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Research on Mechanical Behavior of Cast Concrete Box Girder Bridge with the Bearing Separation

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Abstract

Through statistical analysis of the inspection results of nearly 190000 plate rubber bearings in use in China, it is shown that the failure of the bearings in the existing diseases of small box girder bridges will directly lead to changes in the stress status of the upper structure of the bridge, causing changes in the internal force distribution of each main beam and sudden changes in the reaction force of the bearings. In severe cases, it will threaten the safety of the bridge structure. This article uses finite element software to simulate the stress characteristics of a small box girder bridge when the bearings are damaged, and compares them with the normal stress characteristics of the bearings. It is found that the hollow bearings of the small box girder bridge with three supports arrangement have a significant impact on the bridge. Therefore, timely reinforcement measures should be taken to evaluate and maintain the bridge structure.

Keywords

Small Box Girder Bridge; Bearing Separation; Simulation of Stress Performance.

1. Introduction

As an important accessory component of a bridge, bearings transmit the load from the upper structure to the piers and bear some of the deformation required by the bridge structure. However, due to problems with the bearings themselves and various improper design, construction, and operation processes of bridges, some bridges have developed diseases after a period of operation, and have to undergo bearing replacement.

Plate rubber bearings are one of the indispensable types of bearings in bridge bearings. Currently, rubber bearings are almost entirely used in new highway bridges with spans of no more than 30m and small displacement in China. As a special structural form, simply supported and then continuous beam bridges inherit the dual advantages of both simply supported and continuous beam bridges. They have the characteristics of low cost, good integrity, short construction period, and comfortable driving, thus being widely used in engineering. However, in recent years, with the increase of traffic volume, as well as the quality of rubber product production, improper design and construction of bearings, a large number of diseases have occurred in rubber bearings. The main diseases of rubber bearings include uneven bulging, cracking (including damage), large shear deformation, detachment (including missing), exposed steel plates, eccentric pressure, misalignment, and misalignment.

After preliminary statistical analysis of the inspection results of nearly 190000 in use plate rubber bearings in China (see Table 1), it is shown that among the existing diseases, in addition to the phenomenon of aging and cracking of the bearings, the phenomenon of eccentric pressure detachment and shear deformation exceeding the limit are also prominent. The failure of the support will directly lead to changes in the stress condition of the upper structure of the bridge. For continuous beam bridges formed by prefabricated assembly construction, it will cause changes in the internal force distribution of each main beam and sudden changes in the support reaction force. In severe cases, it will threaten the safety of the bridge structure. Therefore, the study of support detachment is of great significance.

Table 1. Main diseases and proportions of inspected platerubber bearings

Disease type	cracking	Vertical compression exceeding limit	Shear deformation exceeding limit	eccentric pressure	Void and bias	Wear of sliding plate and detachment of stainless steel plate	Total number
number	54153	20694	40684	13648	52486	10697	192362
Rate	28%	11%	21%	7%	27%	6%	100%

2. Engineering Overview and Calculation Model

2.1 Engineering Overview

According to the general structural drawing of 30m small box girder bridge issued by the Ministry of Communications, this bridge is designed to be of Class I safety class, the load class is highway - Class I, and the main bridge span combination is (4 × 30m), the upper structure adopts post tensioned prestressed concrete small box girder, with a beam height of 160cm. Five main beams are placed in the transverse direction of the bridge, with a bridge deck width of 17m and a skew angle of 0 °. Three transverse diaphragms are set in the longitudinal direction of the bridge span. The main beam is poured with C50 concrete, and an 8cm thick C40 concrete cast-in-place layer, waterproof layer, and 10cm thick asphalt pavement layer are set on the bridge deck.

In order to investigate the impact of bearing detachment on the structural performance of beam bridges, the bridge engineering finite element software MidasCivil was used for stress analysis. When modeling a bridge based on the beam grid method, the main beam of the bridge is divided into beam grids using planar member elements according to the introduction of the beam grid method in Hamburg's "Bridge Superstructure Performance". One main beam is a longitudinal beam, and the wet joints and diaphragm beams that connect multiple main beams horizontally are transverse beam grids. The main beam and longitudinal wet joint materials are C50, and the cast-in-place layer of the bridge deck is C40 concrete. The bridge deck pavement is made of asphalt concrete, The virtual beam in the transverse beam grid adopts zero gravity concrete unit weight, and the pavement layer can participate in the force of the whole bridge under the action of vehicle load, so the concrete layer in the pavement layer is considered as a part of the structural force in the finite Metamodeling.

