Damage assessment and reinforcement measures of prestress concrete bridge after fire

Dai Li¹,², Wu Jianqiang¹, Mao Lin¹

¹ Jiangxi Transportation Institute, Nanchang China
² Research and Development Center on Technologies and Equipment of Long-span Bridge Construction Ministry of Transport, PRC, China Jiangxi Nanchang

Corresponding author:dlwhut2012@163.com

Abstract: In order to provide reasonable advice for the maintenance and reinforcement of Bridges after fire, it is necessary to assess the damage of Bridges after fire. In this paper, the damage area of a fire-damaged concrete highway bridge is divided according to the concrete apparent detection, and the damage degree of different parts is determined. Carbonization depth and springback detection were used to determine the area and depth affected by fire. Based on the analysis of the surface fire temperature of components in different areas and the internal temperature of concrete, the degradation of the mechanical properties of concrete and steel bars is further deduced, and the damage assessment of the bridge performance is finally carried out.

1. Introduction

With the rapid development of China's traffic construction in recent years, the number of fire accidents on bridges, under Bridges or in bridge accessories is increasing. When the fire occurs on the bridge structure or structure accessories, it will cause different degrees of damage to each component of the bridge structure, weaken the carrying capacity of the structure, and seriously affect the traffic safety. Therefore, how to evaluate the carrying capacity of bridges after fire and provide a reliable theoretical basis for bridge maintenance and reinforcement is very important. After the bridge structure is affected by fire, the mechanical properties of steel and concrete are changed greatly due to the physical and chemical changes, and the structural members are damaged. From the perspective of the whole structure, the deformation of the structure increases and the carrying capacity decreases under fire, which is closely related to many factors such as the fire range, temperature, duration and heating process. In case of serious fire, the structure may lose efficacy and even collapse.

This paper takes a fire bridge as an example. Combined with the actual situation on site, the finite element model of the bridge structure after fire is established and analyzed by using the existing detection technology. At last, the dynamic and static load test was conducted in order to provide technical support for the maintenance and reinforcement of bridge maintenance agency.

2. General situation

The main bridge is concrete-filled steel tube tie arch, with a length of 3800m, a width of 30m and six lanes in both directions. The bridge was opened to traffic in 2008. The east and west bank approach bridges are all in the form of overpasses, using 30m span prestressed concrete continuous box girder, beam height of 1.8m, using an 8-span link. The width of continuous beam bridge surface is 30m, the single main beam adopts a single box four-chamber section, the lower member pier adopts V-shaped
pier, the foundation is 4 bored piles of 1.2m diameter with a thickness of 2.0m bearing caps, the box girder concrete adopts C50 concrete.

On the early morning of September 20, 2014, a fire broke out in a central parking lot for scrapped buses under the bridge. The fire has caused a large area of concrete spalling of 30m prestressed concrete continuous box girder in the west bank approach bridge, the steel bar is exposed, and the partial prestressed steel bellows are exposed. The damage condition of the bridge is shown in Figure 1.

3. Field detection after fire

3.1. Detect content

Through the inspection of the appearance of the continuous box girder of burned bridge span and adjacent bridge span, and combined with the special inspection results, the damage of the continuous box girder was evaluated, and the impact of fire on the bearing capacity of the bridge structure was analyzed. The main contents of the inspection are as follows.

3.1.1. Appearance test. Determine the fire process and the appearance of the bridge (concrete peeling, cracks, color change, burning and thinning thickness, exposed steel)

3.1.2. Concrete strength test. Ultrasonic rebound method was used to estimate the decline area of concrete strength caused by fire, and the fire site was divided into concrete peeling area, obviously smoked area, slightly smoked area, and no obvious smoked area.

3.1.3. Concrete color and hardness test. For the burned part, first polish off the smoke material attached to the surface layer, then observe the change of color of the concrete surface, use hammer strike method to hit the surface of the member, observe the concrete peeling, record the knocking sound.

3.1.4. Concrete surface damage layer detection. Ultrasonic wave was used to detect the surface damage of concrete, and verify the thickness of the damage layer.

