Influence of post-earthquake fireproof coating damage on structural behaviour of steel-to-concrete post-installed joint

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Abstract. In order to study the influence of fireproof coating damage after earthquake on the behaviour of post-installed joint at high temperature, the numerical analysis method is adopted to simulate the post-earthquake fire performance of post-installed joint under the action of high temperature. Two parameters are considered in this study, and the high temperature performance and thermal-mechanical coupling performance of model with damage thickness of 5 mm-40 mm and damage length of 100 mm-600 mm are analysed respectively. By observing the temperature change of damage at different positions and the performance of fireproof coating with different damage under the action of temperature field, the temperature of bonded-in rebar is obtained. Finally, the influence of damage length and thickness of damage to the performance of post-installed connection is explored.

1. Introduction
Earthquake often leads to secondary fire. The insufficient bond between fire-proof coating and post-installed joint will cause the deformation and lead to the fireproof coating cracking or spalling under the action of earthquake. If the earthquake-induced fire occurs at the same time, the damage of coating will inevitably affect the fire resistance of post-installed joints. Therefore, it is of great significance to study the effect of fire resistance coating damage on the behaviour of steel-concrete post-installed joint.

Aaron J has studied the mechanical behaviour of shear components under high temperature and static force by 3D finite element model, and the geometric nonlinearity was considered[1]. Ozbolt J analysed the mechanical behaviour of anchor bolt under fire by 3D finite element method[2]. Chiang C H studied time-history bond strength of steel bar after high temperature[3]. Li S M studied the pull-out capacity and failure modes of members with different diameter of reinforcement and depth of bonded-in rebar, the relationship between the depth of steel bars, the diameter of steel bars and the bearing capacity of drawing has been investigated[4]. Zou Y draws a conclusion by studied the ultimate bearing capacity of bonded-in rebar connection members under fire that the thickness of fireproof coating and the embedded depth will have a great influence on the bearing capacity of structural member under the action of fire[5]. Lu Z D studied the fire resistance of steel connections under fire. It was found that the thickness of fireproof coating and the embedment depth have great influence on the bearing capacity of members under fire[6]. He also studied the mechanical properties that steel bar specimens under fire and come to a conclusion of high temperature has a great influence.
on ultimate bearing capacity[7]. Studied on the relationship between ultimate bearing capacity and fire time of steel bar specimens under fire by Liu C Q, the ultimate bearing capacity of specimens decreased linearly with the increase of fire time. When the fire time exceeds 45 minutes, the ultimate bearing capacity of specimens for 15 days and 20 days after fire has same reduction[8]. In order to study the fire-resistance limit of bonded-in rebar, Liu C Q has carried out the fire-resistance limit test of six bonded-in rebar test specimens under ISO834 standard curve. It was concluded that the fire-resistance limit of reinforcement member was related to the thickness of fireproof coating. With the thickness increase of fireproof coating, the fire-resistance limit of reinforcement member would grow[9]. The variation of tensile capacity of chemical anchorage connection under high and normal temperature with temperature, time and fire cooling was compared. [10]. Eligehausen R has studied the effect of temperature on bond property and the relationship curve has been obtained[11].

Currently, there is little research on the damage of fireproof coating of steel-to-concrete post-installed joint. The main purpose of this paper is to understand the influence of damage of fireproof coating after earthquake on post-installed joint.

2. Simulation of damage of fireproof coating

2.1. Model design

In order to study the effect of post-earthquake fire coating damage on fire resistance of joint, two-type steel-to-concrete post-installed joint models are established according to different influencing factors. ISO834 standard curve is adopted in the fire simulation and the fire last two hours. In the damage length model fireproof coating thickness is 40 mm and embedment depth is 25 d, the damage length is determined to be 100 mm-600 mm. In the damage thickness model fireproof coating length is 100 mm and embedment depth is 25 d, the damage thickness is determined as 5 mm-40 mm as shown in figure 1.

