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EFFECT OF TIME ELAPSED BETWEEN SUCCESSIVE CONCRETE POURINGS AND LOCATION OF THE COLD JOINTS ON THE FLEXURAL CAPACITY OF RC BEAMS

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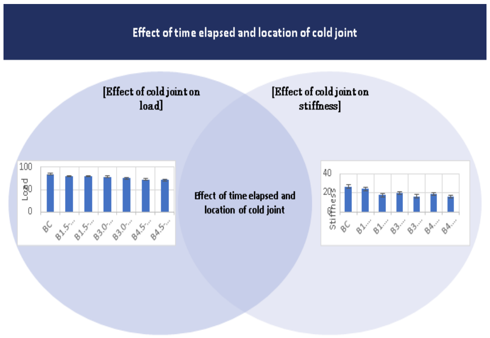
Graphical abstract



Abstract

This research investigates the effect of the time interval between successive concrete pouring and the position of cold joints on properties and flexural strength of RC beams. Two horizontal cold joints at h=110mm and h=50mm were examined. In both cold joint elevations, the time interval between the two pours was varied as 1.5, 3 and 4.5 hours. To achieve the research objectives, six RC beams, in addition to a reference beam of no joint, were tested and analyzed. Test results revealed a decrease of beams' flexural capacity with an increase in time elapsed between periods of pouring from 1.5 to 4.5 hours. The reduction in flexural strength was more evident when a cold joint is located at the compression fiber of a beam (i.e., at h=110mm). Additionally, the stiffness, toughness and ductility structural indices of the tested beams inversely correlated with time intervals between consecutive pourings as well. More specifically, the largest percentage reduction in the ultimate load, stiffness, toughness and ductility of beams with cold joints were 15.58, 41.2, 85.57 and 35.1%, respectively in beams with cold joint at compression fiber (h=110mm) after 4.5 hours between pourings of both layers. Other tested beams with cold joints also showed a reduction in the ultimate load, and all studied structural indices, but with less values when compared with worst scenario discussed above. The results obtained suggest that the behavior of beams with cold joints in structures should be carefully assessed through further research to avoid any catastrophic failures.

Keywords: Cold joint, compression fiber, tension fiber, time elapsed, flexural strength

1.0 INTRODUCTION

A cold joint is a defect or crack that occurs when one of the concrete batches dries before another batch is applied to it [1]. Cold joints are prevalent in major civil engineering projects such as bridges, dams, water tanks and large buildings where continuous pouring is difficult [2]. Conduct of even seemingly insignificant practical components such as limitations in labour, formwork preparation, climatic conditions, construction extensions or surprises at concrete batching plants may prevent fully monolithic concreting from being achieved [3,4]. Cold joints which may form can result in the occurrence of cracks and possible collapse of concrete structures [5]. Such joints lead to poor mechanical characteristics, such as lower resisting forces and increased displacement, which may have implications for structural efficiency [6,7]. Cold joints also make concrete porous and permeable, paving the way for the reinforcement material's rust, and reducing its life span [8,9]. Further, cold joints have bad effects on concrete strength, durability, and aesthetic appearance [10-12]. While measures are taken to reduce the negative impact of cold joints on concrete behaviour, their effects cannot be eliminated [13].

Issa *et al*. [14], Abbas *et al*. [15], and Vanlalruata and Marthong have discussed the influence of vertical, longitudinal and cold joints on concrete (RC) components mechanical properties. The authors discovered a significant decrease in rupture modulus, first crack load, ultimate load, and flexural strength when construction joints are introduced. The consequences of construction joints on flexural and shear behaviour for RC beams/slabs have been investigated by Mathew & Nazeer [16], Al-Rifaie *et al*. [17], Djazmati *et al*. [18] Their studies demonstrate load-carrying capacity, deflection, stiffness, and energy absorption variations among different joint configurations. Furthermore, research conducted by Aziz [20], Bin Osman *et al*. [21], and Gerges *et al*. [22] have investigated the shear strength, compressive strength, and splitting tensile strength of concrete elements with construction joints. Their findings highlight the influence of joint type, interface conditions, and joint shape on the behaviour of structural components.