3.1.5. Carbonization depth detection. Fire will cause free alkali thermal decomposition in concrete and neutralize concrete. The closer to the fire area, the deeper the carbonation is. Phenolphthalein is used to measure the carbonation depth of concrete and determine the declining area of concrete quality.

3.2. Results and analysis

3.2.1. Damage condition. According to the test, the damage of some damaged span girder in the fire section is serious, and the large area of the concrete protective layer of box girder wing plate and web is peeled off (the maximum peeling thickness is about 6cm), damaged and large area of exposed ribs. The bonding force of main reinforcement and concrete is seriously damaged, which leads to the severe damage of structural bearing capacity. Seven prestressed corrugated pipes are exposed in the bottom plate of the box girder at the middle span, and the length of the exposed section is 2~8m.
3.2.2. Damage condition of support and pier. In the process of testing, it was found that after years of service, the steel members of the pier top support all had corrosion phenomenon, among which the fire section of the pier top support was affected by the high temperature of fire, the local rust layer peeled off, and the anti-rust paint of the support was burned out. According to the measured results, the measured height of the fire section pier top support is 3–5mm lower than the designed value. The support will accelerate the aging after being baked at high temperature. Therefore, the pier basin rubber support affected by the fire should be replaced as soon as possible. A large area of the concrete protective layer of pier and column in the fire section peeled off, and the peeling thickness was about 6cm. The concrete was loose after the pier and column were burned.

3.2.3. Concrete strength, carbonation depth detection. A large number of experimental studies at home and abroad show that the strength of concrete decreases gradually with the increase of temperature under elevated temperature. The concrete strength at the bottom of the main beam of a fire section (combining the rebound method and the drilling core method) is shown in Table 1. The results show that there is no abnormal phenomenon in the carbonation depth of the concrete strength measurement area of the fire section.

| Position of test section from initial pier (m) | 5  | 10 | 15 | 20 | 25 |
|---------------------------------------------|----|----|----|----|----|
| Reduction coefficient                       | 0.97 | 0.92 | 0.88 | 0.93 | 0.96 |

3.2.4. Reinforcement performance test. The prestressed concrete continuous box girder is prone to burst in the process of fire, and the spalling surface of concrete becomes the fire surface after the burst, which leads to the change of the temperature field of concrete. As for the exposed section of local bellows of the main girder bottom plate, the bellows are burned by fire directly after the concrete bursts, which makes the steel strand temperature inside the bellows rise, thus causing a large loss of prestress.

4. Damage assessment method

4.1. Effect coefficient method based on frequency

There are many methods of bridge structure evaluation, and the static and dynamic methods are mainly used to collect data through field tests. The static method is mainly load test method. The dynamic method mainly includes the dynamic coefficient method and the frequency-based calibration coefficient method. The load test method and the dynamic coefficient method both need to be used to test the bridge by heavy vehicle, the new bridge assessment is often used, which may not be applicable to the damaged bridge. The frequency-based calibration coefficient method is a dynamic test of the structure of the bridge under the natural pulsation (no forced vibration sources such as heavy vehicles are needed).

Since both deflection and frequency can be expressed as functions of structural stiffness, the relationship between deflection calibration coefficient and frequency calibration coefficient can be established through stiffness conversion. The frequency is the overall structure of the property, while reflect the deflection control deformation of the cross section, in order to unify the comparison, in the most unfavorable deflection coefficient of calibration parameters, establish a frequency calibration coefficient and the relationship between the deflection of calibration coefficient, which leads to the differences between the measured results and the theoretical results, and the structural deflection corresponding to the static stiffness of the structure, and the frequency corresponding to the dynamic stiffness of the structure.

Relevant literature research shows that there is a difference between the dynamic stiffness and the static stiffness of the structure, which leads to the difference between the theoretical frequency
calibration coefficient and the measured frequency calibration coefficient. In order to eliminate the influence of above factors on the frequency of calibration coefficient and 152 Bridges in the actual project (mainly for simply supported beam bridge and continuous girder bridge) as the sample space, the analysis of the measured data, and compared with the theoretical calculation, the deflection of calibration coefficient and frequency calibration coefficient, the regression analysis to establish the relationship between the deflection coefficient of calibration coefficient and frequency formula as follows

\[ \eta_\omega = 0.9982\eta_\phi^{0.5244} \]  

(1)

Using the regression formula (1), the corresponding values of the frequency calibration coefficients were obtained according to the deflection calibration coefficients 1.00, 1.05, 1.10, 1.15 and 1.20, as shown in Table 2.

