A Study on Pullout Strength of Cast-in-place Anchor bolt in Concrete under High Temperature

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ABSTRACT

This paper presents experimental study on the behavior of cast-in-place anchor bolt embedded in concrete subjected to high temperatures up to 500°C, with the specific objectives to obtain basic experimental data and to examine the response of cast-in-place anchor bolts to high temperature exposure. The specimens with two kinds of embedment depth of anchor bolt, 30mm and 50mm, are prepared. Under constant tensile load applied to the anchor bolt, the specimen is heated and the relation between the pullout strength and temperature at fracture is examined. As to the process of heating, two different rate of temperature elevation, 10°C/min. and 0.75°C/min, were prepared. As a result of the test, regardless of different parameters studied in this experiment, comparison with the earlier research results indicated that identical ratio of pullout strength of anchor bolt was obtained when the same temperature of concrete surrounding the bolt head was applied.

KEY WORDS: cast-in-place anchor bolt, concrete, pullout strength, high temperature,

INTRODUCTION

In nuclear facilities, many anchor bolts are embedded in concrete structures in order to support equipments and pipes. In case there is some accident, it is possible that concrete structures will exposed to high temperature. It is well known that the compressive strength of concrete decreases with further increase of temperature. Other mechanical properties also get worse, and there is possibility of the spalling on the surface of concrete exposed to high temperature. Therefore, it is necessary to investigate experimentally the behavior of anchor bolts embedded in concrete exposed to high temperature.

In earlier study, the pullout tests of cast-in-place anchor bolt under high temperature were carried out using the specimens with embedment depth of 30mm [1]. At the rate of 10°C/min., the specimens were heated up to 500°C. Tests results show that the pullout strength decreases significantly with increasing surface temperature. With the maximum temperature up to 500°C, the pullout strength during heating decreases to 20% of it under normal temperature. The pullout strength of cast-in-place anchor bolt in concrete depends on the embedment depth, and the heating process has influence on the temperature distribution inside the specimen. Therefore, additional data is needed to examine the cause to decrease of the pullout strength of cast-in-place anchor bolt in concrete under high temperature.

In this research, the pullout tests of anchor bolts under heating were carried out, using the specimens with two different embedment depth, 30mm and 50mm. Two different rate of temperature elevation, 10°C/min. and 0.75°C/min., were employed in the process of heating. The purpose of this paper is to study the behavior of the cast-in-place anchor bolt in concrete subjected to high temperature and to investigate the cause to determine the pullout strength under heating.

EXPERIMENTAL INVESTIGATION

Specimen and apparatus

In this study, the specimens with two kinds of embedment depth, 30mm and 50mm, as listed in Table 1 were prepared. Material properties are also shown in Table 2. Ordinary normal concrete with compressive strength of 30N/mm² was used to all the specimens. Six hours after casting of concrete, the specimens were covered with wet sand. This curing sand was removed on the day of testing.

<table>
<thead>
<tr>
<th>Specimen</th>
<th>b×D×h(mm)</th>
<th>Anchor Bolt</th>
<th>Compressive strength (N/mm²)</th>
<th>Splitting tensile strength (N/mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABT-S</td>
<td>240×240×120</td>
<td>M12×80</td>
<td>44.3</td>
<td>3.31</td>
</tr>
<tr>
<td>Test 2</td>
<td>30mm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Test 3</td>
<td>30mm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Test 4</td>
<td>30mm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ABT-L</td>
<td>500×500×180</td>
<td>M16×120</td>
<td>38.6</td>
<td>3.31</td>
</tr>
</tbody>
</table>

Table 1. List of specimens
Table 2. Material properties of steel

<table>
<thead>
<tr>
<th></th>
<th>Yield Strength (N/mm²)</th>
<th>Tensile Strength (N/mm²)</th>
<th>Young's Modulous (×10⁵N/mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anchor Bolt M12</td>
<td>378</td>
<td>446</td>
<td>1.91</td>
</tr>
<tr>
<td>Anchor Bolt M16</td>
<td>361</td>
<td>469</td>
<td>2.02</td>
</tr>
<tr>
<td>Deformed Bar Ø13</td>
<td>358</td>
<td>528</td>
<td>1.93</td>
</tr>
</tbody>
</table>

1) ABT-S
In all, 4 tests were carried out including the test reported in Reference [1]. The embedment depth of ABT-S is 30mm, and the dimensions and details of the specimen are illustrated in Fig.1. A headed stud bolt as shown in Fig.2 was used as an anchor bolt. The apparatus used for testing ABT-S is shown in Fig.3. The details of the specimens and apparatus are described in Reference [1].