Other investigations have also utilized finite element analysis to model the behaviour of RC beams with construction joints, as shown by Abdul-Majeed *et al*. [23] and Abdul-Majeed [24]. These studies show that joint layout and configuration significantly influence the strength, ductility, and mode of failure of JBs.

Further, Rathi and Kolase [25], Abass *et al*. ([reshef 26]), and Akin *et al*. These investigations shed some light on the impact of construction joint arrangement and type on global structural response.

Additionally, studies have been carried out regarding the behaviour of specialized concrete, including UHPC with construction joints. Jang *et al*. [27] have shown that steel fibres and grooved shapes affect the increase in shear resistance where construction joint development for (UHPC) was studied

Structural effects of construction joints may depend on one or more factors, including the type and location of the joint area; its size relative to surrounding structure members as well materials characteristics involved in field procedures used during erection/fitting. Thus, detailed inspections and evaluations in every individual case are essential to correctly assess the influence of construction joints on structural dynamics.

In the chosen research, we analyze how the elapsed time between the first and second pouring of concrete affects the performance of cold joints as well as flexural strength in the case RC beams. Also, we seek to explore the influence of joint location and alignments on the flexural behaviour of RC beams. By examining these factors, we aim to contribute to the existing knowledge and provide valuable insights for improved design decisions and construction practices. The remainder of this paper is organized as follows: the methodology provides a detailed process, including the experimental setup or numerical modelling approach. Results and Discussion highlight the key findings and discuss their implications. Finally, the paper's conclusion summarizes the main contributions and suggests avenues for future research.

2.0 METHODOLOGY

This study's methodology begins with the models' preparation, casting, curing, and testing.

2.1 Details of Beam Specimen

Seven normal strength (fc=25 MPa) RC beams have been cast and tested under a four-point loading experiment. The beams were properly engineered to fail in a flexural state according to the ACI Code [28]. The geometry and reinforcement ratio of every experimental beam were the same. Figure 1 displays the geometry and details of the reinforcement of the tested beam specimens. The time elapsed between the first and second pour has been chosen as 1.5, 3.0 and 4.5 hours for practical considerations. After the first layer is poured, the concrete is immediately compacted and left at room temperature for the specified period. Once the target time between the pours is reached, the second concrete layer is poured where three classes of beams have been created to examine the impact of the period of time between the first and second pours. Table 1 shows the description of all beams.

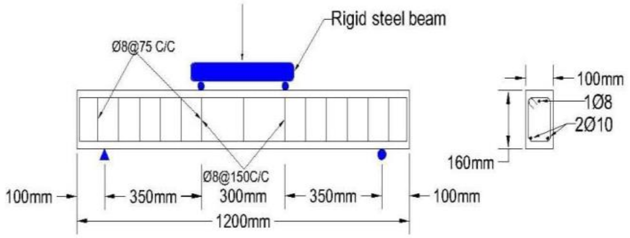


Figure 1 Sample dimensions and details of steel reinforcement

Table 1 Details of Beam specimens

Beam	Number of specimens	Height of joint (mm)	Delay of second pour (Hours)
CB	1	No cold joint	---
B1.5-0.3h	1	50	1.5
B1.5-0.7h	1	110	
B3.0 -0.3h	1	50	3.0
B3.0-0.7h	1	110	
B4.5-0.3h	1	50	4.5
B4.5-0.7h	1	110	

2.2 Casting and Curing

Except for the control beam, which was poured in a single layer, all tested beams have been poured in two layers with a delay time between the first and second layers of either 1.5, 3.0 or 4.5 hours, as stated before. The height of the joint was measured from the bottom fiber. Both layers in all beams have been compacted with the help of an electronic vibrating table to confirm that no air was trapped inside. A steel trowel was used to polish the top surface. The samples were immediately covered with a polyethene sheet to limit the hydration loss of water during hardening and lessen shrinkage. After 36 hours, the mould has been removed. During 28 days, the samples were submerged in basins of water and kept in the normal laboratory environment. After the water from the curing basins had dried out, the specimens were prepared for testing. Figure 2 presents the casting and curing process.

