Applied Research on Hinged Joint Damage Evaluation of Hollow Slab Bridge Based on Acceleration Amplitude Ratio

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Abstract. With the increase of the operating life of domestic hollow slab bridges, a large number of in-service hollow slab bridges have different degrees of joint damage. In order to conduct a qualitative and quantitative evaluation of the different degrees of bridge joint damage, this article relies on the actual engineering background and studies different The dynamic response of a bridge with a hinge joint under the load of a car was determined. The joint failure location of the joint under simulated conditions was the beam end and the mid-span, and the damage levels were 25%, 50%, and 75%, respectively. Compared with relative displacement and relative opening and closing, the hinge joint disease has a greater influence on the acceleration of the beam plate on both sides of the hinge joint, and the acceleration response is the most sensitive. Therefore, this paper proposes a method to evaluate the degree of joint damage based on the acceleration amplitude ratio of the beams on both sides of the joint, which provides a new idea for the actual project to evaluate the degree of damage to the joint hinge.

1. Introduction

In order to meet the needs of the rapid development of highway transportation infrastructure construction, China has built a large number of bridges. However, with the rapid development of China's transportation industry, the volume of traffic has increased year by year, and heavy-load traffic has frequently appeared. More and more bridges exist. Diseases, of which hinge disease is the most prominent. The hinge joint structure is a weak part of construction. Because of its small structure size, it often leads to poor concrete pouring, misplacement or misalignment of the connecting steel bars, etc., while the hinge joint or wet joint is mainly responsible for shearing, which leads to their It is easy to damage [1]~[2], so the damage of the hinge needs to be detected and maintained in time.

At present, domestic and foreign scholars have proposed many methods for the evaluation of the damage degree of hinge joints. Yu Tianlai [3] et al. Introduced the concept of joint damage degree λ and joint joint work factor δ to establish a model of the relationship between joint joint damage degree λ and joint joint work factor δ, and the joint joint damage degree λ and the joint actual resistance The Z-relation model is used to study the damage evaluation method, evaluation index, and determination
criterion for reinforcement of load capacity of prefabricated articulated slab bridges. Zhou Zhengmao [4] proposed three indexes of hinge joint stiffness, hinge joint force transmission capacity and hinge joint stiffness ratio to evaluate the damage degree of hinge joint. Abdo [5] proposed the use of changes in displacement curvature to identify structural damage, and verified by establishing numerical models of different damage conditions. The results show that the method can achieve single and multiple damage judgments.

This paper proposes a method for evaluating the degree of joint damage based on the acceleration amplitude ratio of the beams on both sides of the joint, which provides a new idea for the actual engineering evaluation of the degree of bridge joint damage.

2. Evaluation of hinge joint damage based on acceleration amplitude pair

At present, the relative simple and effective judgment indicators of hinge joint damage are relative displacement of joint hinge [6], relative opening and closing of hinge joint, and so on. Since the acceleration response of the beam and plate at the joint failure is most obvious, this paper proposes to use the acceleration amplitude ratio to evaluate, so as to judge the damage of the joint more accurately. Among them, the relative displacement refers to the vertical staggered distance of the concrete slab beams on both sides of the hinge joint, the relative opening and closing refers to the horizontal opening and closing distance of the concrete slab beams on both sides of the hinge joint, and the acceleration amplitude ratio refers to the acceleration amplitude of each plate span. The ratio of the value to the amplitude of the acceleration in the mid-span of the adjacent beam and plate.

In this paper, the #6 hinge is used as an example to simulate the two damage locations and four different damage levels to obtain the acceleration amplitude under different working conditions, such as shown in Table 1 and Figures 1-2 below.

