Fire damaged box girder inspection and assessment and strengthening treatment

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Abstract. Based on a fire accident in a bridge of the Jinan-Qingdao high-speed railway, the preliminary damage assessment of the box girder was conducted through surface inspection, concrete strength testing, concrete carbonation depth testing and reinforcement protective layer thickness testing methods. Then a corresponding numerical model of the fire damaged box girder was created by the Midas software, and the heat transfer analysis and thermal stress analysis were carried out. The results showed that the fire damaged level of the box girder were Grade II (moderate damage). Finally, the corresponding reinforcement measures were recommended.

1. INTRODUCTION
A railway bridge undergoing a fire accident may suffer a certain damage. A structural safety inspection is necessary to access the damage and design the reinforcement. In this paper, a box girder bridge suffering a fire was taken to study the fire damage mechanism, prestress loss rate of prestressing tendons, and reinforcement measures.

Project Overview: The bridge is the Weifang Special Section (hereinafter referred to as: Weifang Special Bridge) in the Jinan-Qingdao high-speed railroad. The bridge was not yet in operation at the time of the fire. The bridge deck girders are prefabricated simply-supported box girders (see Figure 1 for the cross-sectional dimensions of the girders). The bridge girders are made of C50 grade concrete with prestressing system: 1×7-15.2-1860-GB/T5224-2003 prestressing strands are used (see Figure 2 for the arrangement of prestressing tendons in the girders).

The condition of the damaged box girder after the disaster: the thin quilt used to cover the shed caught fire on the ground under the box girder on the Jinan side of the bridge, and the fire lasted up to 30 minutes. The original headroom under the bridge was 4.95m, the length of the fire pile was about 4m, the width was about 5m, the height was about 1.2m, the actual headroom of the bottom of the beam from the fire was about 3.75m; the ignition height of the fire was about 2m from the bottom of the beam. The atmospheric ambient temperature at the time of the fire was about 15°C. The fire caused damage to the pier body of the Qingdao direction side of pier 647# and the Jinan direction end of girder 648#, resulting in the concrete protective layer falling off.
Detection of box beam damage after fire

2.1. Fire damage area division
According to the residue of the burning site and the spalling and loosening of concrete, it can be determined that the box girder directly below the Qingdao direction at pier 647# is the center of this fire, near pier 647#, and the area of combustible material accumulation is about 4m×5m.

Detection, according to the appearance of the bridge concrete, initially divided 647# beam, 648# beam span into three zones, I zone, III zone for the intact area (members only subject to obvious smoke); II zone for the damage area (fire members concrete spalling or cracking), divided into 648# beam low temperature zone, medium temperature zone, suspected high temperature zone (this is to consider the appearance of damage in line with the characteristics of high temperature zone, but other characteristics do not match, in view of rescue high-pressure water measures may also cause concrete spalling in the medium temperature zone, so tentative), 647# beam medium temperature zone. Facing Qingdao direction, the left side is the left side and the right side is the right side. For details, see Table 1.

2.2. Bridge damage inspection content and results

2.2.1. Apparent damage examination and results
The following results were obtained in conjunction with a survey of the relevant information and cosmetic inspection of the bridge.

a) 647# pier pier Qingdao direction side of the fire affected area, due to the impact of the fire pier surface concrete spalling, concrete spalling depth in the range of 2-7.5cm, and produce reticulation cracks; Qingdao direction side of the left and right bearing pad stone full section of reticulation cracks, crack width in 0.3-0.6mm, depth in 49-110mm, accompanied by concrete bulging phenomenon; bridge pier The concrete spalling volume is about 0.233m³ and the total weight is about 0.58t.

b) Within the fire-affected area of box girder zone II, some concrete spalling occurred in the medium temperature zone at both ends due to the fire, with the spalling depth of concrete around 20-30mm; large area of concrete spalling and exposed reinforcement occurred in the high temperature zone, with the spalling depth in the range of 40-90mm, and large area of web cracking damage occurred in the fire.
damaged area of the girder web; the volume of spalling of the girder was about 2.17m³, excluding the calculated reinforcement volume. The spalled volume of the beam was approximately 2.17m³, excluding the calculated reinforcement volume of 0.03m³, the total volume of spalled concrete was approximately 2.14m³, with a total weight of approximately 5.35 tonnes.