2.2. Analysis of simulation results

2.2.1 Effect of coating damage thickness. According to the heat result shown in figure 2, and the damage length has a great effect on the temperature of I-steel, the temperature increases rapidly in the area where the fireproof coating is damage. Except that, the temperature begins to rise rapidly from the damage area and affect most area of the model. The damage length of fireproof coating is changed by 100 mm, 200 mm, 300 mm, 400 mm, 500 mm and 600 mm. It is found that damage degree of fireproof coating has different influence on fire resistance of post-installed anchors joint. The relationship between damage length of fireproof coating and temperature of bonded-in rebar and I-steel is presented in figure 3.

The temperatures of bonded-in rebar reach to 400 °C after two hours. In the figure 3(a), with the
development of damage length, the temperature variation of bonded-in rebar can be divided into three stages. The first stage: damage length is less than 200 mm, the temperature grows rapidly with the development of damage length, and this stage is linear growth. The second stage: with the damage length reaching 200 mm, the temperature reaches to 440 °C. When the damage length between 200 mm and 400 mm, the temperature of bonded-in rebar increase slightly and increase less than 50 °C. The third stage: temperature increase faster after the damage length reaches 400 mm, and the relationship between temperature and damage thickness is linear. Finally, the temperature of bonded-in rebar reaches 480 °C under the condition of maximum damage.

The temperature of I-steel comes to 1000 °C after two hours of fire. Figures 3(b) which indicate with the damage length increases the temperature of I-steel only augment by 100 °C in the whole heating process. If the damage length is 100-200 mm and 300-400 mm, the temperature is no significant enhance. There is a slightly increase of temperature, when the damage length between 300 mm and 400 mm. Finally, when the damage length changes reach 600 mm, the temperature increase of I-steel is not obvious and the temperature of I-steel only increases 50 °C.

2.2.2 Effect of coating damage thickness. It can be seen from the figure 4 that because the damage area is small, the temperature of fire-proof coating damage zone is obviously higher than other part of steel beam. The damage thickness includes 5 mm, 10 mm, 15 mm, 20 mm, 30 mm and 40 mm. By changing thickness of damage that the influence of damage thickness on fire resistance of post-installed joint is explored.

The bonded-in rebar temperature-damage thickness curve figure 5(a) show that after two hours of fire, the temperatures of bonded-in rebar reach 400 °C. The whole heating process can be divided into
two stages. The first stage: since the conditions of damage thickness is less than 30 mm, the temperature change of bonded-in rebar has little change, which indicates that the damage fireproof coating has less influence on the bonded-in rebar in this case. The second stage: the rapid temperature rise will occur when the damage thickness is greater than 30 mm. When the damage thickness reaches 40 mm the highest temperature of bonded-in rebar has reaches 450 ℃ which seriously affects the fire-resistance limit of post-installed joint.

In the figure 5(b), the curves show that the relationship between temperature of bonded-in rebar and damage thickness is present bi-liner growth. The temperature is growing steadily at the first segment. When the damage thickness of fireproof coating reaches 30 mm, the curve presents the second segment. At this segment, the slope of curve grows and the temperature enhance significantly. Finally, the damage thickness reaches 40 mm and the temperature of I-steel increases by 300 ℃. So the damage thickness of fireproof coating has great influence on the I-steel and the bonded-in rebar.

3. Conclusion
In order to study the effect of fireproof coating damage on steel-to-concrete post-installed joint, the influence of damage length and damage thickness on high temperature of bonded-in rebar and I-steel is studied. Under the action of high temperature, the temperature of I-steel beam and the damage area is analyzed as follows:

(1) The damage of fireproof coating after the earthquake has greatly effect on the fire resistance of post-installed joints. Specifically, the damage length of fireproof coating has a greater effect on bonded-in rebar than I-steel. After the damage length is over 400 mm, the temperature of bonded-in rebar is obviously increased. However, the effect on I-steel is not particularly significant.
(2) The damage thickness of fireproof coating on I-steel beam has great influence on the bonded-in rebar and I-steel. For the bonded-in rebar, when the thickness of damage fireproof coating is greater than 30 mm, the temperature of bonded-in rebar increases rapidly. Similarly, the temperature of I-steel increases rapidly with the increase of damage thickness.

(3) So the fire-resistance of steel-to-concrete anchorage joint can be improved from the selection of fireproof coating material or thickness. Fireproof coating with better thermal properties would effectively improve the fire-resistance performance.

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