# Fire Performance of Hollow-Core Concrete Slabs with and Without Joint Mortar

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**Abstract**

*Hollow-core concrete slabs have been extensively utilized in the construction sector. However, these slabs may lose their flexural capacities under fire due to the increasing temperatures, leading to a premature failure compared with the fire resistance period specified in the building regulations. This research investigates the use of joint mortar in providing axial restraint to enhance the fire performance of hollow-core concrete slabs. An experimental study was conducted through full-scale fire testing of precast hollow-core concrete slabs having a thickness of 120 mm, with and without mortar filled in the gaps at the ends. The water-to-cement ratio of the mortar was selected as 0.5 to align with that typically used in practice. The results showed that the axial restraint was induced by the joint mortar to a certain degree, as evidenced by the reduced thermal expansion of the slabs. However, the increase in the fire resistance of the slabs—as measured by the time to failure—under the specified loading level of 0.3 was marginal and deemed insufficient according to the current building regulations on fire safety.*

**Key words:** *Hollow-core concrete slabs, Fire resistance, Axial restraint, Joint mortar*
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## 1. Introduction

Hollow-core concrete slabs have been extensively utilized in buildings due to their advantages over cast-in-place slabs in terms of convenience and time of construction. However, these slabs may fail to comply with the fire resistance specification in the current building regulations of Thailand [1]. Under elevated temperature conditions, the decrease in the tensile strength of the prestressing steel can lead the slabs to lose their flexural resistance [2]. To enhance the fire performance of hollow-core concrete slabs, it is possible to increase the minimum concrete cover for better insulation of the prestressing strands [3]. Alternatively, additional steel reinforcement can a also be used to allow moment redistribution within the slabs [4-5]. However, these measures have certain limitations regarding the pre-casting process as well as the cost of construction.

Previous studies [6-8] have suggested using axial restraints to improve the fire resistance of hollow-core concrete slabs. This can be done by providing a certain form of constraint on the slabs against thermal expansion. The restriction of the material expansion under the increasing temperature potentially induces an axial thrust that compensates for the reduction in flexural capacities. According to ASTM E119 [9], the use of mortar to fill the joints at the ends of precast concrete slabs can be considered as a condition for providing restraint against thermal expansion. However, the efficacy of this practice in increasing the fire performance of hollow-core concrete slabs has not been clearly confirmed in the literature.

The objectives of this study are twofold. Firstly, the study examines the efficacy of using joint mortar in providing axial restraints for the hollow-core concrete slabs with a specified thickness under elevated temperatures. Secondly, it examines the enhancement of the fire performance of the slabs using joint mortar. To achieve these, full-scale fire tests were conducted on hollow-core concrete slabs with and without mortar filling the joints at the ends.

## 2. Materials and Methods

### 2.1 Hollow-core specimens

Two sets of specimens were tested in this study; with and without mortar filling the gaps at the ends. Each set comprises three precast hollow-core concrete slabs with a cross section as shown in **Fig. 1**, each having the dimensions of 120 mm x 1200 mm x 3400 mm. The hollow-core concrete slabs were reinforced with eight 8 mm prestressing strands (shown as white dots in **Fig. 1**) with a specified concrete cover of 20 mm. **Table 1** provides description of the specimens and the fire test program. Note that the support conditions of “not restrained” and “axially restrained” refer to the setups with and without mortar filling the gaps at both ends of the slabs, respectively.