Table 1 6# Amplitude ratio of two kinds of damage positions of hinge joint with different damage degrees

| Damage location | Beam plate position | Degree of damage |
|-----------------|---------------------|-----------------|
| Span            | 1/4 span            | 0% 25% 50% 75%  |
|                 | Mid-span            | 0.90 1.13 1.80 2.19 |
| Beam end        | 1/4 span            | 0.87 1.99 2.33 2.77 |
|                 | Mid-span            | 0.90 1.84 2.13 2.62 |

Fig.1 Amplitude ratio of beam-plate 1/4 span changes with damage

Fig.2 The amplitude amplitude ratio of the beam-span span varies with the damage
From Table 1 and Figures 1-2, it can be known that the acceleration amplitude ratio varies with the degree of hinge joint when the hinge joints are damaged, and the identification method of hinge joint damage based on the acceleration amplitude ratio changes is obtained, as shown in Table 2.

| Acceleration amplitude ratio | Joint damage | Hinge state |
|-----------------------------|--------------|-------------|
| ≤1                          | 0%           | Intact      |
| (1, 1.5]                    | (0%, 25%)    | Minor injury|
| (1.5, 2]                    | (25%, 50%)   | Moderate injury|
| (2, 2.5]                    | (50%, 75%)   | Severe injury|
| >2.5                        | >75%         | Completely destroyed|

3. Application of real bridge

3.1 Bridge Basic Information

This paper selects the Venus Middle Bridge in Huai’an section of the Beijing-Shanghai Expressway as the measured bridge. The upper structure of the Venus Middle Bridge is a 6 × 13m pre-tensioned prestressed concrete structure with a bridge width of 24m and a lane width of 3.75m. The deck is paved with asphalt concrete. The lower structure is a multi-pillar pier. The abutment adopts a pile foundation to cover the beam abutment, the foundation adopts a bored cast-in-place pile, and the support is a ball-crown plate rubber support.

The bridge hinge joint disease is mainly caused by the analysis of white seepage. Some joint joints have joints falling off, and even joints have through joints, that is, the entire joint is completely off. The test results are shown in Figure 3.

![Fig.3 Detection of hinge joint disease](image)

3.2 Detection scheme

For the evaluation of hinge joint performance degradation of highway bridges, the three key indicators of absolute displacement, relative displacement, and relative opening and closing are mainly used for detection and data collection. The monitoring and collection of relevant data needs to be obtained when the continuous traffic flow passes through the bridge deck. For the same hinge joint measurement point, at least three periods of data need to be detected and the average value is obtained, and each period lasts at least 5 minutes.

Seven hollow beam slab bridges and six hinge joints located in the middle of the horizontal direction were selected for testing. The measuring points are arranged as follows: when 7 displacement sensors are arranged in the span to detect the absolute displacement of the plate beam 6 displacement sensors are used to detect the relative displacement time history between the plates and beams, 6 displacement sensors are used to detect the relative opening and closing time history between the
plates and beams, and 6 displacement sensors are arranged in the 1/4 span of the plate beams for Check the relative opening and closing between the plate and beam. The displacement sensor is overlapped and fixed by scaffolding and AB glue. The field measurement points are shown in Figure 4.

![Figure 4](image)

(a) Measuring points for relative opening and closing of span hinges and absolute deflection of beams and plates
(b) L/4 span hinge joint relative displacement measurement point

Fig.4 Site measurement point arrangement

3.3 Application of real bridge

The detection content of the Venus bridge includes the absolute displacement of the span beam, the relative displacement of the span beam, the relative opening and closing of the span beam, and the 1/4 span relative displacement. The detection time is 30 minutes and the sampling frequency is 200 Hz. The appearance of other hinge joints was good. Select the time history curve of the dynamic response of the beam and slab when the vehicle crosses the bridge in a certain period of time. The upper bridge position of the vehicle is the carriageway, and the corresponding beam and slab are the 6 # -8 # beam and slab. The absolute displacement measured data in the span is shown in Figure 5. Furthermore, the time-history curves of the relative displacements of the mid-span and 1/4-span beams on both sides of the 6 # and 7 # hinge joints in two periods are shown in Figs. 6 and 7.