2.2 Boundary Conditions and Support Arrangement Form

2.2.1 Support Arrangement Form

This article simulates a single main beam of a bridge with three supports, with two opposite supports at one end and one support at the other end. The support is simulated through an elastic connection between the two nodes, and the upper node is rigidly connected to the main beam node through the master slave node constraint function in Midas software. Its stiffness is calculated. According to the regulations in "Highway Bridge Plate Rubber Bearings" JT/T4-2004, the double bearing end should use the specifications of D=300mm and t=76mm; Single bearing end with D=450mm and t=101mm specifications

2.2.2 Simulation Method for Detached Support

For circular plate rubber bearings, the change in internal stress caused by local void is a gradual process, and the stress of the steel plate inside the bearing increases continuously with the increase of void area. The edge load of the bearing on the bias side caused by bias pressure increases rapidly. When the void area reaches 20%, the maximum stress of the steel plate in the bearing has reached 183.4MPa. When the bearing is void, the main tensile stress of the rubber at the junction between the

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steel plate and the rubber layer on the side has reached 21.3MPa, which has exceeded the tensile strength limit (17MPa) of Neoprene specified in the Road Bridge Plate Rubber Bearings JT /T4-2004. Exceeding the specification limit has seriously affected the durability of the bearing.

It can be considered that the local detachment of the plate type rubber bearing is due to the reduction of the effective bearing area of the bearing due to the eccentric pressure of the bearing, while the mechanical properties of the rubber and stiffening steel plates have not been damaged. Therefore, it is believed that the compressive stiffness E and shear stiffness G of the bearing itself have not changed. Due to the dangerous situation where the rubber bearing's internal rubber and steel plates are not suitable for long-term load bearing when the void area of the bearing reaches 20% of the designed effective pressure bearing surface, the ratio of the void area to the designed effective pressure bearing surface is defined as the void rate. During simulation, the limit of the void area is set at 40% of the designed effective pressure bearing surface. Under the condition of complete void bearing, the void rate of the bearing is 100%.

Table 2. Support stiffness simulation parameters

Void rate	D(mm)	E	G(Mpa)	SDX(n/mm)	SDY(n/mm)	SDZ(n/mm)
0%	300	362.84	1	452189.88	1121.63	1121.63
30%				316532.91	785.14	785.14
0%	450	425.197	1	910137.17	1926.46	1926.46
30%				637096.02	1348.52	1348.52

2.3 Load Case

Considering the load conditions, analyze the impact of bridge support detachment on the upper structure: self weight+prestressing+temperature load+phase II+moving load. When the moving load is a standard vehicle, the lane load specified in the specification shall be used to load the moving load on the bridge; Under overloaded operation, the moving load is vehicle load. Referring to the layout of the vehicle fleet in the lane load load section of the General Specification for Design of Highway Bridges and Culverts, as shown in Figure 3.2, the main vehicle is a two axle vehicle, and the heavy vehicle is a five axle vehicle. The vehicle fleet consists of four main vehicles and one heavy vehicle, with a distance of 15m between the main vehicles and a distance of 10m between the main and heavy vehicles. The overloaded fleet adopts the same fleet layout as the car - Super 20, and the heavy vehicle adopts a five axle vehicle with three axles. The vehicle axle load simulation is arranged as shown in the Fig. 1

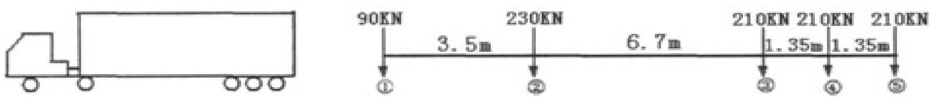

Fig. 1 Schematic diagram of vehicle load arrangement

2.4 Establishment of Finite Element Model

A finite element model is established based on the general diagram of small box girders released by the Ministry of Transport. A single 30m simply supported small box girder is divided into 20 units, and corresponding 20 beam units are arranged horizontally on the bridge. The transverse partition plates set at the mid span and beam ends are also considered as beam units. The bridge pavement layer and Phase II guardrail are converted based on area and applied to the beam units with node static loads. The finite element full bridge model and support boundary simulation results are as follows(see in fig. 2-4).