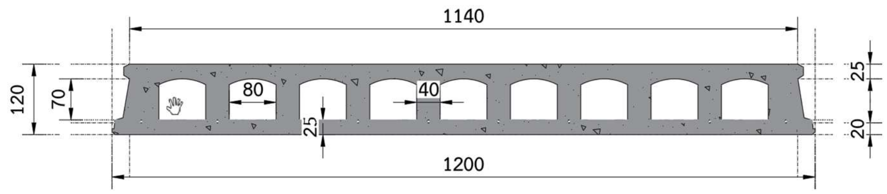



**Fig. 1** Details of the precast concrete slab (units in millimetres)

**Table 1** Summary of the test program

| Set # | Slab # | Cross-sectional configuration | Prestressing steel | Support condition | Loading ratio | Heating duration |
|---|---|---|---|---|---|---|
| 1 | HC01 | 120 mm x 1200 mm (nine hollow cores) | 8 – Ø5 mm | NR | 0.3 | 120 min or until failure |
| | HC02 | 120 mm x 1200 mm (nine hollow cores) | 8 – Ø5 mm | NR | | |
| | HC03 | 120 mm x 1200 mm (nine hollow cores) | 8 – Ø5 mm | NR | | |
| 2 | HC04 | 120 mm x 1200 mm (nine hollow cores) | 8 – Ø5 mm | AR | 0.3 | 120 min or until failure |
| | HC05 | 120 mm x 1200 mm (nine hollow cores) | 8 – Ø5 mm | AR | | |
| | HC06 | 120 mm x 1200 mm (nine hollow cores) | 8 – Ø5 mm | AR | | |

Note: NR=not restrained, AR=axially restrained with joint mortar

## 2.2 Material properties

The precast hollow-core concrete slabs were provided by a precast construction company based in Saraburi province, without available information on their casting date. The compressive strength of concrete was determined using the rebound hammer test according to ASTM C805-02 [10], which was 32 MPa. The tensile strength of the prestressing strands was averaged from testing three samples according to ASTM A370 [11], and the elastic modulus was provided by the manufacturer. The mechanical properties of the prestressing strands are summarized in **Table 2**. The mortar used to fill the gaps at the ends of the slabs was designed with a water-to-cement ratio of 0.5, aligning with that in practice. The mixture proportion of the mortar is shown in **Table 3**. The binder used in mixing the mortar was hydraulic cement conforming to TIS 2594-2556 [12]. Natural river sand complying with the ASTM C33 [13] gradation limits was used as the fine aggregates. The compressive strength of mortar at 28 days—obtained by testing three cubic specimens of 50 mm x 50 mm x 50 mm based on ASTM C109/C109M [14]—was 29.2 MPa.

## 2.3 Testing arrangements and instrumentation

The installation began by placing each set of specimen on a reinforced concrete frame on top of a horizontal furnace as illustrated in **Fig.** ***2***. A 100 mm gap measured from the end of the slabs to the internal face of the supporting frame was specified. This gap is used to simulate a joint between the ends of two precast slab units or a joint between the end of a precast slab unit and the vertical face of supports, according to ASTM E119 [9]. This size of gap ensures the slabs can freely expand under thermal loading for the specimen without axial restraint. For the axially restrained specimen, the 100 mm gaps at both ends of the precast units were filled with mortar up to the thickness level of the slabs. The lateral joints between adjacent precast slab units were also filled with mortar to prevent the furnace heat loss.

