An experimental study for the thermal behavior of composite concrete beam with slab compared with isolated beam under fire

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Abstract. As the number of fire accidents is gradually increasing, many experimental studies on fire performance of concrete have been reported by focusing on thermal behaviors of isolated structural members under fire. However, experimental approaches still have issues due to experimental conditions, such as heating and loading limits. One of them is about using isolated specimens for experiments, because when structural member is solely tested under fire, the behaviors may be different from those of structural members connected to each other. It is worth verifying whether isolated beam shows different behaviors under fire compared to the case with beam-slab connections, considering most structural members are connected to each other in real buildings. With these considerations, this paper aims at evaluating thermal behaviors between isolated specimen and composite specimen from experiments. Toward that goal, fire tests are performed on concrete beams connected with slab and isolated beams by applying high temperatures according to ISO-834 standard time-temperature curve. This study uses two different parameters; the first is fire exposure time and the second is whether it is joint with other structural members. From the experiments, time-temperature curves are obtained at several locations and differences of thermal behaviors between beam with slab and isolated beam are compared to each other.

1. Introduction

Damages due to fire accidents have been increasing with an increase of high rise buildings and complex of skyscrapers. Therefore, studies for the structural and mechanical behaviors of architectural structures under fire are necessary to prevent such severe damages. As it becomes important topic, in current practice, various studies on thermal behavior of reinforced concrete members under fire have been reported using experimental methods (Kodur 2005, Yoon 2017; Kang 2016; Ngo et al 2013; Foster 2007). For the thermal behaviors of concrete slab, Kodur (2005) reported experimental results on thermal behavior of fire-exposed concrete slabs reinforced with fiber-reinforced polymer bars. Yoon (2017) focused on thermal and structural performances of RC frame under fire by fire tests. In a case of thermal behaviors of concrete wall, Kang (2016) investigated the effect of wall thickness on thermal behaviors of RC walls under fire conditions by the fire tests. Also, the differences in thermal behavior between normal and high strength concrete walls for ISO 834 standard fire testing was found by Ngo et
al (2013). In a case of the fire test on a full-scale building, Foster (2007) reported the thermal and structural behaviour of a full-scale composite building subject to a severe compartment fire. However, experimental methods for investigating behaviours of concrete members need to consider various influencing factors, such as heating and loading conditions. One of them is about using isolated specimens for experiments, because when structural member is solely tested under fire, the behaviours may be different from those of structural members connected to each other. It is worth verifying whether isolated beam shows different behaviors under fire compared to the case with beam-slab connections, considering most structural members are connected to each other in real buildings.

With these considerations, this paper aims at evaluating thermal behaviors between isolated specimen and composite specimen. Toward that goal, fire tests are performed on concrete beams connected with slab and isolated beams by applying high temperatures according to ISO-834 standard time-temperature curve. This study uses two different parameters; the first is fire exposure time and the second is whether it is joint with other structural members. From the experiments, time-temperature curves are obtained at several locations and differences of thermal behaviors between beam with slab and isolated beam are compared to each other.

2. Experimental design and method

2.1. Test specimens and variables

Six RC beams are fabricated to evaluate thermal behaviours between isolated specimen and composite specimen under fire as listed in table 1. As shown in figure 1, the size of specimens is 250mm x 400mm x 5000mm (width x depth x length). The beams are loaded with 4.82 tonf which is 40% of their nominal moment capacity. As shown in figure 1, all beams are reinforced with three steel bars of 19mm diameter at the bottom and stirrups of 10mm diameter to prevent shear failure. Also, two slabs are fabricated and each of them is connected to 2 beams on both sides. The size of slab is 2500mm x 5000mm x 150mm (width x length x depth). As illustrated in figure 2(a) and figure 2(b), two beams are connected to both side of one slab.

| Table 1. List of specimens |
|---------------------------|
| Size of beam (mm)         | Fire exposed period (min) | Load (tonf) | Isolated / Connected to slab |
| P1-60-I                   | 60                        | 4.82        | Isolated                     |
| P1-60-R                   | 60                        |             | Connected (right)            |
| P1-60-L                   | 60                        |             | Connected (left)             |
| P1-120-I                  | 120                       | 4.82        | Isolated                     |
| P1-120-R                  | 120                       |             | Connected (right)            |
| P1-120-L                  | 120                       |             | Connected (left)             |

![Diagram of beam and slab connections]

![Diagram of specimen dimensions]
2.2. Materials
The mix proportion used for RC beams as well as slabs is based on table 2. After 28-day curing, the compressive and tensile strength of concrete are 25MPa and 3MPa respectively, as listed in table 2. The yield strength and elastic modulus of all reinforcing steel bars are 448 MPa and 205 GPa, respectively.

| Weight per unit volume (kg/m³) | W  | C  | S  | G  | FA |
|--------------------------------|----|----|----|----|----|
| 25 MPa                         | 83 | 155| 913| 914| 1.86|

2.3. Test set up and data measurement
Before the fire test, all beams are simply supported with an effective span of 4700mm and subjected to 4-point loading system with 1200mm apart between the loading points. The fire tests are performed in the fire furnace as shown in figure 3 and sizes of the heating furnace are 4m and 3m for width and depth, respectively. The specimens are placed within the heating furnace and heated for 1 or 2 hours according to ISO-834 standard heating curve (figure 4). For isolated beam specimen, two side and one bottom surfaces are heated, while inner surfaces of the beams with slab are exposed to high temperatures. As shown in figure 5, the temperatures of specimen are measured during the experiment using thermocouples at 5 different locations of the center and 1/4 point of each specimen.
3. Results and Discussion
The time-temperature curves are obtained from 10 different locations of thermocouples within each specimen and CON and CM series of thermocouples are installed at the center and 1/4 point of each specimen, respectively. Figure 6 shows the time-temperature curves of P1-120-I and the time-temperature curves tend to be similar in other specimens.

