Influence of fireproof damage on structural performance of post-installed anchor joint subjected to post-earthquake fire

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Abstract. To study explore the influence of post-earthquake fireproof coating damage on structural behaviour of steel-concrete post-installed joint, a three-dimensional FE model has been established by ABAQUS software. Parametric analysis has been carried out and the earthquake level on fireproof coating of post-installed joint by changing thickness of fireproof coating is analyzed under the condition of thermal-force coupling. By damage degree variation of fireproof coating, the influence of fireproof coating damage of anchor plate on fire endurance and bearing capacity of post-installed joint is further analyzed.

1. Introduction
Under the action of earthquake, the deformation of components will cause the damage of fireproof coating. Moreover, earthquake often accompanies with secondary fires, and cracking or spalling of fireproof coating will affect fire resistance of joints. Therefore, the bond performance of bonded-in anchor bolt, which is most widely used in anchorage connection will decrease significantly at high temperature. Thus, it is of great significance to study the damage of fire-proof coatings on fire resistance of steel-to-concrete post-installed joint.

Aaron J presents a three-dimensional thermo-mechanical coupled finite element model for structural behavior of shear connectors under fire. From the results of numerical analysis, various thermal and mechanical responses have been studied\textsuperscript{1}. Song Qian-yi conducted post-earthquake-fire tests on welded joints of I-beam. Test results show that load-bearing capacity of welded joints decreases more obviously with the increase of seismic damage.\textsuperscript{2} Pamad Panedpojaman conducted a thermal-mechanical coupling test on concrete column-welded steel plate joints. Test results show that fire resistance of fireproof sealant is superior to fireproof mortar.\textsuperscript{3} Pucinotti carried out thermo-mechanical coupling tests on six earthquake-damaged joints without fire protection. Degradation of structural strength and stiffness caused by earthquakes for node fire analysis.\textsuperscript{4} The earthquake-damaged post-installed joint was tested under high temperature conditions by Xu Lei. It is concluded that bearing capacity and stiffness of joints under different damage and high temperature coupling have decreased to some extent.\textsuperscript{5} Liu Zheng designed basic tensile performance test proves that bearing capacity are reduced under low temperature and high temperature conditions.\textsuperscript{6} Chen Hai-qiang analyzed tensile strength of anchored specimens of inorganic rubber and organic rubber on different temperature. The test results indicated that tensile capacity of organic agent was better than that of inorganic adhesive, however, inorganic specimens had better performance in seismic
Wang Xin investigated experimentally the anchorage failure of bonded-in rebar using organic agent. The failure mode of specimens is same as that of ordinary reinforced concrete beams. Zhou Meng carried out tensile tests on different anchor joints. Through the processing of the test data, the influence coefficient of anchor bolt in the group anchor and the influence coefficient of anchor plate stiffness were obtained. Nicolas of France carried out the pull-out test of post-installed joint under constant tensile load on steel bar. A thermal analysis has been investigated by a gradual heating up to joint failed in order to explore the influence of temperatures on joint behavior.

2. Model Design
A FE models of steel-to-concrete post-installed joint with various damage levels of fireproof coating for anchor plate are established. The different thickness of fireproof coating has been considered and the effect of fireproof coating damage on bearing capacity of post-installation joints under high temperature is studied. The ISO-834 standard temperature curve is adopted to simulate the fire action, A scenario of three-surfaces fire exposure for two hours has been designed as shown in Figure 1. The initial thickness of fireproof coating of anchor plate is 40 mm. The different damage degree of fireproof coating after earthquake is simulated by modifying the damage thickness of fireproof coating of anchor plate. The targeted damage thickness is 5 mm, 10 mm, 15 mm, 20 mm, 25 mm, 30 mm and 35 mm, respectively. The fireproof coating of anchor plate is shown in Figure 2.

