Bolt connection performance post fire in steel bridges

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Abstract. Fire events reduce the strength of the steel structure on the bridge and can cause collapse which results in losses, so it is necessary to consider the effects of fire when planning construction. Considering that the joints affect the performance of steel structures, the results of research on the performance of steel beams need to be augmented by testing the post-fire girder bridge bolt connection performance. Structural tests will be carried out on six specimens of bridge steel beam elements with high quality bolt connections in the center of the beam with sliding type bolt connections. Two control specimen beams were tested with shear loads without combustion. Two specimens with temperature of 700°C and 900°C with different torque bond variables. From the displacement control test using UTM on six specimens, it will be known the performance of each type of connection by evaluating changes in carrying capacity, stiffness, deflection capacity, ductility, and stress-strain capacity due to the influence of temperature acting during the fire process. The results can prove which type of bolt connection is better for use on bridges with fire risk.

1. Introduction

Fire can cause collapse or severe damage to steel bridges with reinforced concrete floors. In the event of damage that is not too severe, the effect of fire cannot be calculated with certainty. Publication and research on the resistance of bridge structure elements to fire are also still very limited. When compared with steel building structures, the behavior of steel girders on bridges to fire is very different from steel beams in buildings related to the nature of fire, structural geometry, and cross-sectional characteristics so that the results of research on buildings cannot be applied directly to bridge girder [1]. The compressive force due to a collision of an oil tank truck on a steel frame bridge element causes a fire with high temperature and cannot withstand the work load [2]. The experimental results above are in line with the results of numerical tests which prove that at temperatures of 600°C the stiffness and flexural capacity of beams have decreased very significantly [3]. High temperatures also reduce the stress-strain relationship of steel material [4]. Experimental investigations have shown that the fundamental behavior and strength of steel bars depend mostly on the surface temperature of the steel [5]. The collapse of the steel profile due to fire in the middle span is faster than on the edge of the span [6]. The strength degradation of steel-concrete composite beams is affected by temperature and combustion time, whereas the temperature increases, the steel-concrete composite beam will experience a decrease in ductility factor which causes the ability of the beam to accept the load is also getting smaller [7]. The bolts that are given a proof load are still in the elastic tension range, so the elongation bolt lengthening that occurs is relatively small. If the initial tensile force exceeds the proof load, the bolt stress that occurs is in a plastic condition and approaches 90% of the tensile strength of the bolt. Such stress conditions are considered quite dangerous [8]. At these temperatures the maximum stress that can
be achieved is far below the melting stress of the material [9]. However, there is still very little research on the performance of post-fire steel structure joints. Therefore, research on the performance of steel structure trays really needs to be investigated to support the results of post-fire steel beam performance and alternative of performance handling. From the test, it will be known the performance of each connection type by evaluating changes in carrying capacity, stiffness, deflection capacity, ductility, and stress-strain capacity due to the influence of temperature acting during the fire process. The test results can prove the type of bolt connection is better for use on bridges with the risk of fire.

2. Research methods

The outline of this study discusses three types of testing, namely test materials to determine the properties of steel materials, testing specimens to determine changes in steel characteristics, and testing the structure of steel connections to get support for the joints. The specimen model of the structural test will be carried out on specimens consisting of the girder model extending the bridge IWF.150.75.5.7 with bolt connections placed in the center of the girder span shown in Figure 1. The type of bolt used is in accordance with the type of bolt provided by ASTM namely A325 with diameter Ø 1/2 in bolt. A325 bolts are made of medium carbon steel with melting strength (yield strength) from 560 to 630 MPa [10] and the type of plate used is steel plate (BJ37) with 12mm of thick. The details of the beam specimen connection plan are shown in Figure 2. The steel beam specimen consists of six steel beam specimens with a sliding bolt connection (SS type).

The research steps to be carried out are tensile testing of steel profile materials with specimens according to ASTM E8 / E8-09 standards, each of which is in accordance in Table 1. Then burning two steel beam specimens at a temperature of 700°C (SS / 700), with one specimen with a snug-tight bond and given initial load (proof load). Burning two steel beam specimens at a temperature of 900°C (SS / 900), one specimen with a snug-tight bond and with a force that is given a prelude (proof load). Test the structure with UTM on two control specimens that are not burned with one specimen with a bolt connection fitted (snug-tight) and equipped with an initial tensile force (proof load) (SS / 020) and four specimens’ post-installation. From this experimental study, we can test the decline in specimens by using the results of tests on control specimens (SS / 020). Differences in the maintenance of each beam specimen related to the combustion process are shown in Table 1.

