tie beam damages

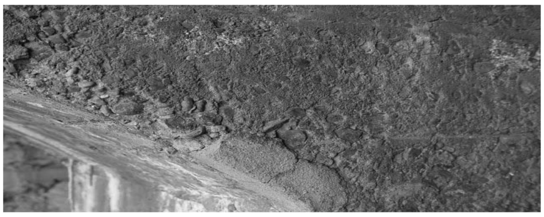

Fig. 6 Damages of spandrel arch corner

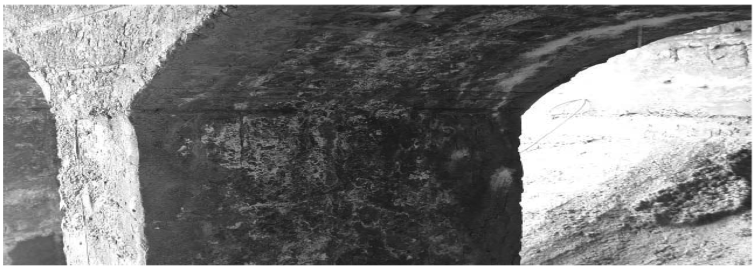

Fig. 7 Cracks damages of pier and pier caps of spandrel arch

(a)

(b)

Fig. 8 Damages of spandrel arch piers: (a) Spalling of concrete of pier cap beam, (b) Spalling of concrete of pier

Fig. 9 Corrosion of steel bar in higher edge of cap beam

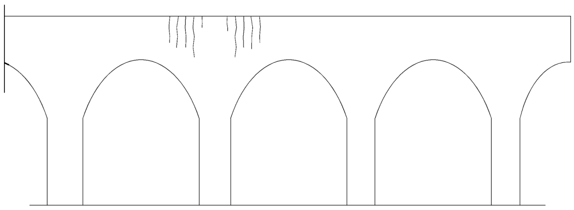

Fig. 10 Flexural cracks in cap beam

Fig. 11 Corrosion of main beam

Fig. 12 Corrosion of bearing steel plates and shift

Fig. 13 Damages of corbel

Fig. 14 Damage of pavement

Table 2 Depth of concrete carbonation

Bridge type	Old simply supported beam bridge				New arch bridge					
Bridge components	Abutment	Pier	Main beam	Lifting beam	Abutment	Pier	Spandrel arch pier	Arch plate	Arch rib	Horizontal tie beam
Depth of carbonation (mm)	50	30	24	26	15	16	55	10	8	12

4.2 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 concrete in sampling inspection by batch. The

Table 3 Summary of rebound method results

Bridge type	Old simply supported beam bridge				New arch bridge					
Bridge components	Abutment	Pier	Main beam	Lifting beam	Abutment	Pier	Spandrel arch pier	Arch plate	Arch rib	Horizontal tie beam
Compressive strength (MPa)	26.5	32.8	30.9	31.4	33.2	40.7	37.1	39.8	44.8	32.2

Table 4 Compressive strength and modulus of elasticity of concrete (JTG D62 2004)

Compressive strength of concrete (Mpa)	15	20	25	30	35	40	45	50	55	60	65	70	75
Modulus of elasticity (Mpa) $\times 10^4$	2.20	2.55	2.80	3.00	3.15	3.25	3.35	3.45	3.55	3.60	3.65	3.70	3.75

Rebound method is applied to the main components of the new arch bridge and the old simply supported beam bridge. The equipment of Rebound method is the Rebound hammer (ZC3-A). The results of compressive strength test of concrete by using Rebound method are listed in Table 3. From this table it can be noted that the average value of compressive strength for the main arch rib of new arch bridge is 31.3 MPa and the average value for lifting beam of old simply supported beam bridge is 15.4 MPa. According to Table 4, the actual value of modulus of elasticity (E) of concrete can be calculated by using interpolation for the values of compressive strength. Therefore, the value of modulus of elasticity is 3.039×10^4 MPa for the new arch bridge and 2.228×10^4 MPa for the old simply supported beam bridge (JTG D62 2004).