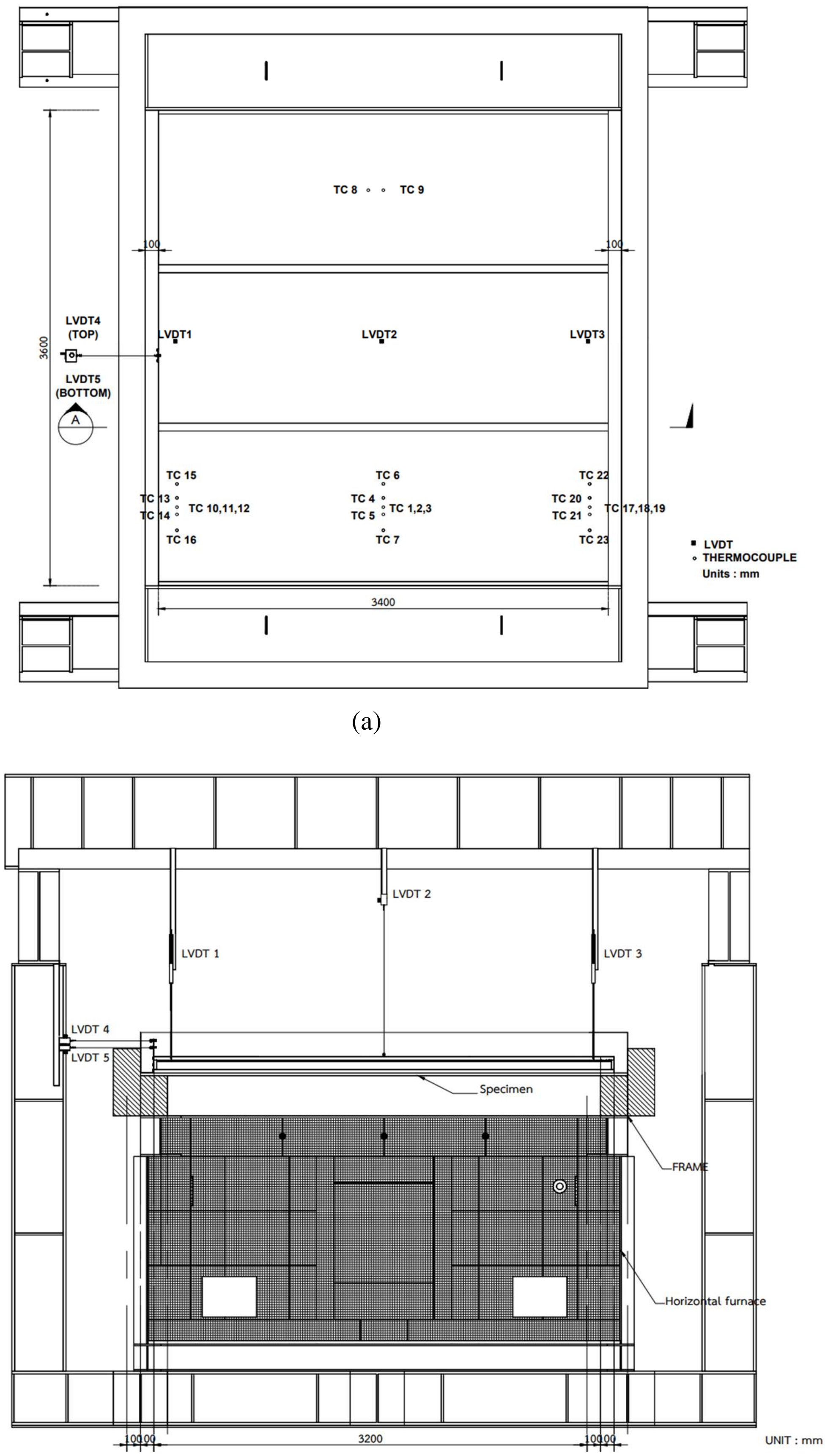
Throughout the fire test, the middle slab was monitored for its deflection using three linear variable displacement transducers (LVDTs): one Kyowa-DTP-D-500S wire-type transducer with a measurement range of ±500 mm at midspan and two Kyowa-DTJ-A-200 rod-type transducers with a measurement range of ±200 mm at supports (**Fig. 2**). The thermal expansion of the middle slab was also measured using two Kyowa-DTP-D-500S wire-type transducers on a steel plate fixed to the end of the slab (**Fig. 3**). The steel plate was used to allow mortar to completely fill the gap and provide the axially restraining effect. To avoid interfering with the actual behavior of the slab in the middle, the temperature sensors (type-K thermocouples) were installed on adjacent hollow-core slab units at various locations during the test (**Fig. 2** and **Fig. 4**).

**Table 2** Mechanical properties of prestressing strands

| Number of strands | Diameter (mm) | Area (mm$^2$) | Tensile strength, $f_{pu}$ (MPa) | Elastic modulus, $E_{pu}$ (GPa) |
|---|---|---|---|---|
| 8 | 5 | 19.6 | 1776 | 200 |

**Table 3** Mixture proportion of mortar

| Water/binder ratio | Cement (kg/m$^3$) | Water (kg/m$^3$) | Sand (kg/m$^3$) |
|---|---|---|---|
| 0.5 | 300 | 150 | 1962 |




(a)



(b)

