Quantitative analysis of diaphragm plate caused by pedestal void of assembled box girder

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Abstract: In this paper, ANSYS finite element software is used to study the influence of pedestal void on the diaphragm force of prestressed prefabricated box girder bridge. Three different working conditions of no support void, side span support void and middle span support void were simulated respectively, and then the principal tensile stress and vertical deflection of each diaphragm key point were studied under different working conditions. The results show that the support void has almost no effect on the main tensile stress and vertical deformation of the diaphragm in the mid-span, but has a significant effect on the diaphragm at the end of the beam. The influence of the middle span support void on the main tensile stress of the diaphragm is larger than the opposite span support void. The effect of side-span bearing void on the vertical deflection of diaphragm is greater than that of mid-span bearing void. The void of the support will lead to the uneven force of the whole structure and finally affect the stability of the whole structure.

1. Introduction
In China, prefabricated prestressed concrete girder Bridges are mostly used in medium and small span Bridges, and rubber bearing has become the most commonly used bridge bearing form in highway Bridges because of its advantages such as simple structure, low cost, convenient construction and less maintenance.[1] But in the actual process, due to improper construction and maintenance, the support will appear empty, deformation, cracking and other phenomena, which will lead to changes in the stress of the bridge structure, which will affect the safety of the bridge structure in serious cases.[2]

Wu Xiaoguang et al. investigated various diseases of beam-and-plate rubber bearings, and finally found that the occurrence frequency of local voiding and shearing diseases is the highest.[3] Zhu Xiaqing et al. studied the support void: the void failure of the support will affect the mechanical performance of the main girder[4]. Jiang Yuanhui et al. used different stiffness combinations to simulate the support void and studied its influence on the hollow slab hinge joints. The results showed that the support void had no influence on the mid-span position of the hinge joints, but had a great influence on the stress of the hinge joints at the beam end[5]. Lei Sumin made an in-depth study on bearing void and believed that: bearing void has a greater impact on the support of the piers, followed by neighboring piers, and the shadow of other piers is small[6]. According to Hu Fengqiang et al., the void of support has a greater influence on the structure force, and the void of side beam support has a greater influence on the structure than the void of middle beam support[7]. Liu Xiuqing et al. found that when a certain seat is empty, the shear force value borne by the adjacent support increases, which is easy to cause secondary diseases[8].
Many scholars have studied the harm of bearing void and preventive measures, but there is a lack of quantitative research on the influence of bearing void on the mechanical performance of bridge diaphragm. In this paper, the finite element model of a prefabricated box girder is established by using ANSYS. By comparing the stress and strain properties of the diaphragm at different support void positions, the influence of support void on the mechanical properties of the diaphragm is obtained.

2. Project overview and finite element model
The supporting project selected in this paper is a prestressed concrete prefabricated box girder bridge. The load grade is highway I level. The superstructure is prestressed reinforced concrete box girder of 8×30m. Four main girders are placed laterally. Five diaphragms are set longitudinally across the bridge, and the main girder, wet joints and diaphragms are all made of C50 concrete. The standard tensile strength of the prestressed steel bundle is 1860MPa, and the tension control stress is 1395MPa. The substructure is double column pier, light abutment and pile foundation. The bearing is a plate rubber bearing, and each beam end is provided with a single bearing.

Using ANSYS software to analyse the mechanical performance of the assembled box girder diaphragm. The displacement transformation matrix of the two elements is established without considering the reinforcement slip, and then the stiffness matrix of the prestressed concrete composite elements including the contribution of the prestressed reinforcement is derived. According to the concept of embedded combined stiffness, the concrete condition of the prestressed steel beam can be ignored when dividing the elements. It is considered that it can pass through the concrete element arbitrarily, which effectively solves the influence of concrete shrinkage and creep effect on the prestress.[9]

The concrete adopts Solid65 solid element, and the prestressed steel adopts Link8 rod element. The geometric model of the bridge structure is shown in Figure 1. The free mesh in ANSYS is used for mesh division. The meshing of the overall structure is shown in Figure 2. The bridge has 96,909 physical units and 30,694 nodes.