![Figure 5](image)
![Figure 6](image)
![Figure 7](image)

Fig.5 Time-history curve of absolute deflection of beam and plate
Fig.6 Time-history curve of relative displacement in span
Fig.7 Time-history curve of 1/4 span relative displacement

The appearance test results show that the # 6 hinge joint has been diseased, but the 7 # hinge joint is in good appearance. According to the absolute deflection of the beam and plate, it can be found that the absolute displacement of the 7 # plate and the 8 # plate are relatively close, and the 6 # plate and the The difference between the absolute deflection of the 7 # plate and the 8 # plate is large, which may be due to the weakening of the lateral load transmission capacity of the hinge joint after the 6 # hinge joint is diseased, and the relative displacement of the beam plates on both sides thereof is
relatively large. From Figures 5 to 7 the maximum relative displacements in each state are shown in Table 3.

| Relative displacement of # 6 hinge 1/4 span | Relative displacement of # 7 hinge 1/4 span | Relative displacement of hinge joint # 6 | Relative displacement of # 7 hinge span |
|---------------------------------------------|---------------------------------------------|----------------------------------------|----------------------------------------|
| 0.035                                       | 0                                           | 0.142                                  | 0.009                                  |
| 0.033                                       | 0                                           | 0.138                                  | 0.011                                  |

According to Table 3, it can be found that during this period, the measured relative displacement of the # 6 hinge joint span is larger than that of the 7 # hinge joint, and the relative displacement of the 7 # hinge joint span is close to 0, indicating that the 6 # hinge joint Diseases have appeared in the mid-span position, but the position of the 7th joint is better. If you observe the relative displacement of the 1/4 span of the two joints, it can be found that the 6 # joint also appears relatively out of the 1/4 span. Small relative displacement, but there is no relative displacement in the 1/4 span of # 7 hinge joint, and the hinge joint is in good condition. Combined with the time-history curve of the relative displacement of the mid-span, it can be determined that the destruction position of the # 6 hinge joint is 1/4 span to the mid-span, and the 7 # hinge joint is in a good condition, which is in line with the actual hinge joint analysis position. Anastomosis shows that the method of estimating the position of the hinge joint disease based on the relative displacement is reliable. The relative opening and closing and acceleration time history curves of the mid-span beam plate in the same period are further obtained, as shown in Figs. 8-9.

![Fig.8 Open-close time history curve](image1)

![Fig.9 Acceleration time history curve](image2)
From Figure 8, it can be found that there is almost no relative opening and closing of the beam plates on both sides of the 7th hinge joint during this period, but the relative opening and closing of the beam plates on both sides of the 6th hinge joint is relatively obvious. 7th hinge joint is in good condition without damage. According to the above analysis, it is known that the acceleration dynamic response is most sensitive when the hinge joint is broken. Analysis of Figure 9 shows that the acceleration time history of the 6th plate is greater than that of the 7th plate, but the acceleration amplitude is small, indicating that the 6th hinge joint has occurred disease, but the degree of disease is not high, it is further obtained that the amplitude ratio of the acceleration of the 6th hinge joint is 1.14, and the amplitude ratio of the acceleration of the 7th hinge joint is 0.98. According to the evaluation methods in Table 2-5 above, when the acceleration amplitude ratio is close to 1, the hinge joint is in good condition. When the acceleration amplitude ratio is [1, 1.5], the damage degree of the hinge joint is less than 25%, which is a slight damage. The damage degree of the 6th hinge joint is far less than 25%, which is a slight damage, and the condition of the 7th hinge joint is in good condition, which is consistent with the damage result judged by the relative displacement method and the actual situation.

4. Conclusion

In this paper, using ANSYS finite element simulation of the dynamic response analysis of a hollow slab bridge, it is found that as the damage degree of the hinge joint increases, the relative displacement of the hinge joint and other indicators also increase. And combined with the Venus Middle Bridge for real bridge verification, it is found that when the acceleration amplitude ratio is less than 1, the hinge joint is in good condition; when the acceleration amplitude ratio is at [1, 1.5], the damage degree of the hinge joint is less than 25%, which belongs to Minor damage; when the acceleration amplitude ratio is [1.5, 2], the damage degree of the hinge joint is between 25% and 50%, which is a medium damage; when the acceleration amplitude ratio is [2, 2.5], the hinge joint is broken. The degree is between 50% and 5%, which is a serious injury. When the acceleration amplitude ratio is greater than 2.5, the joint damage is greater than 75%, which is a complete damage. This method provides a new idea for evaluating the damage degree of bridge joints in practical engineering.

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