**Fig. 2** Experimental setup: (a) layout and (b) section A

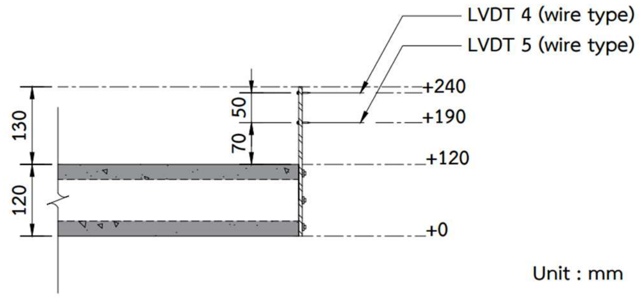



**Fig. 3** The measurement of thermal expansion

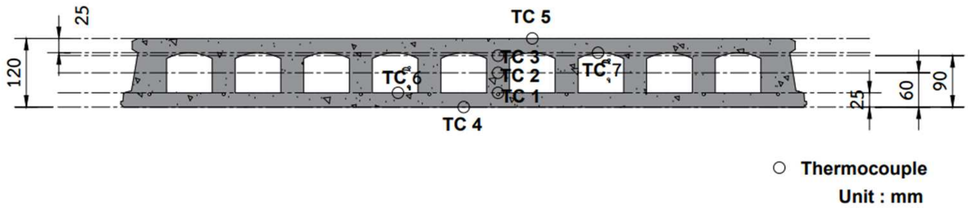



**Fig. 4** Temperature measuring devices on the cross-section of a hollow-core slab

## 2.4 Testing procedures

The testing procedures started by loading the specimen with sandbags. The sandbags were used to provide uniform loading mainly because of their ease of installation. The number of sandbag layers was pre-determined to reach a specified loading ratio of 0.3—which corresponds to a typical service load level in practice. This load ratio was computed as a fraction of the applied uniformly distributed load to the maximum value causing the slab to fail in flexure at normal temperature, based on ACI 318 [15] using the previously reported material properties. After loading, the specimen was heated on the underside by controlling the furnace temperature according to ISO 834-1 [16] until reaching a structural failure. The limiting deflection and rate of deflection, as specified by ISO 834-1, were also used for terminating the fire test. The fire tests were conducted at the Fire Safety Research Center (FSRC) of Chulalongkorn University located in Saraburi province. **Fig. *5*** shows specimen set #1 during the test.

## 3. Results and Discussions

The experimental results are reported in a comparison between the specimens with and without joint mortar at the ends of the hollow-core slab units.

## 3.1 Fire resistance

The fire resistance of specimen set 1 without joint mortar was determined as 39 minutes, with the rate of deflection exceeding the ISO 834-1 limit. With joint mortar, the fire resistance period was extended to 47 minutes—an increase by 20%—based on the same termination criterion. Still, this enhanced fire resistance failed to comply with the minimum requirements in the current building regulations. By visual inspection, the specimens with and without joint mortar failed abruptly after the fire exposure of 40 minutes and 47 minutes, respectively. Both specimens appeared to fail in flexure, as illustrated in **Fig. *6***.

**Fig. 5** Specimen set #1 during the fire test

**Fig. 6** Specimen set #1 after collapse

## 3.2 Midspan deflection

The measured deflections at midspan during the fire tests are plotted in **Fig.** *7*, comparing between the specimens with and without joint mortar. The deflection was observed to slightly reduce due to the joint mortar. The maximum deflections were 131 mm and 150 mm, respectively, for the precast units with and without mortar fillings at the ends. This reduction of the midspan deflection showed evidence of the axially restraining effect provided by filling the joints at the ends of the hollow-core concrete slabs with mortar.

The specimen with mortar-filled end joints consistently exhibited lower deflections throughout the test period compared to the case without mortar joint filling. Specifically, the deflection at the end with mortar measured 131.03 mm, while the unfilled end reached 149.84 mm. This decrease in deflection underscores the axial restraining effect provided by the joint mortar.

## 3.3 Thermal expansion

The displacements measured on the steel plate at the end of the specimen (see **Fig. 3**) were used to draw a plane for estimating the thermal expansion of the slab units. The results are shown in **Fig. 8**. A comparison between the specimens with and without the joint mortar reveals that there were virtually no differences in the thermal expansion within the first 10 minutes of the fire tests. After 20 minutes, the specimen with the joint mortar expanded distinctively less, showing the induced axial restraint against thermal expansion.