3. Determine the calculation conditions and key points
In order to clearly explore the influence of different support empty positions on the mechanical performance of prestressed concrete prefabricated box girder bridge diaphragm, this paper studies the most serious case of direct support empty, that is, when the support is completely empty, the stress and strain of each diaphragm are studied.

Take all the diaphragm as the research object, for the convenience of the following description, the diaphragm number processing. As shown in Figure 1, A total of 3 rows of diaphragm boards are arranged along the longitudinal direction of the whole connection, and the numbers from left to right are A, B and C respectively. Each row has 5 horizontal diaphragm boards. Take the first row of diaphragm boards as an example: from back to front, they are numbered A1, A2, A3, A4 and A5. When the support is empty, the boundary condition of the node at the empty support is removed to analyse the influence of the support void at different positions on the stress and strain of the diaphragm plate.
This paper mainly studies the influence of different position of support void on the force of assembled box girder diaphragm. Different position of support void will bring different influence to the bridge structure, which is specifically divided into the following three working conditions:

Working condition I: no support void phenomenon;
Working condition II: the side span support is empty, that is, the left beam body support of A1 diaphragm is empty;
Working condition III: the middle span support is empty, that is, the middle beam body support of A1 and B1 diaphragm is empty.

The key point is the middle point of the lower edge of each diaphragm.

4. Finite element analysis of support void and diaphragm force

4.1. Influence of support void on main tensile stress of diaphragm plate

The spatial stress state at any point is composed of six stress components: \( \sigma_x, \sigma_y, \sigma_z, \tau_{xy}, \tau_{zy}, \tau_{zx} \). According to the theory of maximum tensile stress intensity, the crack criterion of concrete is the maximum principal tensile stress.[10] Therefore, in this paper, the maximum principal tensile stress \( S_1 \) is used to study the stress of the key points of the diaphragm. The principal tensile stress of each key point under different working conditions is shown in Table 1:

Table 1. Stress statistics of key points of diaphragm under different working conditions (unit: MPa)

| Bulkhead position and number | Working condition I | Working condition II | ratio | Working condition III | ratio |
|-----------------------------|---------------------|---------------------|-------|-----------------------|-------|
| left                        |                     |                     |       |                       |       |
| A1                          | 0.276               | 0.227               | 0.82  | 0.256                 | 0.93  |
| A2                          | 0.037               | 0.044               | 1.20  | 0.040                 | 1.09  |
| A3                          | 0.053               | 0.035               | 0.66  | 0.053                 | 1.01  |
| A4                          | 0.034               | 0.107               | 3.18  | 0.068                 | 2.02  |
| A5                          | -0.024              | 1.694               | 71.11 | 1.375                 | 57.69 |
| middle                      |                     |                     |       |                       |       |
| B1                          | 0.058               | 0.043               | 0.75  | 0.043                 | 0.74  |
| B2                          | 0.091               | 0.054               | 0.59  | 0.043                 | 0.48  |
| B3                          | 0.668               | 0.374               | 0.56  | 0.258                 | 0.39  |
| B4                          | 0.044               | 0.045               | 1.03  | 0.199                 | 4.51  |
| B5                          | -0.019              | 0.310               | 16.25 | 1.697                 | 88.81 |
| right                       |                     |                     |       |                       |       |
| C1                          | 0.128               | 0.207               | 1.62  | 0.136                 | 1.07  |
| C2                          | 0.030               | 0.036               | 1.20  | 0.026                 | 0.86  |
| C3                          | 0.045               | 0.043               | 0.94  | 0.058                 | 1.29  |
| C4                          | 0.016               | 0.070               | 4.37  | 0.359                 | 22.48 |
| C5                          | -0.020              | -0.004              | 0.19  | -0.013                | 0.65  |

Table 1 shows that:

1. When there is no support void, the maximum principal tensile stress of the key point appears at the position of the diaphragm B3, and the size is only 0.668MPa. However, the axial tensile strength of C50 concrete is 2.65MPa, so it can be considered that all the diaphragm plates are in a safe state.