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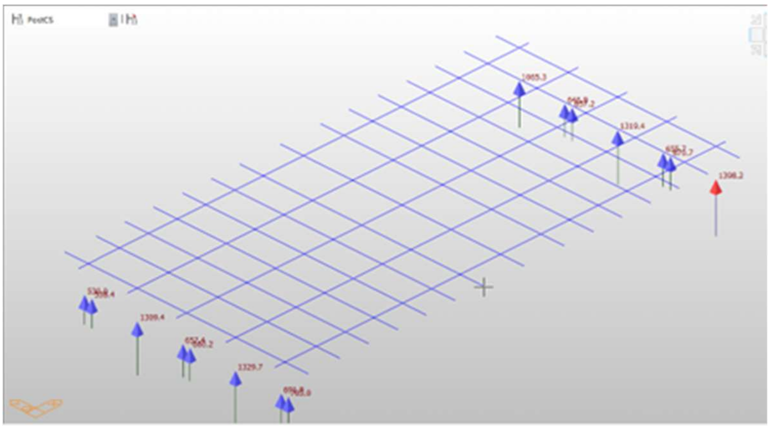

Fig. 2 Support reaction

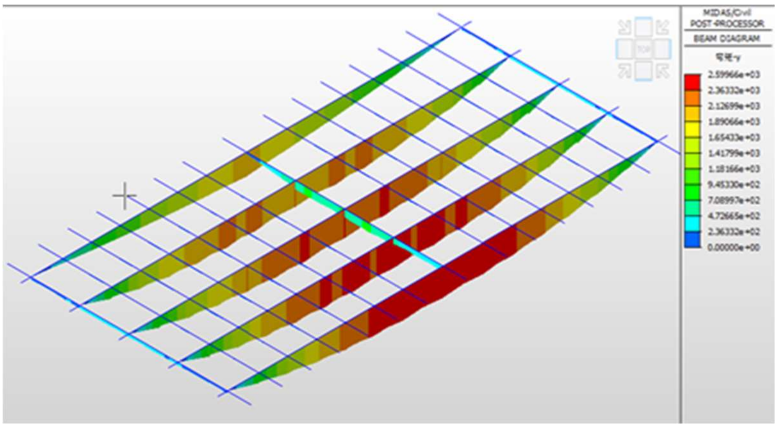

Fig. 3 Bending moment results

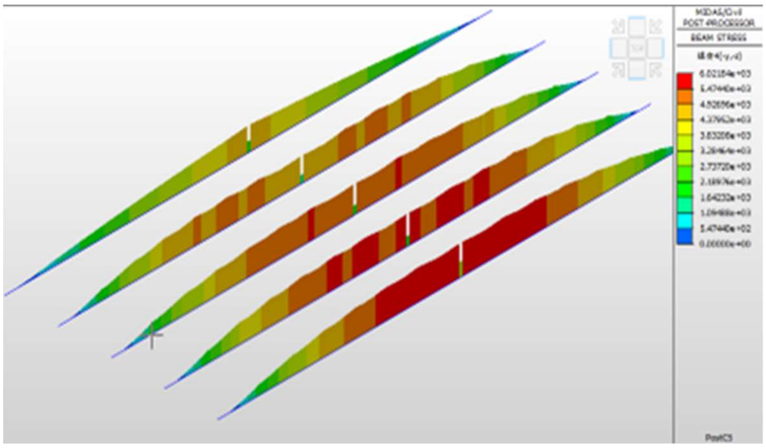

Fig. 4 Normal stress of beam bottom plate

3. The Impact of Bearing Detachment on Bridges

For bridge bearings, the failure and damage of bearings will lead to changes in the stress state of the bridge structure, especially for simple supported small box girder bridges composed of multiple small box girders, which will lead to the redistribution of internal forces in the main beam and cross beam, and sudden changes in the support reaction of bearings. In more serious cases, the safety of the bridge will be seriously affected.