2.2.2. Concrete strength and carbonation depth testing

In testing the strength of box girder concrete, the rebound method[3] is used, which is a surface hardness method. For the detection of the depth and area of carbonation of box girder concrete, the phenolphthalein reagent test method is used in this paper[4].

| Series | Component name | Design strength | Carbonation depth(mm) | Presumptive strength value(Mpa) | Carbonation depth ratio | Strength Min.(Mpa) |
|--------|----------------|-----------------|-----------------------|-------------------------------|------------------------|-------------------|
| 1      | 648# beam bottom plate mid-temperature zone | C50 | 0.0 | 57.4 | / | 57.4 |
| 2      | Suspected high temperature zone at the bottom plate of beam 648# | C50 | 0.0 | 54.9 | / | 54.9 |
| 3      | 648# beam web suspected of high temperature area | C50 | 0.0 | 56.7 | / | 56.7 |

| Series | Component name | Reinforcing Steel Type | Average value(mm) | Design value(mm) | (Average value - Design value)/mm |
|--------|----------------|------------------------|-------------------|-----------------|----------------------------------|
| 1      | 648# beam bottom plate mid-temperature zone | Transverse reinforcement | 36 | 35 | +1 |
| 2      | Pier 647# pier body | Transverse reinforcement | 45 | 45 | 0 |
| 3      | Pier 647# pier bearing pad stone | Vertical reinforcement | 43 | 42 | +1 |

The concrete spalling situation is most serious at the bottom of the beam and web slab zone II in the mid-temperature zone and around the suspected high-temperature zone fire damage area to level the concrete strength for testing. The test results are shown in Table 1.

The presumed concrete strengths of the piers and bearing pads in this example are greater than the concrete strength design values and are comparable to the concrete strength of the intact piers, with no significant change in the depth of concrete carbonation in the fire damaged areas. The presumed strength of the concrete in the fire-damaged area of the bridge main girder underslab was greater than the design concrete strength, the fire did not cause any reduction in the strength of the bridge concrete and the depth of carbonation was not significant.
2.2.3. Methods for testing the protective layer thickness of reinforcing steel
The protective layer thickness of the reinforcement was tested using the electromagnetic induction method [5]. The results are shown in Table 2.

The protective layer of reinforcement in the pier and support stones of the bridge pier is comparable to the design value. The thickness of the protective layer of reinforcement in the unspalled area of the main girder is comparable to the design value, and the remaining thickness of the protective layer of concrete in the spalled area plus the spalled depth of concrete is comparable to the thickness of the protective layer of reinforcement in the intact area.

3. Finite element analysis of fire-damaged beams

3.1. Calculation of temperature field of box girder section

3.1.1. Build finite element calculation model
The model was built using Midas Fea, in which the cross-sectional dimensions of the box girder were the same as those of the actual project box girder. At the same time, the prestressing bars were set up in the model according to the design drawings, and the corresponding prestressing force was applied to each of the prestressing bars according to the design drawings. As the pier and the box girder are connected by means of supports in a form that is difficult to express in the finite element model, and the damage caused by the fire to the pier during the inspection process does not have much impact on the bridge as a whole, the pier entity is not reflected in the finite element model studied in this paper.

3.1.2. Beam finite element model temperature analysis

3.1.2.1. Box girder bottom plate temperature transfer
In this project example, the box beam extended fire duration is 30min, after the analysis of the model studied in this paper, the temperature transfer result graph of the bottom of the beam with extended fire time of 0.5h and the temperature graph of the top surface of the bottom plate under each extended fire time node are obtained.

It is evident from Figure 4 that the maximum temperature at 30min of fire delay, i.e. 0.5h, is 486.80°C and the minimum temperature is the model default initial temperature of 20°C. By heat transfer the temperature at the bottom of the box girder bottom plate is transferred to the top of the bottom plate at 398.46°C. As can be seen from Figure 5, the temperature rise graph of the top surface of the box girder base plate with extended fire time is not the same as the ISO834 standard temperature rise curve development law, which shows that the fire-induced temperature transfer gradient is not linear and fixed, the total thickness of the base plate 0.7m, with the thickness rising from the bottom to the top surface of the base plate, the transfer temperature gradient is not the same.
3.1.2.2. Analysis of prestress loss values

The 27 prestressing tendons in one span box girder were analyzed for prestress loss rate after fire. Since the box girder is symmetrical, the remaining 26 prestressing tendons except N1a were symmetrically divided into the bottom reinforcement and the lateral reinforcement between the two webs of the girder for stress loss rate analysis, and the bottom reinforcement loss rate is shown in Table 3. According to the example of the project, the stress loss rate of N1a prestressing reinforcement is 8.95% at 30 min of extended fire time.