2. When the side span support is empty, the main tensile stress of diaphragm A5, which is closest to the empty support, reaches 1.694MPa, which is close to the axial tensile strength of concrete at 2.65MPa. The ratio of the unprecedented principal tensile stress between the support and the support is 71.11, which indicates that the diaphragm is in a dangerous state. The adjacent diaphragm B5 is affected to a certain extent, and the main tensile stress after stripping is 0.310MPa, which is 16.25 compared with the unprecedented principal tensile stress after stripping. The remaining diaphragm plates are far away from the empty support, so the variation range of the main tensile stress is small.

3. When the middle span support is empty, both sides of the diaphragm closest to it are greatly affected. The principal tensile stress of the left diaphragm A5 reaches 1.375MPa, and the ratio of the principal tensile stress to the unprecedented principal tensile stress is 57.69. The principal tensile stress...
of the right diaphragm B5 reaches 1.697 MPa, and the ratio of the principal tensile stress to the unprecedented principal tensile stress is 88.81, which is close to the axial tensile strength of concrete. Therefore, both of them can be considered to be in a dangerous state. The remaining diaphragm plates are far away from the empty support, so the variation range of the main tensile stress is small.

Draw a line diagram of the ratio of main tensile stress after support detachment under different working conditions, as shown in Figure 3:

![Figure 3. Broken line diagram of principal tensile stress ratio under different working conditions.](image)

As can be seen from Figure 3:

1. When the edge span support is empty, there is only one peak point in the line chart. When the middle span support is empty, there are two peak points in the line chart, and the value is larger. Therefore, it can be considered that the influence of the void of the middle span support on the main tensile stress of the diaphragm is larger than the void of the side span support.

2. The void of the support has almost no effect on the main tensile stress of the mid-span diaphragm, but has a significant effect on the diaphragm at the end of the beam. When the support void disease occurs, the main tensile stress of the nearest diaphragm will be greatly affected, which is close to the ultimate tensile strength of concrete, and the diaphragm is in a dangerous state. In addition, the void of the support may cause a great change in the main tensile stress of the similar diaphragm, while the influence on the far diaphragm is small and can be ignored.

4.2. Influence of pedestal void on vertical deflection of diaphragm

Bearing void has the most significant effect on the vertical deformation of the bridge structure, so the vertical deflection is taken as the research object for the strain in this paper. The frontal view and side view of the vertical deformation of the bridge structure under different working conditions are shown in Figure 4–Figure 6, respectively. The vertical deflection statistics of each key point are shown in Table 2:

![Figure 4. Vertical deformation diagram of working condition I.](image)
Table 2 shows that:
(1) when there is no support void, the whole bridge is in the downward-bending state. The middle diaphragm has the largest downward torsion, and the downward torsion gradually decreases to both sides, which is probably in a symmetric state. The deflection of the end diaphragm is concentrated at about 0.13cm.

(2) When the side span support is empty, the deflection of the diaphragm A5, which is closest to the empty support, reaches 1.493cm, and the ratio of deflection to the unprecedented detachment is 11.84. The ratio of the lower deflection to the lower deflection of the adjacent diaphragm B5 is 1.56. The rest of the diaphragm is far from the empty support position, so the vertical deflection change range is small.

(3) when the middle span support is empty, the two sides of the diaphragm closest to it are greatly affected. Among them, the deflection of the left diaphragm A5 is 0.347cm, and the ratio of deflection to the unprecedented deflection is 2.75. The deflection of the right diaphragm B5 is 0.561cm, and the deflection ratio to the unprecedented deflection is 4.2. The rest of the diaphragm is far from the empty support position, so the vertical deflection change range is small.
The ratio of vertical deflection of the support before and after stripping under different working conditions was plotted as a line chart, as shown in Figure 7:

As can be seen from Figure 7:
(1) when the middle span support is empty, there are 2 peak points in the line chart; when the edge span support is empty, the peak point of the line graph is only one, but its value is very large. It is considered that the effect of side-span support void on the vertical deflection of diaphragm plate is greater than that of mid-span support void.