4.3 Corrosion of steel reinforcement test

The corrosion of steel reinforcement is the main causes of the structural concrete deterioration. In this study, the evaluation of steel bars corrosion follows the instant detection technique which is established by the Highway Scientific Institute of Communications Ministry in China. The test adopts the scribe digital reinforcement rust instrument produced by kangkerui engineering inspection technique limited corp. in Beijing. In this test, four regions are selected to evaluate the corrosion of steel reinforcement. These regions include piers No.1, No.2, and No.9 of spandrel arch, and arch top of rib arch No.2 of hole No.1. Table 5 lists the corrosion conditions values of potential of steel bars corrosion according to ASTM C 876. The potential of steel bars corrosion values for pier No.1of spandrel arch are listed in Table 6. According to the measured results, there is a high

Table 5 Corrosion conditions of steel reinforcement

Potential of steel bars corrosion value (m.v)	Corrosion condition
< -426	Severe corrosion
< -276	High (<90% risk of corrosion)
-126 to -275	Intermediate corrosion risk
> -125	Low(10% risk of corrosion)

Source: (ASTM C879-91 1999, Ha and Velu 2007)

Table 6 Potential of steel bars corrosion values for Pier No.1of spandrel arch(m.v)

Test area	1	2	3	4	5	6	7	8	9	10	11	12
cross1	-346	-348	-376	-396	-389	-389	-346	-373	-399	-365	-366	-355
cross2	-373	-367	-365	-375	-370	-385	-375	-373	-399	-372	-352	-366
cross3	-356	-354	-395	-396	-359	-372	-386	-387	-370	-389	-400	-343
cross4	-375	-389	-353	-344	-367	-370	-360	-386	-377	-396	-376	-360
cross5	-341	-364	-351	-390	-348	-361	-348	-359	-362	-380	-389	-361
cross 6	-363	-396	-374	-367	-364	-365	-398	-341	-355	-368	-386	-341
cross 7	-354	-354	-349	-381	-365	-354	-385	-382	-389	-368	-372	-347
cross 8	-347	-382	-395	-358	-379	-342	-351	-383	-362	-393	-390	-398
cross 9	-370	-358	-356	-356	-379	-398	-355	-367	-343	-376	-384	-382
cross 10	-352	-395	-346	-392	-377	-375	-380	-393	-341	-344	-386	-367
cross 11	-376	-389	-393	-363	-361	-374	-354	-361	-392	-399	-340	-384
cross 12	-344	-378	-384	-383	-388	-379	-364	-400	-342	-380	-367	-349

Severe corrosion, >90% risk of corrosion

potential of steel bars corrosion in the parts of spandrel arch piers. The corrosion is severe for pier No.1 and pier No.2, and for pier No.9 is high (<90% risk of corrosion). The arch rib has the lowest potential of steel bars corrosion (a low risk of corrosion of 10%) for arch rib top. These results are in agreement with the appearance inspection results of the bridge.

5. Analysis of designed internal forces

There is need to analyze the bridge structure to obtain the designed internal forces of all controlled sections when the dead load and live loads are acted on the sections to provide evidence for loading tests and correctly judge the state of the bridge. In this study, the analysis of the bridge structure forces adopts Dr. Bridge Ver. 3.1 software. The bridge structure forces include the internal forces and stresses caused by dead and live loads. According to the design code of highway bridges and culverts 1975, the loads combinations are adopting in this analysis include:

- Loading combination I = dead load + car-15 grade + crowed load (3.5 kN/m^2)
- Loading combination II = dead load + lifting car-18 grade

5.1 Analysis of the new arch bridge

5.1.1 Analysis of internal forces at different construction stage of the original bridge model

In this study, there are three stages of construction. These stages are:

- Stage one: arch rib construction;
- Stage two: arch rib and arch wave construction;
- Stage three: arch rib, arch wave, and arch plate construction.