3.1 Impact of Bearing Detachment on Bridge Bearing Reaction Force

The simulated working conditions of three supports consider the situation where one support at both ends of each beam experiences local detachment. To facilitate differentiation, the main beam is named A, B, C, D, and E. The eight supports on the left are named A1 A2 B1 C1 C2 D1 E1 E2, and the seven supports on the right are named A3B2B3C3D2D3E3. Analyze the most unfavorable stress situation on the structure caused by local detachment of a certain support on the left side of the bridge. Based on the location of the support, 30% of the support detachment occurred at five locations: A2, B2, C2, D2, and E2. The reaction force of the support at the detachment is summarized in the table.3 below.

By analyzing the three bearing reaction value table under various working conditions, it can be determined that for a three bearing simply supported small box girder structure, the type of bearing damage caused by a single bearing detachment will only cause a significant change in the bearing reaction force of the same row of bearings when the bridge experiences bearing detachment. Taking the C2 bearing (double bearing end bearing of the middle beam) as an example, when the C2 bearing experiences bearing detachment, C2 support and C2 support in the same row and adjacent support reactions will undergo a certain degree of change in support reactions. At this point, the reaction force of the C2 support decreased from 660.16KN to 508.44KN, while the reaction force of the B1 and D1 supports increased from 1309.44 and 1329.69 to 1350.82 and 1373.08, with varying amplitudes of -22.98%, 3.16%, and 3.26% respectively. The C1 support of the same main beam increased from 657.41KN to 721.29KN, an increase of 9.72%, but there was no significant change in the reaction force of the opposite support.

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Table 3. Left support reaction force variation amplitude

	position	Standard vehicle left end support reaction force (KN)	Left end support reaction force variation amplitude (-%)
30% void of C3 support	A1	529.92	-0.02
	A2	538.34	-0.01
	B1	1309.61	0.01
	C1	657.45	0.01
	C2	660.20	0.01
	D1	1329.84	0.01
	E1	691.79	-0.01
	E2	704.86	-0.02
30% void of C2 support	A1	526.36	-0.69
	A2	536.79	-0.30
	B1	1350.82	3.16
	C1	721.29	9.72
	C2	508.44	-22.98
	D1	1373.08	3.26
	E1	691.53	-0.04
	E2	701.92	-0.44
30% void of E3 support	A1	529.57	-0.09
	A2	538.02	-0.07
	B1	1309.29	-0.01
	C1	657.41	0.00
	C2	660.20	0.01
	D1	1329.54	-0.01
	E1	692.48	0.09
	E2	706.11	0.16
30% void of E2 support	A1	529.63	-0.08
	A2	537.80	-0.11
	B1	1305.11	-0.33
	C1	653.66	-0.57
	C2	657.03	-0.47
	D1	1366.06	2.73
	E1	798.23	15.38
	E2	580.41	-17.67
30% void of D2 support	A1	529.91	-0.02
	A2	538.29	-0.02
	B1	1309.52	0.01
	C1	657.53	0.02
	C2	660.28	0.02
	D1	1329.75	0.00
	E1	691.78	-0.01
	E2	704.92	-0.01

	position	Standard vehicle left end support reaction force (KN)	Left end support reaction force variation amplitude (-%)
30% void of D1 support	A1	525.46	-0.86
	A2	534.17	-0.79
	B1	1315.48	0.46
	C1	700.77	6.60
	C2	717.30	8.66
	D1	1136.45	-14.53
	E1	742.07	7.26
	E2	737.09	4.55
30% void of A3 support	A1	530.89	0.16
	A2	538.87	0.09
	B1	1309.33	-0.01
	C1	657.45	0.01
	C2	660.17	0.00
	D1	1329.58	-0.01
	E1	691.49	-0.05
	E2	704.55	-0.06
30% void of A2 support	A1	607.56	14.63
	A2	427.93	-20.52
	B1	1348.05	2.95
	C1	657.20	-0.03
	C2	658.88	-0.19
	D1	1326.22	-0.26
	E1	691.16	-0.10
	E2	704.45	-0.08
30% void of B1 support	A1	559.91	5.64
	A2	587.06	9.04
	B1	1119.15	-14.53
	C1	713.65	8.56
	C2	700.57	6.12
	D1	1334.88	0.39
	E1	687.95	-0.56
	E2	700.38	-0.66
30% void of B2 support	A1	529.90	-0.03
	A2	538.28	-0.02
	B1	1309.48	0.00
	C1	657.55	0.02
	C2	660.28	0.02
	D1	1329.82	0.01
	E1	691.78	-0.01
	E2	704.90	-0.01