### Table 1. Specimen type and combustion.

| Code          | Temperature (°C) | Duration (Minute) |
|---------------|------------------|-------------------|
| SS/020 (snug-tight) | Room             | -                 |
| SS/020 (proof load) | Room             | -                 |
| SS/700 (snug-tight) | 700              | 120               |
| SS/700 (proof load) | 700              | 120               |
| SS/900 (snug-tight) | 900              | 120               |
| SS/900 (proof load) | 900              | 120               |

Figure 1. Illustration of test objects.
3. Results and discussion

3.1. Tensile test
The results of tensile testing of materials to determine material properties are shown in the following table 2:

| Code with Temperature | Maximum Load (kgf) | Yield Strength (N/mm$^2$) | Tensile strength (N/mm$^2$) |
|-----------------------|--------------------|----------------------------|-----------------------------|
| KT/T5 - 020 IWF       | 8,850              | 358.99                     | 432.26                      |
| KT/T12 - 020 Plat     | 8,350              | 271.46                     | 326.14                      |
| KT/T5 - 700 IWF       | 6,750              | 255.36                     | 319.20                      |
| KT/T12 - 700 Plat     | 7,300              | 250.09                     | 292.11                      |
| KT/T5 - 900 IWF       | 5,839              | 224.46                     | 280.57                      |
| KT/T12 - 900 Plat     | 6,570              | 222.36                     | 259.72                      |

Tensile test results prove that the strength of steel that has been burned to decrease due to high temperature factors.

3.2. Flexural test
The results of the Load and Deflection Relationship flexural testing of control specimens are shown in Figure 3.

![Figure 3. Graph of load-deflection relationship control specimen.](image)
Specimens with a snug-tight bond undergo melting point at a load of 7.6 Tons with the resulting deflection of 187mm. That is because the IWF body plate is in direct contact with the bolt. Unlike the case with bolt ties that are given an initial pull (proof load) which results in critical shear on the plate, this results in added strength / transfer strength to the performance of the IWF profile so that it can withstand loads up to 8.3 tons with a 250mm deflection.

Both specimens were burned at a temperature of 700°C and then cooled to room temperature and then carried out flexural testing so that the tests showed different performance from control specimens where the effect of temperature resulted in decreased performance on steel and reduced shear force from proof load. The P-Delta relationship is shown in Figure 4.

![Figure 4](image.png)

**Figure 4.** Graph of load-deflection relationship post fire specimen at 700°C.

Specimens that have been incinerated occur significant deflection and the performance of the specimen withstood a reduced load due to the initial temperature giving up to 700°C. Specimens with a snug-tight bond underwent a melting point at a load of 7.09 tons with the resulting deflection of 228.5 mm, while specimens with a proof load bond experienced a melting load of 7.36 tons with a deflection of 226 mm. The performance of the two types of joints is almost the same in the displacement relationship and there is a reduction in shear forces between the plates due to the influence of the temperature applied to the proof-load bond specimen.

Followed by specimens that were burned at 900°C and cooled to room temperature. After the specimen is at room temperature then flexural testing is performed. There was a significant decrease in the performance of the connection due to the influence of high temperatures where there was a decrease in the performance of the critical slip in the proof load connection and the two specimens of different types almost had the same strength as that given at 700°C. The P-Delta relationship is shown in Figure 5.

![Figure 5](image.png)

**Figure 5.** Graph of load-deflection relationship specimens post fire at 900°C.
Specimens with a snug-tight bond undergo a melting point at a load of 6.69 tons with the resulting deflection of 223.75 mm, while the specimen with a proof load bond melts at a load of 7.06 tons with a deflection of 210.35 mm.

3.3. Discussion of test results

The recapitulation of the load and deflection relationship with the six specimens is shown in the following figure 6:

![Figure 6](image)

**Figure 6.** Graph of load-deflection relationship of all specimens.

From the flexural testing chart, the performance of control specimens with snug-tight bolt bonding (SS020 Snug-tight) with a maximum load of 7.49 tons and deflection of 188.15 mm. While the control specimen with initial pulling on the bolt (SS020 proof load) obtained a maximum load of 8.33 tons with deflection of 203.6 mm. After combustion at a temperature of 700°C, the performance of the SS700 proof load specimen decreased significantly by 12% with a maximum load of 7.36 tons and deflection of 226 mm. Then it was proven again the specimen testing with combustion temperature 900°C. This proves the strength of the critical slip decreases significantly when given high temperatures.

Control Specimen Beam proves the difference in bolt connection performance between snug tight and with Proof Load where the connection condition with initial pull is stronger because the connection undergoes critical slip so that the stiffness in the joint increases stronger compared to the snug tight specimen condition where the pure bolt holds the slide on the plate continued. The performance of the specimen after burning has decreased significantly. However, experimental results prove the connection performance with a proof load bond is stronger than the snug-tight bond. Tensile material test results prove that the decrease in strength of steel material as shown in table 2 where all steel material that has been burned has decreased strength.

4. Conclusion

Based on the results of the study and data analysis conclusions can be drawn as follows:

- The pre-fire joint performance given the initial tensile strength of the bolts is better due to increased strength due to critical slip compared to bolt joints which are only tightened with fitting conditions which only hold direct shear on the plate.
- It has been demonstrated in experimental testing that performance bolt connection after a fire at 700°C decreased performance and the connection of both types have similar performance. This is also evidenced by flexural testing after 900°C combustion where the performance of the two types of connections has similarities.
- There was a significant decrease in critical slip performance from the initial tensile strength given to the post-fire bolts due to the influence of high temperatures of 700°C and 900°C.
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