2) ABT-L
The dimensions and details of ABT-L are illustrated in Fig.4. Specimens are all square blocks with side length 500mm considering the cone failure area, and with a depth of 180mm. Four deformed bars with diameter of 13mm were
arranged in the specimens so that they will not fail due to bending. As an anchor bolt, a headed stud bolt illustrated in Fig. 5 was used. This anchor bolt was embedded at the center of all specimens with embedment depth of 50mm as shown in Fig. 6. Four square nuts and steel pipes were installed to be fixed with the testing apparatus. Five specimens were installed with 13 thermo-couples to measure the temperatures of concrete and bolt inside the specimens during heating. (See Fig. 1 (b))

The testing apparatus for ABT-L is shown in Fig. 7, and detail of heating specimens is illustrated in Fig. 8. The specimen was fixed to the testing apparatus with four bolts from the bottom of the specimen. Then, the head of bolt, which is connected with the embedded anchor bolt using coupler, was pulled up vertically by a hydraulic jack. The tensile load applied to the anchor bolt is measured by load cell set on the hydraulic jack. To improve thermal efficiency, the insulators were installed around the specimen and the heaters. One side of specimen with anchor bolt was heated by hot air by increasing its temperature using the electric heater with Nichrome wires.

**Testing procedure**

First, the pullout strength under normal temperature was examined. To examine the effect of high temperature on pullout strength, the specimens were heated while applying constant tensile load $P$ on the anchor bolt. The tensile load $P$ was decided between 0N and the average of the pullout strength under normal temperature $P_0$. The pullout test was
completed when the specimen fractured. Above the specimen, a thermo-couple was employed to measure the air temperature near the heating surface of specimen (See Fig.8). This temperature (surface temperature) was controlled with the processes of heating as shown in Fig.9. With Heating Process □, the specimen is heated up to 500 °C at the rate of 10 °C/min. After that, 500 °C was kept for two hours unless the specimen fractured, and the heating was finished. For Heating Process □, the rate of heating is 0.75 °C/min which is much slower than Heating Process □.

EXPERIMENTAL RESULT

Results of pullout tests

Fig.10 shows the results of tests with the tensile load $P=0.6P_0$. As for the specimens with embedment depth of 50mm, in the case of heating at the rate of 10 °C/min, the anchor bolt was pulled out when the surface temperature reached 368 °C. With the heating at the rate of 0.75 °C/min, the surface temperature at breaking point was 223 °C, which is much lower than it with heating at the rate of 10 °C/min. While, as for the specimens with embedment depth of 30mm, the surface temperature at breaking point was 357 °C and 217 °C with the heating at the rate of 10 °C/min and 0.75 °C/min, respectively. All the specimens fractured until the surface temperature of the specimens reached 500 °C. In other words, the specimens, which did not fracture during elevate the temperature, did not fracture by finishing the heating.

The relation between the pullout strength and surface temperature of the specimens at breaking point are plotted in Fig.11. Here, the results reported in reference [1] are included. The vertical axis stands for the pullout strength normalized by the average of the pullout strength under normal temperature. It can be observed that, in spite of different embedment depth, there is little difference of the relations between the pullout strength and surface temperature of ABT-S and ABT-L. The pullout strength decreases significantly with increasing surface temperature. During heating up to 500 °C at the rate of 10 °C/min, the pullout strength decreases to about 20% of it under normal temperature. In the case of heating at the rate of 0.75 °C, the pullout strength decreases to only 40% of it under normal temperature. However, the temperatures at breaking point were about 100 °C lower than it of specimens heated at the rate of 10 °C/min, when the same ratio of tensile load was applied to anchor bolts.
Effect of embedment depth

In this research, the specimens were heated from the surface where the anchor bolts were installed. Therefore, the difference of temperature will exist in the vertical direction, and it is expected that the embedment depth will have effects on the pullout strength under heating. Nevertheless, the comparison with the results of different embedment depth, 30mm and 50mm, indicates that there is little difference of the relation between surface temperature and the pullout strength of anchor bolts.