## 3.4 Temperature data

The temperature data recorded at various locations during the fire tests are illustrated in **Fig. 9**. It is observed that the temperatures of the two specimens were closely similar throughout the testing duration, except for the first 20 minutes where a slight deviation was observed. These temperature records confirmed that the results reported previously were not due to the differing temperatures between the specimens but were the effect of the joint mortar.

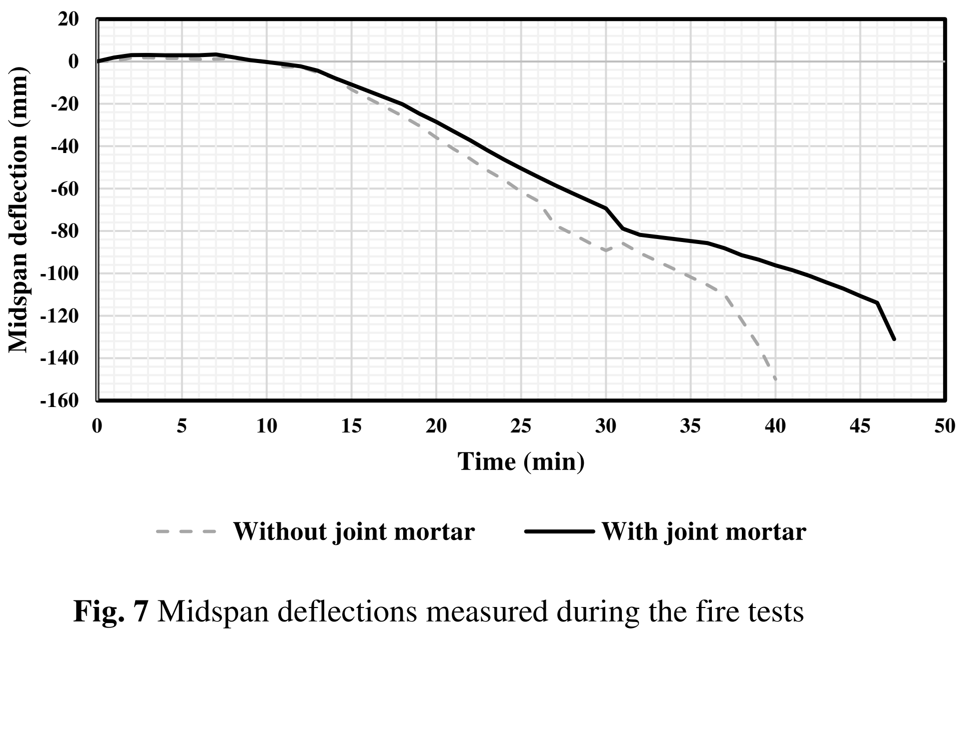
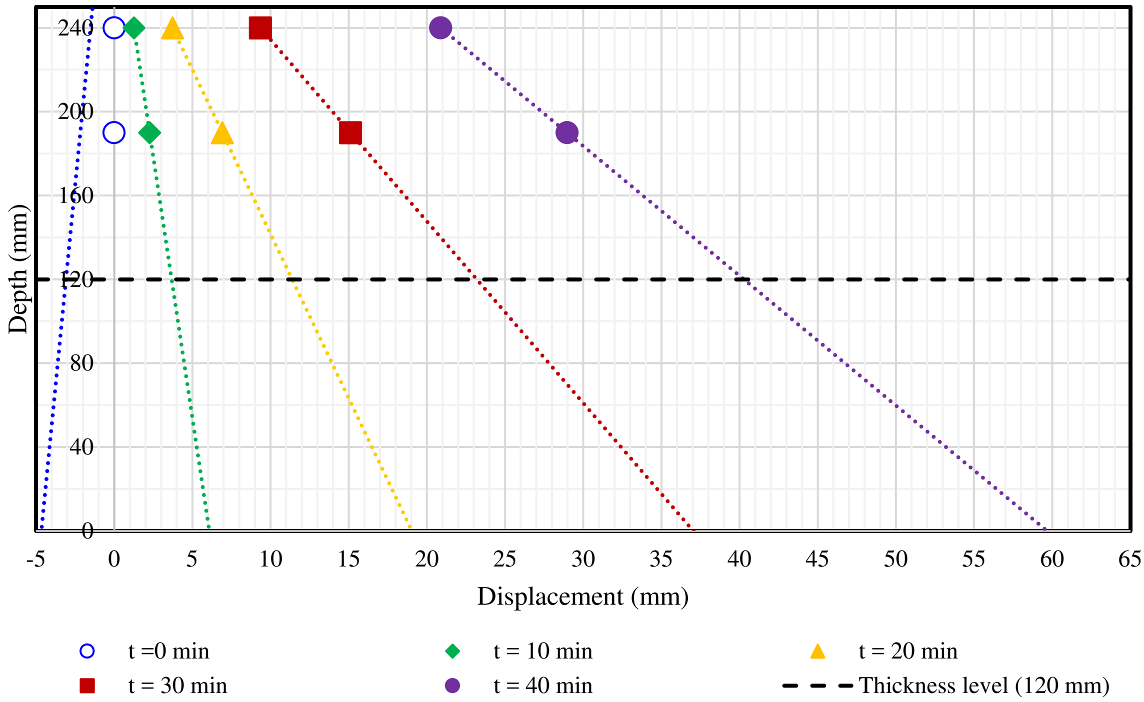
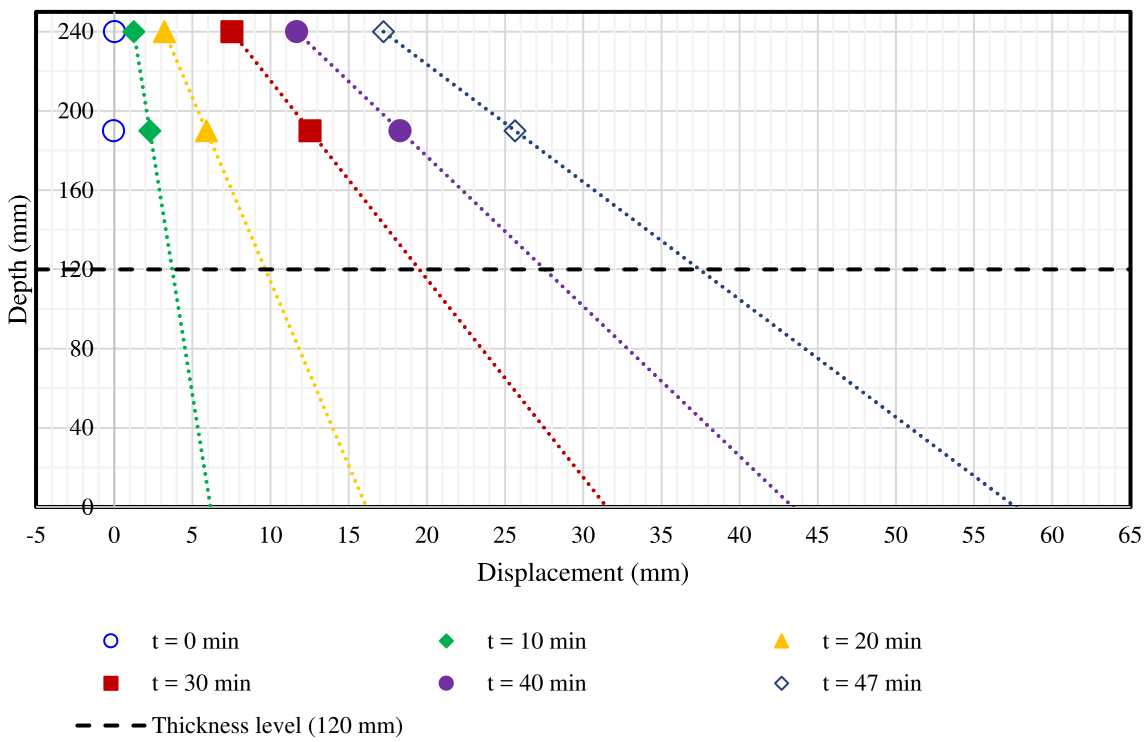