3. Results analysis

3.1. Temperature of bonded-in rebar
The simulation results of bonded-in rebar temperature is shown in Figure 3 and the temperature history for damage thickness 5 mm, 20 mm to 35 mm are compared in Fig. 4. It can be seen that damage thickness has a great influence on high temperature performance of post-installed joint. When the damage thickness is 5 mm and 20 mm, the temperature changes slightly. While the damage thickness is 35 mm, the temperature of bonded-in rebar reaches 470℃ at 65 minute which is the maximum temperature for damage thickness 25 mm after 2 hour fire exposure. The peak temperature of bonded-in rebar is 625℃.
3.2. Bearing capacity and displacement
Based on the analysis discussed above, it can be found that temperatures of bonded-in rebar increase significantly when anchor plate fireproof coating has damaged. To study the influence of temperature rise of bonded-in rebar on fire resistance performance and bearing capacity of post-installed joint, the thermal-mechanical coupling analysis of steel-to-concrete post-installed joint with damaged fireproof coating is carried out and the load-bearing capacity of joint is analyzed by displacement-controlled loading system under fire. Fig. 5 presents the stress of bonded-in rebar in failure state. The results show that with temperature increase serious damage occurs in the zone where the bonded-in rebar is connected with steel plate.

![Stress results of bonded-in rebar in failure mode](image)

The relationship between damage degree of fireproof coating and ultimate bearing capacity is analyzed, and the reduction degree of ultimate bearing capacity is compared with normal temperature state as shown Fig. 6 and Table 1. It can be found that ultimate bearing capacity of post-installed joint decreases gradually with increase of damaged thickness of fireproof coating. When the damaged thickness of fireproof coating reaches 25 mm, the bearing capacity has dropped to 50% of ultimate strength. Especially, when the damage thickness changes to 35 mm, the ultimate bearing capacity has reduced to 82.7%.

![Ultimate bearing capacity comparison](image)

![Bearing capacity-displacement curve](image)

**Table 1. Comparison of ultimate bearing capacity of fireproof coatings with different thickness**

| Damage thickness (mm) | 5    | 10   | 15   | 20   | 25   | 30   | 35   |
|-----------------------|------|------|------|------|------|------|------|
| Ultimate bearing capacity (kN) | 52.4 | 45.7 | 40.2 | 37.5 | 32.2 | 26.0 | 8.9  |
| Bearing capacity reduction | 15.4% | 26.2% | 35.1% | 39.4% | 49.8% | 58.4% | 82.7% |

![Ultimate bearing capacity comparison](image)

![Bearing capacity-displacement curve](image)

The bearing capacity-displacement curves for different fireproof coating damage have been depicted in Figure 7. When the damage of fireproof coating changes from 5mm to 10mm, the maximum displacement varies from 18mm to 15mm, and the ductility of bonded-in rebar is greatly reduced. As degree of damage changes from 10 mm to 15 mm, displacement is reduced from 15 mm to 5 mm, accompanied by a large decline in bearing capacity. At this time the failure mode transfers to a brittle failure.
3.3. Maximum deflection analysis

Figure 8 shows the relationship of ultimate deflection and damage thickness. It is shown that when damage thickness is less than 10mm the deflection exceed 14mm which means a satisfactory deformation capacity of specimen. However, after the damage thickness exceeds 10 mm, the deflection decrease significantly to about 5 mm. After damage thickness reaches 35 mm, the ultimate deflection is seriously reduced with less than 1 mm and joint has basically lost its carrying capacity.

![Figure 8. Maximum deflection comparison](image)

4. Conclusion

Through studying the effect of damage thickness of fireproof coating on temperature of bonded-in rebar under the coupling action of heat and force, a FE analysis of steel-to-concrete post-installed joint are analyzed and the main results have been shown as follows:

- It is found that fireproof coating damage of anchor plate greatly affects high temperature performance and bearing capacity of bonded-in rebar. When damage thickness range of fireproof coating is 5-35mm, the bearing capacity decreased by 15.4%-80%. The ultimate displacement and deflection are greatly reduced, and the failure mode becomes brittle failure.

- It is necessary to improve fire resistance performance of post-installed joint by choosing fireproof material with good thermal insulation in the post-earthquake fire structure design.

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