In Fig.12, the temperature distribution around the anchor bolt at breaking point is shown. In the case of heating at the same rate, it can be seen that the surface temperatures at breaking point of ABT-L and ABT-S were similar when the same ratio of tensile load was applied to anchor bolt. Moreover, the temperatures of bolt head were also identical. The thermal conductivities of concrete and anchor bolt are greatly different. Concrete is difficult to convey temperature, while steel is easy to convey it. The specimens used in this research were designed to get cone failure as failure mode, and the embedment depths were relatively shallow. Consequently, when the specimens were heated with the same process of heating, the temperatures of bolt head had little difference in spite of different embedment depth. From the comparison with the result of embedment depth of 30mm and 50mm, it seems that the cause which determines the pullout strength of cast-in-place anchor bolt under heating is the temperature of bolt head and surrounding concrete.

Effect of heating speed

The relation between the temperature of bolt head at breaking point and the pullout strength of cast-in-place anchor bolt is shown in Fig.13. When the temperature of bolt head is less than about 160°C, identical ratio of pullout strength of anchor bolt was obtained, provided the same temperature of the bolt head was applied, regardless the difference of the rate of heating. In the case of heating at the rate of 10°C/min, only the surface temperature of specimen are extremely high and there is great difference in temperature inside the specimen. While, the difference in temperature inside the specimens heated at the rate of 0.75°C/min is little. In other words, the surface temperature of specimen heated at slow rate is lower than it at rapid rate, when the temperatures of bolt head are identical.

When the temperature of bolt head is more than 160°C, the relation between the temperature of bolt head at breaking point and the pullout strength of cast-in-place anchor bolt is different. The pullout strength under heating at the rate of 10
C decreases to 20% of it under normal temperature. However, the pullout strength of the specimens heated at the rate of 0.75°C/min decreases to 40% of it under normal temperature when the surface temperature is around 250°C, namely, when the temperature of bolt head is around 160°C. Moreover, the pullout strength did not decrease less than 40% of it under normal temperature, even though the specimens were heated up to 500°C. When concrete is heated with a rapid increase of temperature, there is possible that the spalling happens on the surface of concrete. The spalling occurs due to rapid increase of temperature, thermal stress, and the steam pressure. In this research, the specimens were cured with wet sand by the day of testing, and the specimens which fractured during heating at the rate of 10°C/min broke into pieces with a sound of explosion. Therefore, it is believed that the spalling happens on the surface installed an anchor bolt, and causes the pullout of the anchor bolt in the case that the small tensile load is applied to anchor bolt.

CONCLUSION

In this research, the pullout testing of a cast-in-place anchor bolt in concrete under high temperature up to 500°C of surface temperature was carried out. The specimens with two kinds of embedment depth of anchor bolt, 30mm and 50mm, were used. Controlled by surface temperature, two different rate of temperature elevation, 10 degrees centigrade /min. and 0.75 degrees centigrade /min were applied. From this experimental investigation, it is concluded,

1. In case of the same rate of temperature elevation, the relation of decrease ratio of pullout strength and the surface temperature was identical regardless of different embedment depth of anchor bolt.

2. Comparison with the results of different rate of heating indicates that the relation between the temperature of bolt head and the pull-out strength under heating was identical, when the temperature of bolt head was less than 160°C. The pullout strength of cast-in-place anchor bolt subjected to high temperature decreased to 40% of it under normal temperature.

3. When the temperature of bolt head was over 160°C, the pullout strength of anchor bolt during heating at the rate of 10°C/min decreased to 20%. While, within the scope of this research, with heating at the rate of 0.75°C/min, the pullout strength did not decrease to less than 40%. Therefore, not all the pullout strength under high temperature was determined by the temperature of the bolt head.

REFERENCE