Table 2. The Relationship between frequency and deflection check coefficient

| Rating scale | 1  | 2  | 3  | 4  | 5  |
|--------------|----|----|----|----|----|
| Deflection check coefficient \( \eta_f \) | 1.00 | 1.05 | 1.10 | 1.20 | 1.50 |
| Frequency check coefficient \( \eta_\omega \) | 0.998 | 0.973 | 0.950 | 0.907 | 0.807 |

According to the deflection check coefficient and frequency check coefficient, the damage degree of the bridge is defined in Table 3, which is divided into six grades.

Table 3. The damage degree of the bridge (divided into 6 grades)

| Rating scale | Deflection check coefficient \( \eta_f \) | Frequency check coefficient \( \eta_\omega \) | Status |
|--------------|-------------------------------------|-------------------------------------|--------|
| 1            | <1.00                               | >0.998                              | Intact condition |
| 2            | [1.00,1.05)                         | (0.973,0.998)                       | Minor damage, no maintenance required |
| 3            | [1.05,1.10)                         | (0.950,0.973)                       | Regular maintenance and minor repairs |
| 4            | [1.10,1.20)                         | (0.907,0.950)                       | Medium repairs |
| 5            | [1.20,1.50)                         | (0.807,0.907)                       | Comprehensive repair |
| 6            | \( \geq 1.50 \)                     | \( \leq 0.807 \)                    | Out of run |

4.2. Dynamic load test

Under the condition that there is no traffic load on the bridge deck and no regular vibration source near the bridge, the micro-vibration response of bridge span structure caused by random load excitation such as wind load, ground fluctuation and water flow at the bridge site is measured. The vibration acceleration of measuring points across the bridge structure is mainly recorded in the pulse test, and vertical vibration sensors are arranged in the test span.

In order to reduce the external interference to the surrounding environment of the bridge, all traffic, including pedestrians, was interrupted during the pulsating experiment.

Table 4 Dynamic load test results
5. Main damage forms and repair measures

5.1. Main damage forms
After the damage detection and analysis of the bridge structure after fire, the following main damage forms can be obtained. (1) The surface concrete bursts off, even the steel bar is exposed, the bottom of the beam is easy to appear tensile crack, the section loss is large, the bending stiffness decreases; (2) The elastic modulus of reinforcement decreases, the bonding force between reinforcement and concrete decreases, and the prestress loss is large; (3) The durability and bearing capacity of the structure are obviously reduced; (4) There are different degrees of corrosion in steel members of basin support.

5.2. Repair measures
The fundamental principles of post-fire reinforcement of bridges is the safety coefficient of the structure should not be reduced, the durability of the structure should be strengthened, and the appearance should be flat and beautiful. According to the actual situation of on-site inspection, the following reinforcement measures shall be formulated.

It is necessary to ensure that the reinforcement measures can work with the original structure in the design of repair and reinforcement. Cut off the burned concrete completely before maintenance and reinforcement so as not to affect the reinforcement effect. The complexity of the factors affecting the effective prestress loss of the internal prestress of the fire section beam should be fully considered, and the comprehensive maintenance and reinforcement scheme should be determined to prevent excessive reinforcement.

6. Conclusion
The method based on frequency calibration coefficient can be used to quickly test and evaluate the status of bridges under no traffic load or light load test. This method will not increase the damage of bridges and is very suitable for the rapid detection and evaluation of damaged bridges such as fire. After the fire, the bridge damage is usually in the form of surface concrete burst and loss of prestress, which leads to a significant reduction in the durability and bearing capacity of the structure.

In the design of repair and reinforcement, it is necessary to ensure that the reinforcement measures can work in coordination with the original structure as far as possible, which is mainly to completely cut out the burned concrete. The damaged structure should be strengthened in time to prevent further deterioration of the structure. In the future, the research on the technology of repairing damaged Bridges after fire should be further strengthened.

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