The accumulated stress and internal forces at different construction stages of the new arch bridge are listed in Table 7.

Table 7 Internal forces and cumulative stresses at different construction stages of the new arch bridge

Section	Rib No.	Construction stage	Internal force		Cumulative stress (MPa)		
			Axial force N (kN)	Moment M (kN.m)	Lower edge of arch rib	Upper edge of arch wave	Upper edge of arch plate
Arch bottom	1~8	Stage 1	174.9	19.5	-1.394	0	0
		Stage 2	207.2	6.9	-0.650	1.212	0
		Stage 3	513.7	-134.4	3.760	0.909	-0.922
	9	Stage 1	130.9	14.2	-0.834	0	0
		Stage2	141.4	5.8	-0.181	1.222	0
		Stage 3	256.1	-69.5	2.545	0.892	-0.731
Arch top	1~8	Stage 1	156.3	11.8	-0.234	0	0
		Stage 2	183.7	22.2	-0.151	1.583	0
		Stage 3	488.6	-38.7	1.856	2.231	0.469
	9	Stage 1	116.9	9.0	-0.159	0	0
		Stage 2	125.5	14.6	0.012	1.600	0
		Stage 3	243.4	-18.3	1.254	2.036	0.331

5.1.2 Calculation of transverse distribution coefficient

To accurately understand the state of the bridge structure under live load in the stress state, the coefficient of transverse distribution of the new arch bridge is solved by using the elastic supporting. The spring stiffness of elastic support is obtained by longitudinal analysis and the coefficient of transverse distribution is calculated on $L/12$ and $2L/12$ of arch bottom section. The coefficients of transverse distribution for the new arch bridge are listed in Table 8.

Table 8 Values of coefficient of transverse distribution of the new arch bridge

Section	Live load	Arch 1	Arch 2	Arch 3	Arch 4	Arch 5	Arch 6	Arch 7	Arch 8	Arch 9
Arch bottom	Car-15	0.4702	0.4866	0.474	0.4741	0.4741	0.4741	0.4741	0.1542	0
	Car-80	0.3286	0.4648	0.4524	0.4523	0.4523	0.4523	0.2351	0	0
	Crowed	0	0	0	0	0	0	0.061	1.3716	1.504
$L/12$	Car-15	0.4986	0.5072	0.5362	0.5311	0.5301	0.5311	0.4391	0.1924	0
	Car-80	0.3606	0.4103	0.4066	0.4019	0.4014	0.4018	0.315	0.0644	0
	Crowed	0	0	0	0	0	0.0156	0.2454	1.0834	1.5252
$2L/12$	Car-15	0.5062	0.5077	0.5108	0.5067	0.5033	0.5067	0.4213	0.2056	0.0244
	Car-80	0.3882	0.3479	0.3465	0.3405	0.338	0.3405	0.2853	0.1106	0
	Crowed	0	0	0	0	0.0043	0.0741	0.3374	0.9784	1.5153
Arch top	Car-15	0.5057	0.5051	0.4957	0.4933	0.4909	0.494	0.4128	0.2155	0.0396
	Car-80	0.3938	0.3309	0.3256	0.3213	0.3187	0.3259	0.2793	0.1192	0
	Crowed	0	0	0	0	0.0104	0.0937	0.3569	0.9598	1.4982

Table 9 Summary of the maximum and minimum values of moment and the maximum value of axial force at different live load grade

Section	Car-15 grade live load			Car-80 grade live load			Crowed load 3.5kN/m^2		
	M max	M min	N max	M max	M min	N max	M max	M min	N max
Arch bottom	156.7	-156.2	261.1	475.8	-514.6	644.3	221	-190.6	463.5
Arch top	113	-37.5	259.6	225.1	-49.5	535.3	95.9	-45	264.3