(2) after the support is empty, the downward deflection of the corresponding structure is unconstrained.

The void of the support has almost no effect on the vertical deflection of the diaphragm in the middle span, but it has a significant effect on the diaphragm at the end of the beam. When the support is empty, the vertical displacement of the nearest diaphragm is affected the most, and there is a great downward torsion, and the influence on the far diaphragm is not great.

5. Conclusions and Suggestions
In this paper, through the establishment of the ANSYS finite element model under different working conditions, the principal tensile stress and vertical deflection data are obtained and analysed. The final conclusion is as follows:

(1) The influence range of support void on the bridge structure is not the area size of the support, but will affect other places close to it. The void of the support has almost no effect on the main tensile stress and vertical deformation of the diaphragm in the mid-span, but it has a significant effect on the main tensile stress and vertical deflection of the diaphragm at the end of the beam.

(2) after the support is empty, the nearest diaphragm is prone to disease; the diaphragm that is close to it will also be affected, while the diaphragm that is far away will hardly be affected. This leads to uneven force on the whole structure, which ultimately affects the stability of the whole structure.

(3) the influence of the middle span support void on the main tensile stress of the diaphragm is larger than the opposite span support void. The effect of side-span bearing void on the vertical deflection of diaphragm is greater than that of mid-span bearing void.

(4) in the actual engineering, attention should be paid to the failure inspection of the void of the support to avoid the occurrence of the void of the support. Clean up the debris around the support in time and paint the support for rust prevention. Keep the support around the clean, repair or replace the support, regularly grease the support, etc.

References
[1] Yuankai Guo, Jiafei Fu. Journal of Yancheng Institute of Technology (Natural Science
[2] Shenghua Hu, Liuyu Zhang, Penghui Zhi, Shufa He, Yanfei Sun. Influence of Bearing Failure on Mechanical Performance of Continuous T-Beam Bridge. Highway Traffic Science and Technology (Application Technology Edition), 2020, 16(08):174-178.

[3] Xiaoguang Wu, Shulei He, Peng Zheng, Yue Yin, Zhiqiang Guo. Journal of Zhengzhou University (Engineering Science), 2019, 40(01):67-71.

[4] Xiaoqing Zhu, Huai Chen, Yingfeng Yu. Influence of Bearing Clearance on Mechanical Performance of Xizhangcun Bridge. Journal of Zhengzhou University (Engineering Science), 2010, 31(5):70-73.

[5] Yuanhui Jiang, Yi Cui. Finite Element Analysis of Bearing Empty of Hollow Plate Bridge and Stress Relation of Hinge Joints. Transportation World, 2017(08):67-69.

[6] Sumin Lei. Influence of Bearing Cavitation on Mechanical Performance of Multi-span Continuous Beam under Bias Loading. Railway Construction, 2018, 58(12):42-45+49.

[7] Fengqiang Hu, Jing Chen, Yibiao Xu, Xiaomao Feng. Journal of Nanchang University (Engineering Science), 2015, 37(02):123-127.

[8] Xiuping Liu, Song Wu, Shouchong Peng, Xiaoting Ding. Analysis of Influence of Bearing Empty on Static and Dynamic Characteristics of Hollow Plate. Municipal Technology, 2020, 38(04):263-265+269.

[9] Peiheng Long. Numerical Analysis Method of Cracking of Prestressed Concrete Box Girder Bridges. Tongji University, 2005.

[10] Tingxian Ke. Study on Cracking Effect of T-Beam Flange Thickness. Journal of Highway Transportation Science and Technology (Applied Technology Edition), 2015, 11(02):154-155.