The experimental results show that the temperature differences between isolated beam and beam with slab range up to 300°C, depending on the location of thermocouples. As shown in time-temperature curves in figure 6, the temperatures rise rapidly until 10-20 minutes of the fire test then suddenly the
increase rate of temperatures slows down. When the temperature reaches around 100°C, the increase rate of temperatures tends to slow down, and temperatures stay in stagnation zone for a while, as presented in figure 6. This can be considered as a stagnation zone for water evaporation within concrete. Also, as shown in figure 6, the highest temperatures are found in CON1 and CM1 and the temperatures of CM series tends to be slightly higher than those of CON series. This shows that, the temperatures rise higher, as the location of the thermocouple is closer to heating surface and adjacent heating surface of thermocouple is larger.

The highest temperature comparison in figure 7(a) and 7(b) shows the temperature differences between the isolated beams and right beams connected to slab. Although the temperature differences range up to 130°C as shown in figure 7(a), it is hard to determine any tendency until 60 minutes under fire, since several temperatures of isolated beam(P1-60-I) show higher temperature than those of the beam with slab(P1-60-R) and several temperatures show the opposite result. However, as the heating continues until 120 minutes, most of the temperatures of P1-120-R increase higher than those of P1-120-I, as presented in figure 7(b). The temperature differences between P1-120-R and P1-120-I range from 0-300°C on account of the location of thermocouples, but 7 out of 10 temperatures of P1-120-R shows higher than those of P1-120-I at the end.

As shown in figure 2(b), temperatures of A zone of right beams connected to slab are slightly higher than those of isolated beams. This is because the slab prevents the heat from transferring due to beam-slab joint part. Also, this phenomenon can be found in left beams connected to slab.

The highest temperature comparison in figure 7(c) and 7(d) show that the temperature differences between the isolated beams and left beams connected to slab range up to 0-220°C. It is clear that most of the temperatures of beam connected to slab(P1-60-L) are higher than those of the isolated beam(P1-60-I) until 60 minutes under fire as shown in figure 7(c). Then this tendency becomes distinct during 120 minutes of fire test as in figure 7(d), showing that most of the highest temperatures of P1-120-L are higher than those of P1-120-I. The temperature differences between P1-120-L and P1-120-I range up to 220°C depending on the location of thermocouples, but 5 out of 8 results of P1-120-L shows higher results than those of P1-120-I at the end, since temperature of P1-120-L at CON1 and CM1 was not obtained. In the case of CON3 and CM3, the temperatures of P1-120-I are higher than those of P1-120-L before 60 minutes, but then the result goes reverse at the end of the 120 minutes of the fire test.
Figure 7. The highest temperatures at different locations of thermocouples (a) P1-60-I and P1-60-R (b) P1-120-I and P1-120-R (c) P1-60-I and P1-60-L (d) P1-120-I and P1-120-L
As shown in figure 7, the temperatures of the beams connected to slab are mostly higher than those of the isolated beams. This tendency shows significant in figure 7(c) and 7(d) than in figure 7(a) and 7(b), which is comparing the results between the isolated beams and left beams connected to slab. Considering the fact that the locations of the thermocouples of P1-120-L are closer to heating surface than those of P1-120-R, the result indicates that the tendency gets clearer as the location of the thermocouples are closer to heating surface.

4. Conclusions
To evaluate the thermal behaviors between isolated specimen and composite specimen, fire tests are performed on concrete beams connected with slab and isolated beams by applying high temperatures according to ISO-834 standard heating curve. Results from the analysis indicate that:

- In the experiment, the results show that temperature between isolated beam and beam with slab range up to 300°C, depending on the location of thermocouples. Also, the temperatures of the beams connected to slab are mostly higher than those of the isolated beams.
- This tendency gets clearer as heating time gets longer, since some of the time-temperature curves show that the temperatures of the isolated specimen was higher than those of specimen connected to slab before 60 minutes, but then the result goes reverse at the end of the 120 minutes fire tests. The result indicates that this tendency gets clearer as the heating time gets longer.
- Also, this tendency is shown slightly stronger in the left beams connected to slab than the right beams connected to slab. The result indicates that the tendency gets clearer as the location of the thermocouples are closer to heating surface.
- In the case of beam-slab joint part as shown in figure 2(b), temperatures of A zone of beams connected to slab are slightly higher than those of isolated beams. This is because the slab prevents the heat from transferring due to beam-slab joint part.
- Further studies are needed to investigate the other conditions that influence the tendency and to see the same tendency applies in other structural members.

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