Table 10 Results of bending moment of main beam of the old simply supported beam bridge

Section	Dead load moment	Car-15grade+crowed live load		Car-80 grade	
		M max	M min	M max	M min
Lifting beam	4620.0	1951.0	0.0	1960.0	0.0
Pier cap beam	-17500.0	0.0	-5656.0	0.0	-5150.0
Mid-span of main beam	4720.0	6150.0	-4286.0	5160.0	-2580.0

5.1.3 Calculation of internal forces

The calculation of internal forces acted by the live load on arch bottom and arch top is used basis of car-15 grade, lifting car-80 grade, and crowed load (3.5 kN/m^2). The summary of the maximum and minimum values of axial force and moment at different live load grade are listed in Table 9.

5.2 Analysis of the old simply supported bridge

The calculation of internal forces for the old simply supported beam bridge is based on live loads of car-15 grade, lifting car-80 grade, and crowed load (3.5 kN/m^2). The results of bending moment of main beam acted by all loads are listed in Table 10.

6. 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 damaged components of the bridge are selected for test. For the new arch bridge, these components include arch top, arch bottom, and the horizontal thrust of arch bottom. While, for the old simply supported bridge, these components include mid-span of lifting beam of span No.1, corbel of span No.1, pier top, and mid-span of the main beam. The main content of static load test includes three stages. The first stage is to measure the stresses variation in all the selection components. The second stage is to measure deflections which include vertical deflection of mid-span of simply supported beam, mid-span of lifting beam, and arch top. The third stage deals with cracks observation by using the crack-observational instrument. This test is based on the references: JTGD60 2004, JTGD62 2004, Widening Report of Jilin Bridge 1976, CJJ 2003.

Table 11 Characteristic parameters of the vehicle 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	30	85	85	200	325	125

6.1 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 four tipping-bucket automobiles FAW produced by the heavy-duty factory in Changchun city in China. The overall weight is 200 kN. The characteristic parameters of the vehicles for static load test are listed in Table 11.

6.2 Layout of measuring points

Figs. 15 and 16 illustrate the layout of measurement points of the new arch bridge and the old simply supported beam bridge respectively, and Fig. 17 illustrates the transverse layout of vehicles loads of the new arch bridge. Fig. 18 shows the transverse layout of vehicles loads of the old simply supported beam bridge.