**Fig. 7** Midspan deflections measured during the fire tests

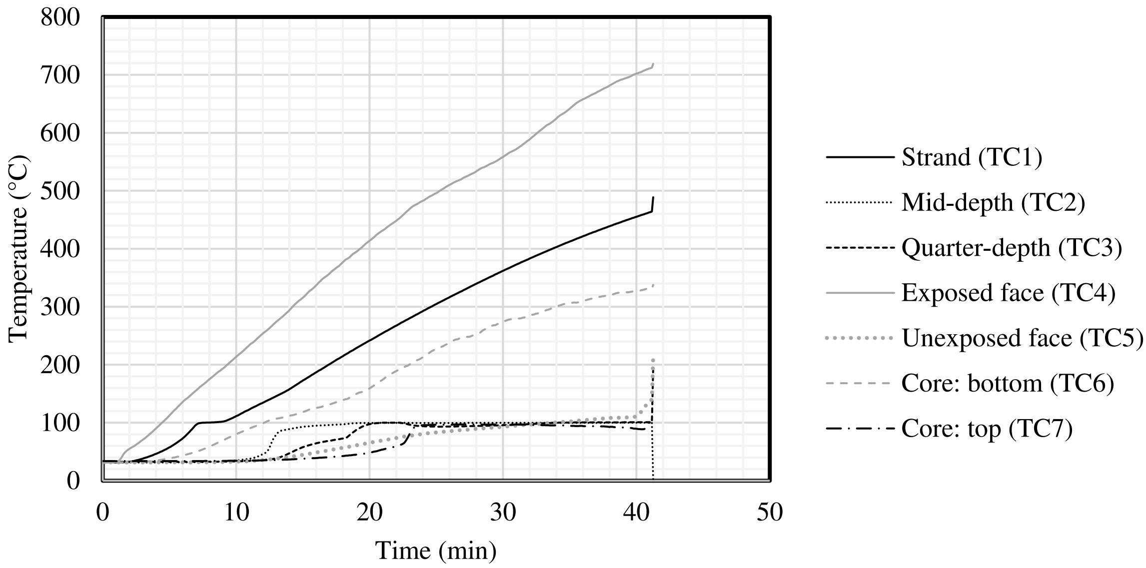



(a)

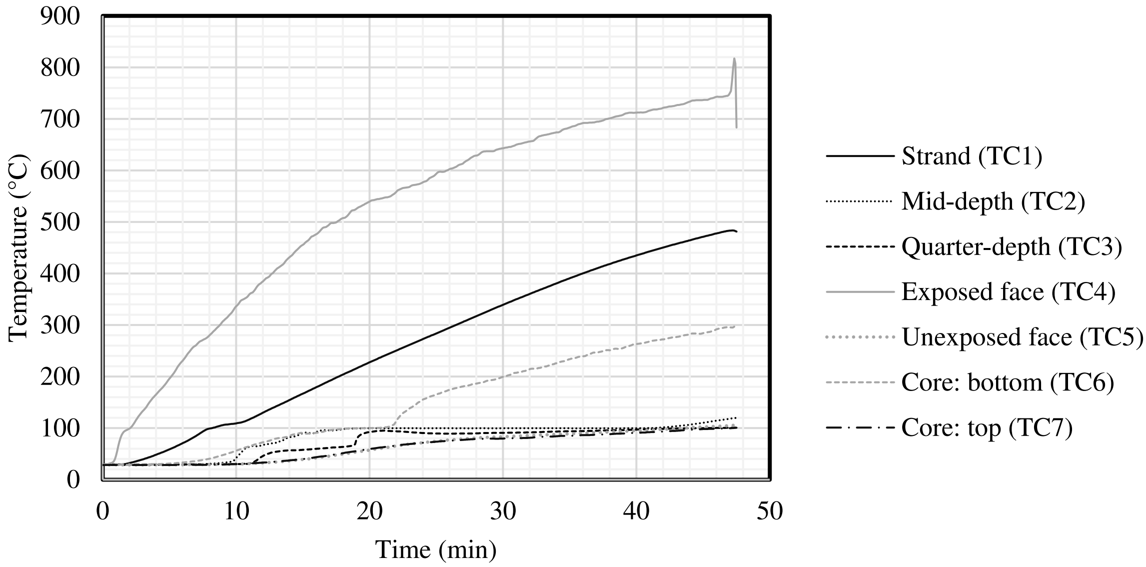



(b)