When a single support is damaged, although the bridge itself may experience internal force redistribution due to changes in the lateral statically indeterminate structure of the bridge, the transverse diaphragm at the end of the bridge beam can effectively bear the problem of uneven distribution of reaction forces between each beam caused by support detachment, so that the main beam of the bridge does not suffer overall structural damage due to a single support damage.

The normal support on a beam and the reaction force of the support when the left and right supports are detached are reflected on the same chart. It is found that only when the support in the same row is detached will it affect other supports in the same row. Taking the two working conditions of the center beam support being detached as an example, the detachment of C3 support (single support at the right end of the center beam) has a certain impact on the right end of the bridge support.

The detachment of the C2 (double support at the left end of the middle beam) support is shown in the figure to coincide with the normal state reaction value of the support, indicating that the detachment of the support will not have a significant impact on the opposite side support.

Comparing and analyzing the reaction force of two or three bearings under a single bearing void condition, the impact of bearing void on the bridge is often not only related to the bearing and its adjacent bearings, but also on the reaction force of the main beam and adjacent main beams with void bearings. That is, no matter how many bearings are installed on the main beam, the disease of bearing void will affect all bearings in the same row on the main beam.

Therefore, for bridges with multiple supports on one side of a single main beam, more attention should be paid to diseases such as bearing detachment, and the damage to the middle beam under the influence of such diseases is often more severe than that to the edge beam.

3.2 Impact of Support Detachment on Shear Force of Bridge end Crossbeam

A diaphragm is a component set between beams to maintain the shape of the cross-section and enhance the lateral stiffness of the bridge. It acts on the live load distributed on the bridge. The shear force of the bridge crossbeam can be used as a parameter to measure the horizontal distribution level of the bridge load caused by the diaphragm. Analyzing the shear force of the crossbeam can to some extent obtain the lateral distribution law of the load on the concrete small box girder. The simply supported small box girder of this span is equipped with a transverse partition at both the beam end and the middle of the span. Each transverse partition is named based on the main beam and is: A-B B-C C-D D-E. The calculation results are shown in the table 3 below.

The distribution pattern of cross beam shear force is similar to the distribution of support reaction force. When a single support of the middle beam and secondary edge beam is detached, there is a significant change in shear value at the left and right end diaphragms on the same side. However, this change does not involve the mid span diaphragms and the opposite end diaphragms. Moreover, when a single support is detached from the same main beam support under the three support arrangement, the shear force level of the single support arrangement end beam is significantly higher than that of the double support end.

For the edge beam, the shear force of the A-B left end crossbeam decreased by 17.88% when the A2 support was detached, and the shear force of the D-E left end crossbeam increased by 12.33% when the E2 support was detached. The analysis found that although A2 and E2 were both end supports arranged with double supports for the edge beam, A2 was the inner support of the edge beam, while E2 was the outer support of the edge beam. When the support was detached, the direction of torsion of the edge beam was different, so the shear force of the diaphragm also increased or decreased by different degrees, It indicates that the impact on the hollow diaphragm of different side supports of the same beam is also different.

For the center beam, the C2 support is one of the double support arrangements at the left end of the center beam, and the C3 support is the single support arrangement at the right end of the center beam. When the C2 support becomes vacant, the shear force of the B-C left end crossbeam increases by 16.16%, while the shear force of the C-D left end crossbeam decreases by 18.37%.

This indicates that after the C2 support becomes vacant, some of the function of the support is borne by the C1 support, while the other part is borne by the B-C left end diaphragm; And due to the

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occurrence of support detachment, there will be a trend of relative torsion in the middle beam. On one side, the shear force of the diaphragm increases, while on the other side, there will be a decrease in shear force; Once a single support arrangement occurs, the same side diaphragm will inevitably experience significant shear growth and there is a possibility of damage.