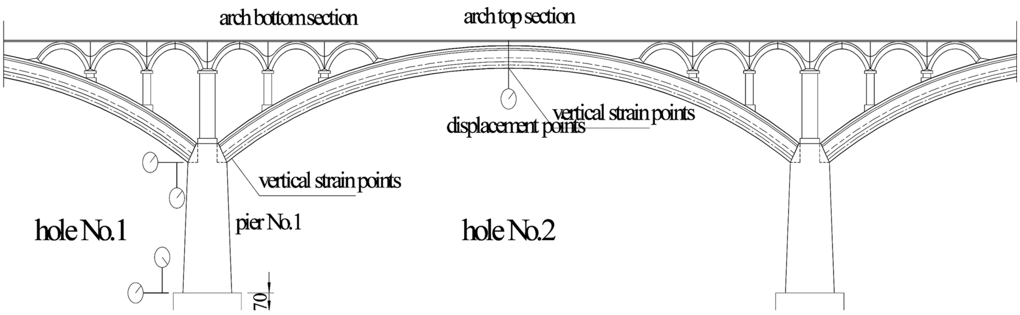

Fig. 15 Layout of measurement points of the new arch bridge

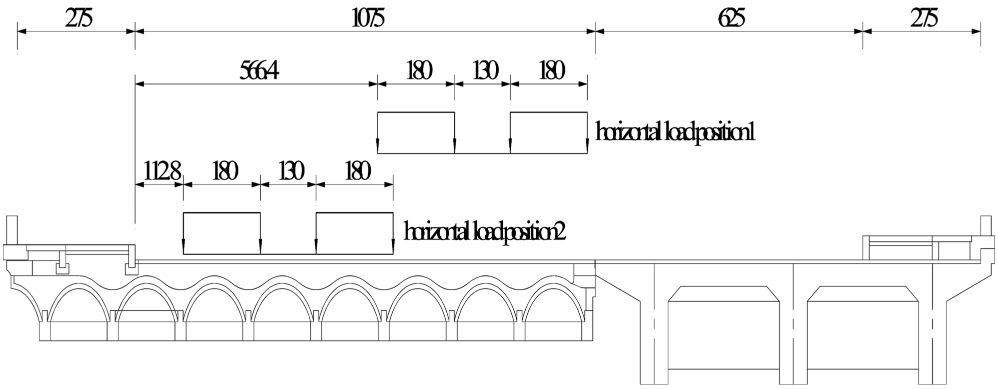

Fig. 16 Transverse layout of vehicles loads of the new arch bridge

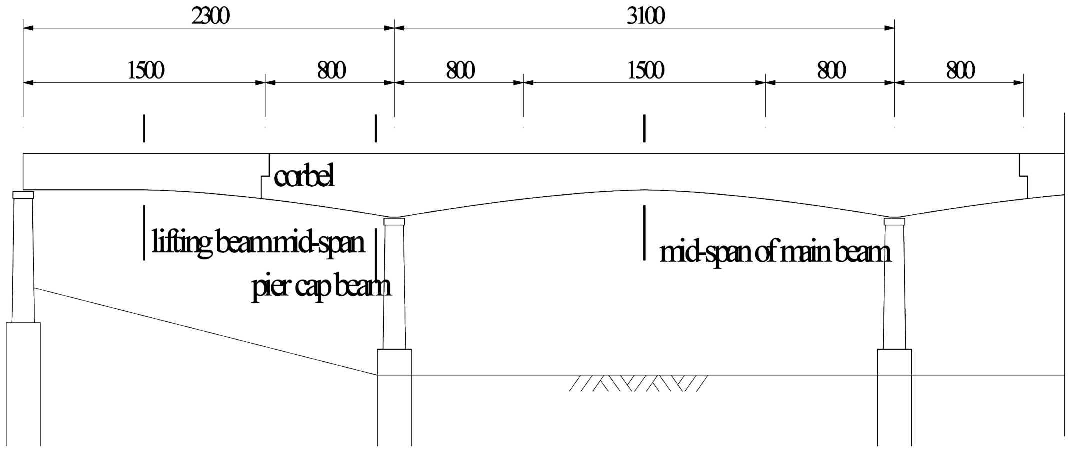

Fig. 17 Layout of measurement points of the old simply supported bridge

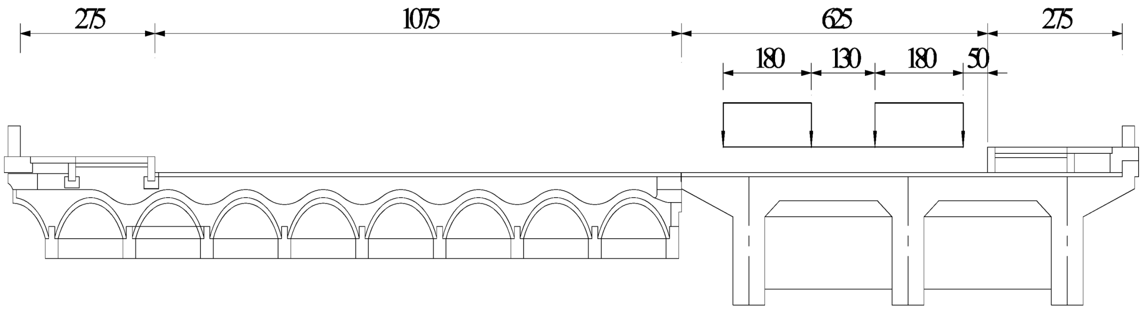

Fig. 18 Transverse layout of vehicles loads of the old simply supported bridge

Table 12 Equipments of test

Equipments	Vibrating wire strain sensor	Bridge strain sensor	Dial indicator	Vibrating wire strain sensor acquisition system	Bridge strain sensor acquisition system	Precision digital level	Cracks reader 25 times	Hammer of strength of concrete	100W hair dryer
Quantity (piece)	52	10	20	2	1	1	1	1	1