**Fig. 8** Thermal expansion of the hollow-core concrete slabs during the fire tests: (a) without joint mortar and (b) with joint mortar




(a)




(b)

**Fig. 9** Temperatures of the hollow-core concrete slabs during the fire tests: (a) without joint mortar and (b) with joint mortar

## 4. Conclusions

An experimental study was conducted to investigate the potential impact of the joint mortar on the fire performance of hollow-core concrete slabs. Full-scale fire tests were carried out on precast hollow-core concrete slabs having a thickness of 120 mm, with and without mortar filled in the 100 mm gaps at the ends, using the ISO 834-1 standard fire.

The results confirmed that using the joint mortar with a water-to-cement ratio of 0.5 can induce a certain degree of axial restraint to the hollow-core concrete slabs, as evidenced by the reduced deflection and thermal expansion during the fire tests. The fire resistance period was extended from 39 minutes to 47 minutes, accounting for an increase by 20%, when the specimen was axially restrained by the joint mortar. However, this enhanced fire resistance still failed to comply with the minimum requirement of 60 minutes according to the current fire safety regulations.

Despite its potential merit in fire safety applications, this study has certain limitations. Due to constraints on available resources, certain parameters were not included in the experiment. Further studies may include other variables, such as thickness of hollow-core slabs, size of gaps, and mortar type, in the experimental design.

**References**


[1] Pothisiri, T. & Kositsornwanee, C. (2015). Experimental investigation of the fire resistance of thin hollow-core concrete slabs with simple supports. *Engineering Journal*, 19(2), 139-155.

[2] Allam, S. M., Elbakry, H. M. & Rabeai, A. G. (2013). Behavior of one-way reinforced concrete slabs subjected to fire. *Alexandria Engineering Journal*, 52(4), 749-761.

[3] Kodur, V. K. & Shakya, A. M. (2014). Modeling the response of precast, prestressed concrete hollow-core slabs exposed to fire. *PCI Journal*, 59(3), 78-94.

[4] Pečenko, R., Hozjan, T., Planinc, I. & Bratina, S. (2019). A computational model for prestressed concrete hollow-core slab under natural fire. *International Journal of Concrete Structures and Materials*, 13, 1-17.

[5] Shakya, A. M. and Kodur, V. K. R. (2015). Response of precast prestressed concrete hollowcore slabs under fire conditions. *Engineering Structures*, 87, 126-138.

[6] Chang, J. J., Moss, P. J., Dhakal, R. P. & Buchanan, A. H. (2010). Effect of aspect ratio on fire resistance of hollow core concrete floors. *Fire technology*, 46, 201-216.

[7] Lim, L., Buchanan, A. H. & Moss, P. J. (2004). Restraint of fire-exposed concrete floor systems. *Fire and Materials*, 28(4), 95-125.

[8] Thienpont, T., De Corte, W., Caspeele, R. & Van Coile, R. (2023). Fire resistance and associated failure modes of axially restrained hollow core slabs. *Fire Safety Journal*, 139, 103827.

[9] ASTM International (2024). ASTM E119: Standard test methods for fire tests of building construction and materials. West Conshohocken, PA.

[10] ASTM International (2018). ASTM C805: Standard test method for rebound number of hardened concrete. West Conshohocken, PA.

[11] ASTM International (2024). ASTM A370: Standard test methods and definitions for mechanical testing of steel products. West Conshohocken, PA.

[12] Thai Industrial Standards Institute (2013). TIS 2594-2556: Standard for reinforced concrete structures. Bangkok, Thailand.

[13] ASTM International (2024). ASTM C33: Standard specification for concrete aggregates. West Conshohocken, PA.

[14] ASTM International (2021). ASTM C109/C109M: Standard test method for compressive strength of hydraulic cement mortars (using 2-in. or [50 mm] cube specimens). West Conshohocken, PA.

[15] American Concrete Institute (2019). ACI 318: Building Code Requirements for Structural Concrete and Commentary.

[16] International Organization for Standardization (1999). ISO 834-1: Fire-resistance tests - Elements of building construction - Part 1: General requirements. Geneva, Switzerland.