Figure 2 Casting and curing process

2.3 Testing Procedure

The beam samples have been tested at the Engineering College-University of Thi-Qar. A flexural testing device with 200 kN capability was used to measure the flexural strength of the analyzed beams during the experiment. A steel spreader beam installed atop the tested beams divided the machine force into two equal point loads. A digital dial gauge was used to quantify the deflection at the mid-span of the tested beams with a 14 mm travel and 0.01 mm certainty. Any gaps between the specimen from the supporting or loading device were filled with rubber shims, and a constant force of 0.5 kN/s was applied continuously until the test specimens failed. Before testing, it should be noted that all examined beams had been painted with a white hue to make monitoring the cracks and tracking their progression easier. Figure 3 presents the testing procedure.

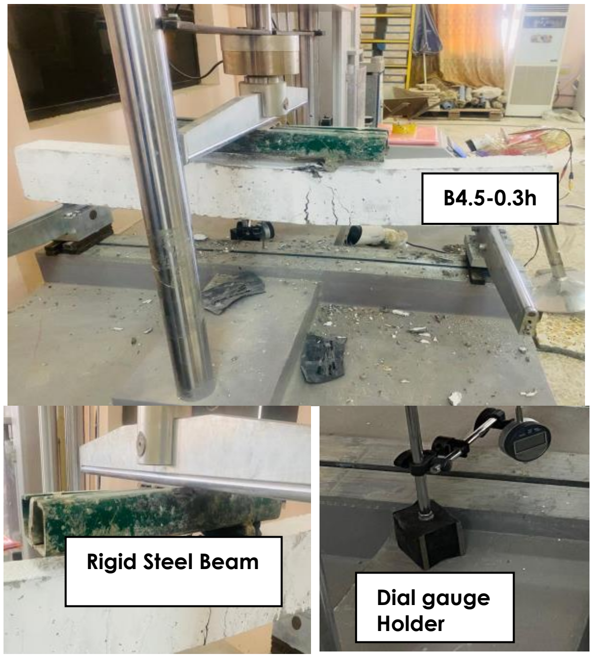


Figure 3 Testing setup

3.0 RESULTS AND DISCUSSION

3.1 Cracking Load and Ultimate Load

The initial crack and maximum load of the tested beams are displayed in Table 2. In general, it should be observed that the cold joint had little to no impact on the initial crack (Pcr) and only significantly impacted the ultimate load and this agrees with reference [26]. The location of the cold joint, has negatively influenced the load carrying capacity and midspan deflection. A significant reduction in the flexural loading capacity has been reported when the joint is located at the compression zone of the beam's cross section (i.e., at 0.7h),and this agrees with reference [13].

Table 2 Results of the tested beams

Beam	Cracking load, P_{cr} (kN)	Ultimate load, P_u (kN)	P_u Decreasing percentage (%)	Ultimate deflection, Δ_u (mm)	Δ_u Decreasing percentage (%)
CB	18	84.23	---	10.67	----
B1.5-0.3h	18	80.08	4.93	9.82	7.90
B1.5-0.7h	18	79.79	5.36	8.32	22.00
B3.0-0.3h	15	78.33	7.00	9.20	13.70
B3.0-0.7h	18	75.62	10.22	7.67	28.11
B4.5-0.3h	20	72.62	13.78	6.94	34.95
B4.5-0.7h	18	71.10	15.58	6.62	37.95

In Figure 4, the effect of cold joints on ultimate load is presented. For tested beams (B1.5-0.3h) and (B1.5-0.7h), which were cast after 1.5 hours from pouring the first layers, the decrease in strength was 4.93% and 5.36% compared to that of the reference beam (CB). For beams (B3-0.3h) and (B3-0.7h), which were cast after three hours after pouring the first layers, the decrease in strength was 7.00 and 10.22%, respectively. While for tested beams (B4.5-0.3h) and (B4.5-0.7h), which had 4.5 hours elapse between the first and second layers, the decrease in strength was 13.78 and 15.58%, which indisputably shows that a longer time delay between the first and second layers may result in a larger decrease in the total capacity ,this agrees with reference [3].