Table 4. Cross beam shear force under standard vehicle load

	C2 bearing separation	C3 bearing separation	A2 bearing separation	A3 bearing separation	B1 bearing separation	B2 bearing separation	D1 bearing separation	D2 bearing separation	E2 bearing separation	E3 bearing separation
D-E Left Diaphragm	5.17	0.71	1.75	0.85	14.48	0.33	-80.95	0.15	12.33	-1.40
C-D Left Diaphragm	-18.37	0.11	2.48	0.39	1.89	0.08	40.72	-0.01	-5.69	-0.37
B-C Left Diaphragm	16.16	-0.12	3.75	0.68	-41.12	0.04	-1.99	-0.04	-2.43	-0.27
A-B Left Diaphragm	-3.03	-0.18	-17.86	0.87	45.06	-0.04	-4.76	-0.03	-0.34	-0.24
D-E inter Diaphragm	0.17	0.37	-0.09	-0.27	0.11	0.06	0.11	0.03	-0.15	-0.30
C-D inter Diaphragm	0.03	0.12	-0.06	-0.22	0.25	0.13	-0.12	-0.06	0.01	-0.01
B-C inter Diaphragm	-0.05	-0.10	0.03	0.01	0.13	0.05	-0.20	-0.08	0.10	0.17
A-B inter Diaphragm	-0.69	-1.63	0.50	1.66	-0.50	-0.35	-0.57	-0.16	1.22	2.35
D-E Right Diaphragm	-0.03	-5.33	-0.05	-0.94	-0.09	-2.00	-0.06	24.10	0.52	32.78
C-D Right Diaphragm	0.00	41.98	-0.08	-5.63	-0.09	-0.41	0.08	-15.80	0.46	-14.14
B-C Right Diaphragm	0.09	-37.95	-0.13	-12.90	-0.02	24.58	0.20	1.65	0.29	-8.31
A-B Right Diaphragm	0.36	12.04	-0.37	43.59	0.30	-24.36	0.56	5.41	0.42	-3.30

4. Conclusion

Using finite element software for simulation calculations can to some extent achieve the simulation of concrete small box beams. By simulating a simple supported small box beam with three supports arranged on a single beam, it can be found that the failure of the middle support has a significant impact on the adjacent bearings of the simple supported bridge. At the same time, the failure of the beam end bearings arranged on a single support has a much greater impact on the bridge than the beam end bearings arranged on two supports. Since the void and failure of bearings is a common disease in the current bridge operation process, it is recommended to improve the Factor of safety and strength reserve of bearings in bridge design to ensure that the bridge structure can basically maintain normal operation after the void and failure of individual bearings, and avoid the consequences of chain failure of other bearings after the void of individual bearings. Once it fails, measures should be taken as soon as possible to inspect and replace the bearings to prevent other bearings from affecting their service life due to changes in stress performance.

References

[1] Wang W YE,J LIN Z,et al.Analysis of Formation Causes of Diagonal Cracks in Box Girder Webin Construction Process [J]. Bridge Construction,2010,1:010.

[2] WANG G,Xie J,Fu YInvestigation Research on Crack of Long-span Prestressed Concrete Box Girder Bridges in Service [J] . Journal of Highway and Transportation Research and Development. 2008,8:012.

[3] Mohammad A Alhassan, Mohsen A Issa. Estimation of drying shrinkage-induced stresses at bridge deck slab-overlay bond interface [J]. Journal of the Chinese Ceramic Society, 2011,39(1):92-98.

[4] Mori A, Moss P J, Cooke N,et al. The behavior of bearings used for seismic isolation under shear and axial load[J]. Earthquake Specrta,1999,15(2):199-224.

[5] Earthquake Engineering Research Center. Experimental investigations on the seismicresponse of bridge bearings [R]. Berkeley,CA,USA:EERC,2008.

[6] Chun Shu Li, Guang Ming Yuan, Hao Feng. Stress Analysis and Fatigue Life Estimation of Bridge Rubber Bearing[J]. 2013, 2493:345-349.