6.3 Equipments of test

The equipments of load test are listed in Table 12.

6.4 Results of static load test

6.4.1 Deflection analysis

For the new arch bridge and the old simply supported bridge, Fig. 19 and Fig. 20 show the

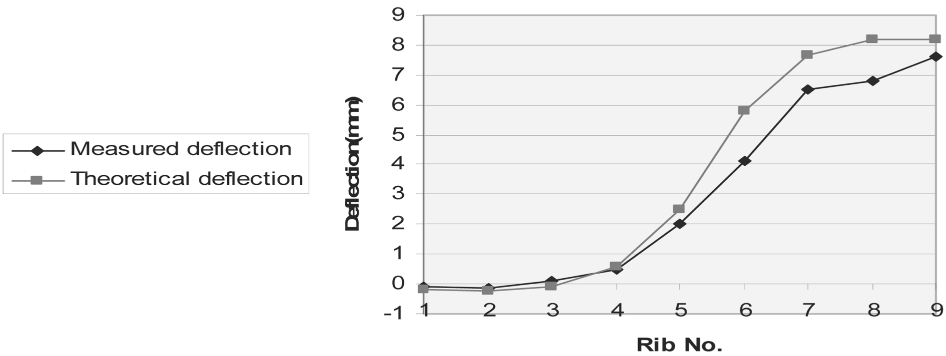

Fig. 19 Measured and theoretical values of deflection of arch top section for horizontal load position 1

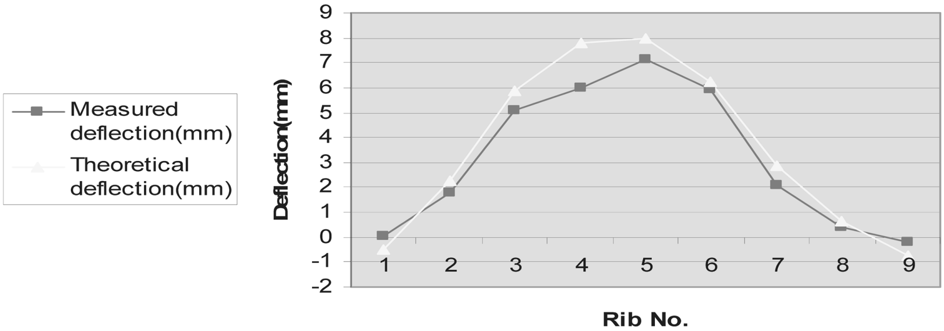

Fig. 20 Measured and theoretical values of deflection of arch top section for horizontal load position 2

Table 13 Measured values and theoretical values of deflection of the old simply supported beam bridge (mm)

Load condition	Theoretical deflection			Measured deflection			Ratio		
	Lifting beam	Corbel	Main beam	Lifting beam	Corbel	Main beam	Lifting beam	Corbel	Main beam
Positive moment	1.94	2.14	-2.16	1.63	1.95	-1.63	0.840	0.910	0.756
Negative moment at pier top	3.44	5.12	-5.2	2.96	4.01	-4.16	0.862	0.784	0.801
Positive moment	-3.88	-7.76	10.94	-3.46	-6.30	8.13	0.891	0.811	0.743

measured and the theoretical values of deflection for horizontal load position 1 and 2. From these figures it can be noted that the measured values of deflection are smaller than theoretical values. Therefore, the performance working of the bridge in a good condition and has enough stiffness to resist the external and internal loads. The values of measured and the theoretical values of deflection for horizontal load position 1 and 2 for the old simply supported bridge are listed in Table 13. The whole deflection and integrity of the bridge meet the requirements and the state of elastic working is fine.