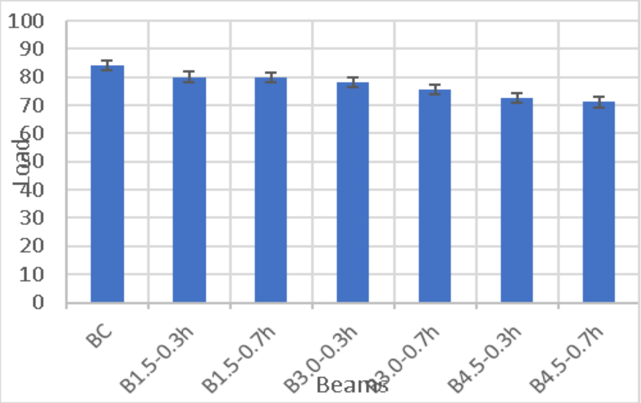


Figure 4 Effect of cold joint on ultimate load

3.2 Load Versus Deflection

The relationships between applied load and eflection for the experienced beams are displayed in Figures 5 to 7. It may be seen that almost all load-deflection curves are featured by three distinct regions. The linear behaviour of the load-deflection curves (i.e., the elastic stage) without cracking typically precedes the nonlinear behaviour of the curve with elastic cracking. Finally, the third region of plastic behaviour of clear deflection increases without an appreciable increase in load applied. The deflection values of the control beam were higher than those of the beams with cold joints (CJ), which means that such joints have negatively influenced the ductility of the cold joint beams.