### Table 3  Stress loss rate of box girder bottom plate prestressing reinforcement under 500℃ working condition with the growth of extended fire time

| Extended fire time | Loss rate of prestressing tendons in bottom slab (%) | N1a | N1b | N2a | N2b | N2c | N2d |
|-------------------|----------------------------------------------------|-----|-----|-----|-----|-----|-----|
| 0.1               | 2.26 2.32 1.85 2.29 2.68 2.02                     |     |     |     |     |     |     |
| 0.2               | 4.36 4.40 3.45 4.24 4.95 3.99                     |     |     |     |     |     |     |
| 0.3               | 6.15 6.16 4.77 5.84 6.83 5.69                     |     |     |     |     |     |     |
| 0.4               | 7.69 7.65 5.88 7.17 8.38 7.13                     |     |     |     |     |     |     |
| 0.5               | 8.95 8.89 6.83 8.30 9.71 8.32                     |     |     |     |     |     |     |

The stresses are as shown in the table, the nine prestressing bars located in the bottom plate of the box beam have a higher rate of prestress loss at 30 min of extended fire than the prestressing bars on both sides of the box beam. From this, it can be seen that the thickness of the protective layer of prestressing tendons has a greater influence on the performance of prestressing tendons after fire. The thicker the protective layer thickness is, the smaller the prestress loss is.

### Table 4  Stress loss rate of prestressing steel bars on both sides of box girder under 500℃ working condition with the growth of extended fire time

| Extended fire time | Loss rate of prestressing tendons on both sides of box girder (%) | N3  | N4  | N5  | N6  | N7  | N8  | N9  | N10 |
|-------------------|---------------------------------------------------------------|-----|-----|-----|-----|-----|-----|-----|-----|
| 0.1               | 0.53 0.52 0.20 0.17 0.03 0.04 0.00 0.00                      |     |     |     |     |     |     |     |     |
| 0.2               | 1.38 1.29 0.68 0.53 0.21 0.20 0.09 0.06                      |     |     |     |     |     |     |     |     |
| 0.3               | 2.23 2.07 1.28 0.97 0.49 0.45 0.27 0.18                      |     |     |     |     |     |     |     |     |
| 0.4               | 3.00 2.78 1.89 1.43 0.80 0.72 0.49 0.35                      |     |     |     |     |     |     |     |     |
| 0.5               | 3.72 3.44 2.49 1.87 1.13 1.01 0.75 0.55                      |     |     |     |     |     |     |     |     |

4. Bridge Strengthening Recommendations

According to the test evaluation and finite element analysis, the damage caused by the fire of 648# girder and 647# pier of Weifang Special Bridge of Jinan-Qingdao Railway is mainly concrete spalling, exposed tendons, loose concrete in the fire area, apparent network cracking, slight prestressing and loss of stiffness, loss of anti-cracking bearing capacity, in which the fire damage of the main girder is level 2 (moderate damage), which has a large repair value and can be repaired by corresponding technical means. The recommendations are as follows:

- Epoxy mortar is used to seal the surface of the bottom plate and web cracking area in the low-temperature zone.
- Removal of loose concrete from the bottom surface of the base slab in the fire damage and high
temperature zone, and application of high elastic concrete repair above the beam grade.

- Considering the effect of fire on the prestressing damage of the girders, in order to ensure the stiffness of the bridge and prevent the corner of the girders from exceeding the standard, it is recommended to make the corresponding prestressing compensation outside the body appropriately.
- Considering that the beam reinforcement in the fire damaged area is affected by quenching, and at the same time to prevent cracking of the repair mortar at the bottom of the beam, carbon fiber is pasted to the repair area.

5. Conclusions

From the analysis, it can be seen that the box bridge 648# girders and 647# piers in this fire, the main defects are concrete spalling, exposed tendons, loose concrete in the fire area, apparent network cracking, slight prestressing and loss of stiffness, loss of cracking resistance bearing capacity, the overall use performance is not much reduced. The corresponding reinforcement of fire damaged areas can maintain the serviceability of the structure.

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