6.4.2 Stress-strain analysis

6.4.2.1 The new arch bridge

When the load condition is the positive bending moment on the arch top, the strain is bigger in the interior edge of arch top within arch ribs No.5, No.8, and No.9. The corresponding strain values of arch ribs No.5, No.8, and No.9 are -52 $\mu\varepsilon$, -56 $\mu\varepsilon$, and -63 $\mu\varepsilon$ respectively. While the corresponding theoretical strain values are -67 $\mu\varepsilon$, -71 $\mu\varepsilon$, and -78 $\mu\varepsilon$, respectively. All measured values are smaller than of theoretical values, and the testing coefficient of the stress range between 0.77 to 0.81. These indicate that there is confident strength on the section of arch top. When the arch bottom is in a state of negative bending moment, the maximum measured strain value is 117 $\mu\varepsilon$ less than the theoretical value 131 $\mu\varepsilon$. The stress testing coefficient is 0.89. Therefore, the actual stress state consistent with requirements and there is a certain strength reserve on the section of arch bottom.

6.4.2.2 The old simply supported beam bridge

The concrete strain values of lifting-beam mid-span section, the section of corbel, and the mid-span section of main beam are 239 $\mu\varepsilon$, 133 $\mu\varepsilon$, and 368 $\mu\varepsilon$ respectively, while the theoretical values of strain are 189 $\mu\varepsilon$, 97 $\mu\varepsilon$, and 313 $\mu\varepsilon$ respectively. The testing coefficient of stress ranges between 0.731-0.852. These indicate that the strength of the bridge satisfy the application requirements.

6.4.3 Horizontal displacement of pier No.1

When the horizontal push is applied to arch bottom, the horizontal displacements of upstream side and downstream side of pier No.1 are 0.32 mm and 0.28 mm respectively. The displacement will recover when the load is removed. These results indicate that the pier is in good elastic working state.

6.4.4 Vertical settlement of pier No.1

When the condition of load is the positive bending moment on arch top and the negative bending moment on the arch bottom, the vertical settlement of upstream side of pier No.1 is 0.02 mm, and the horizontal displacement of downstream side of pier No.1 is 0.01 mm. These results indicate that the lower layer of the base of pier is in a good elastic working state and the bearing capacity of the foundation satisfies the requirements.

6.4.5 Cracks observation

For the new arch bridge, the original cracks do not enlarge and no new cracks were observed both bottom and top of the arch when the load test is applied to the sections. For the old simply supported beam bridge, the cracks on the upper edge of the corbel section are developed, but cracks will recover after when the load is removed. The original cracks of main beam are no developed and there are not new cracks in the section when the load test is applied, indicating that the bridge structure is in a good elastic working state.

7. Dynamic load test

The dynamic performance of the bridge structure is an important index to evaluate the operating state and bearing capacity of the bridge. The main aim of the dynamic load test is to check the response between free vibration characteristics and forced vibration response of the span of the bridge structure. The main contents of dynamic load test include measuring of natural frequency, damping ratio, and impact factor of the bridge.

Fig. 21 Equipments of dynamic load test

7.1 Conditions of test

The dynamic strain and acceleration speed are measured in situ for the arch top of the new arch bridge and mid-span of the old simply supported beam bridge in the state of free opened traffic. The time for continuously detecting is 60 minutes.

7.2 Equipments of dynamic load test

The application of equipments for the dynamic load test is shown in Fig. 21. Two 941B-detecting vibration apparatus are arranged on the arch top and mid-span of the simply supported beam respectively. These equipments include collection system (DH5922 dynamical data collection system), sensor type 941B-detecting vibration apparatus, displacement sensor, and storage device type IBM PC.