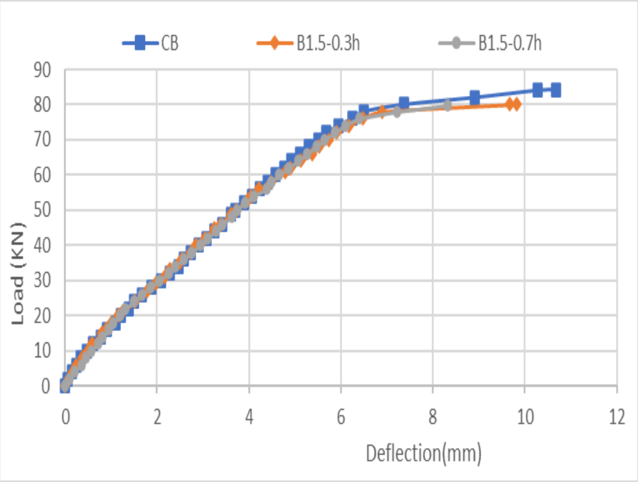


Figure 5 Load-deflection for beams were cast after 1.5 Hours

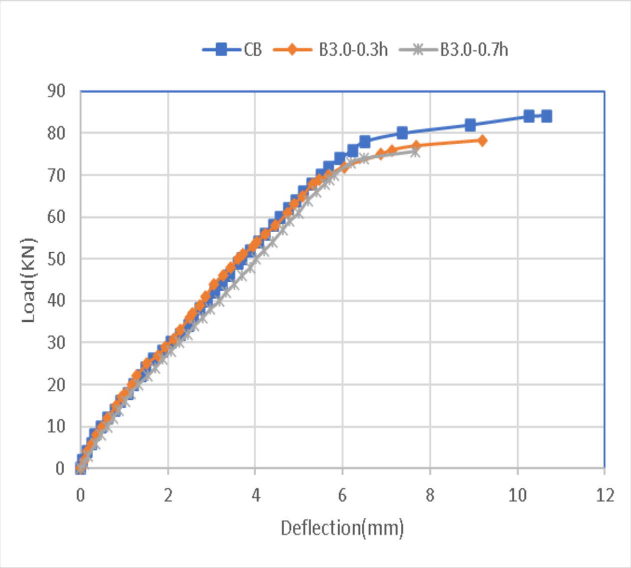


Figure 6 Load-deflection for beams were cast after 3 hours

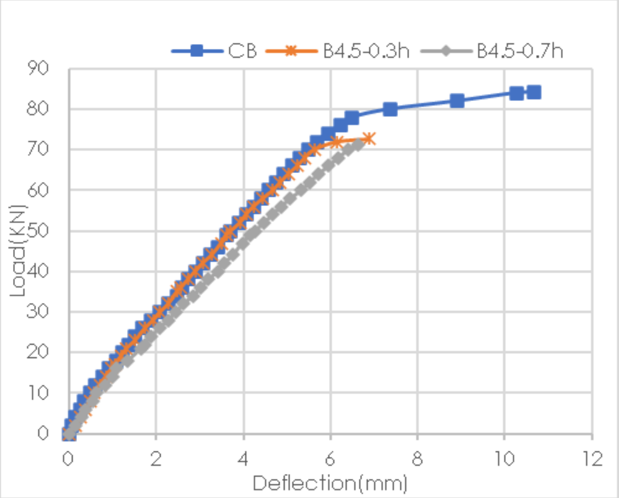


Figure 7 Load-deflection for beams casted after 4.5 hours

3.3 Failure Modes and Crack Pattern

Figure 8 displays the tested beams' crack pattern. All beams failed due to extensive flexural stresses, as expected.

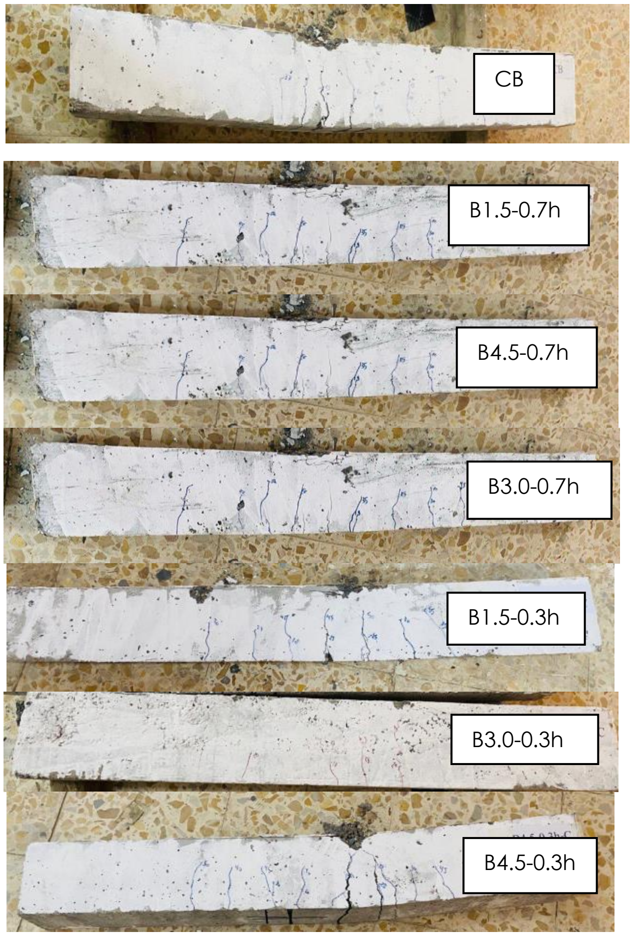


Figure 8 Crack patterns of all beams

The first crack in the control beam (CB) and the other beams started roughly at 18 kN load. By increasing the applied loading, the cracks formed started to grow further and progress towards the compression fibre of the beams, and new cracks began to form. Some minor flexural-shear cracks have been appeared during testing. The ultimate load capacity of "cold joints" tested beams depends on the cold joints' location and the time period between the first and second pour. When the load was raised, the flexural cracking generally worsened until each beam's maximum capacity was reached.

3.4 Effective Stiffness

This sort of construction problem necessitates the evolution of effective stiffness. The stiffness of the beams was determined using the slope of the line between the origin and a point before the cracking load to compare the experiment's results quantitatively. This shows that when the beams were in the linear stage, the load vs. deflection curve defined the stiffness of the beam. It is clear that an increase in the time elapsed between pouring the first- and second layers reduces stiffness. The reference beam's (CB) effective stiffness was 26.26 kN/m, while the stiffnesses of all other beams with cold joints were less than the control beam, as indicated in Table 3. The loss in the ultimate carrying capacity of non-homogeneous specimens can be explained by a drop in stiffness caused by joint movement.