7.3 Results of dynamic load test

The vibration curve is measured in the state of free open traffic. Natural frequency of bridge is obtained by analysis of frequency spectrum. Fig. 22 shows the vibration curve. The measured value of natural frequency of the new arch bridge is $\omega = 4.22$ Hz and for the old simply supported bridge is $\omega = 3.42$ Hz. Whereas, the theoretical values of natural frequency are $\omega = 3.75$ Hz and $\omega = 2.592$ Hz. The ratio between measured and theoretical values is 1.13 for new arch bridge and 1.32 for old simply supported bridge. For two parts of bridge, the measured values greater than the

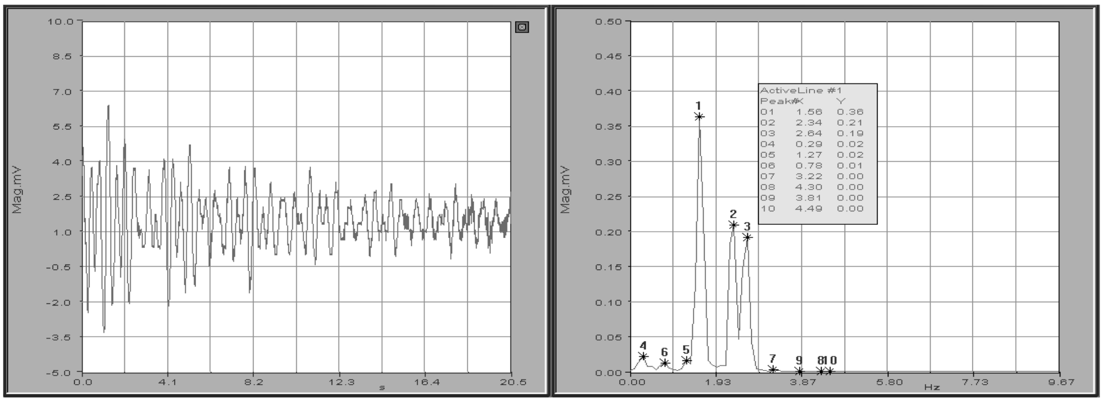

Fig. 22 Vibration curve

theoretical values. Thus, the practical stiffness of bridge structure is bigger than theoretical stiffness. The damping ratio can be calculated by using the equation

$$\zeta = \delta / 2\pi \tag{1}$$

Where:
ζ = The damping ratio
δ = The average decreasing ratio

The damping ratio of the new arch bridge is 0.032 and 0.045 for old simply supported. The general damping ratio of reinforced concrete structure is ranged between 0.02 and 0.06. Therefore, the values of damping ratio of two parts of bridge are located within these ranges.

8. Conclusions

According to the damage inspection of bridge structure appearance and experimental results of load, the conclusion of this study are:

1. For the new arch bridge, the quality of main arch ring and horizontal tie beam is good. There are not series cracks for the structure. According to the results of load test, the deflection, strain, and cracks satisfy the requirements. Because of the vertical cracks in parts of arch wave, the whole mechanical performance of main arch is affected by the cracks. There are serious damages in the part of spandrel arch, resulting in larger deformation of structure. There are cracks within pavement of deck. Because of these damages within the spandrel arch and damages of deck pavement. Therefore, the recommendation of this study is necessary to repair of spandrel arch and pavement of deck.
2. For the old simply supported beam bridge, there are some forced cracks in main beam and lifting beam of new simple bridge. The whole state is good. According to the results of load test, the deflection, strain, and cracks meet the requirements of existing bridge. When the load is equal to car-15, lifting car-80, the bridge can satisfy the demand of car-15 grade. But there are serious corrosion and spalling of concrete in the corbel. These damages influence the normal using and durability of the bridge structure. Therefore, there is a need to repair the corbel.

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