Additionally, the existence of joints at the compression fibre should be observed. (i.e., 0.7h) had the greatest negative influence on the tested beams' ultimate flexural capacity regardless of the time elapsed between the first and second pours of concrete. In addition, as the time pours of both layers of concrete increases, the degradation in stiffness increases as well. Figure 9 show the effect of cld joints on stiffness.

Table 3 Effective Stiffness of Tested Specimens

Beam	Stiffness (KN/mm)	Reduction (%)
CB	26.60	---
B1.5-0.3h	24.00	9.7
B1.5-0.7h	17.50	34.2
B3.0-0.3h	20.00	24.8
B3.0-0.7h	16.30	38.7
B4.5-0.3h	18.75	29.5
B4.5-0.7h	15.65	41.2

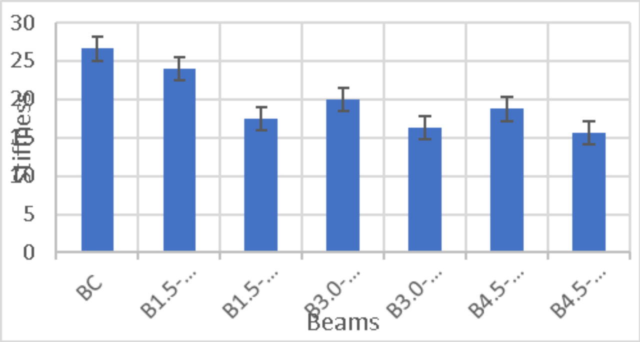


Figure 9 Effect of cold joint on stiffness

3.5 Toughness

Table 4 provides information about the planned and listed toughness of the tested beams. Determine the influence of cold joints on flexural behaviour. The region under the load-deflection curve has been employed to produce this index [29]. The reduction percentages of toughness ranged from 9.31 to 38.23% for the beams which were cast after 1.5 hours from pouring the first layers. For tested beams were cast after 3.0 hour from poring the first layer, the maximum decrease in toughness was 46.31%. While for tested beams which had time elapsed between first and second layers of 4.5 hours, the decrease in toughness has reached to 60.56% which clearly indicate that the increase of time between the first and second layers can cause a greater reduction in toughness and this agrees with reference [3].

Table 4 Effective Toughness of Tested Beams

Beam	Toughness (kN.mm)	Reduction (%)
CB	651.95	---
B1.5-0.3h	591.27	9.30
B1.5-0.7h	426.97	34.50
B3.0-0.3h	471.65	27.65
B3.0-0.7h	350.04	46.31
B4.5-0.3h	307.34	52.82
B4.5-0.7h	257.11	60.56

3.6 Effective Ductility

When there is a construction joint in concrete members, one of the most crucial considerations that must be made is the ductility. The ability of a structure or member to sustain a load after yielding longitudinally in the inelastic range without failing is known as ductility. The definition of the ductility index is presented in Eq. 1:

$$\mu = \Delta u / \Delta y \qquad \text{(Eq. 1).}$$

Specimens with a horizontal cold joint showed a lower ductility index than reference specimens. This result is consistent with the findings presented in the reference [15]. The reduction percentages of ductility ranged from 7% to 20.5% for beams which were cast after 1.5 hours from pouring the first layers. For tested beams which were cast after 3.0 hours from pouring the first layers , the decrease in ductility index was 31.6%. While for tested beams which had time elapsed between first and second layers of 4.5 hours, the decrease in ductility index was 35.1% which clearly indicate that the increase of time between the first and second layers can cause a greater reduction in ductility index.

Beam	Δy (mm)	Δu (mm)	μ (Ductility index)	Decrease in ductility (%)
CB	6.24	10.67	1.71	-----------
B1.5-0.3h	6.17	9.82	1.59	7.0
B1.5-0.7h	6.09	8.32	1.36	20.5
B3.0-0.3h	5.88	7.00	1.19	30.4
B3.0-0.7h	6.55	7.67	1.17	31.6
B4.5-0.3h	5.70	6.94	1.16	32.1
B4.5-0.7h	5.95	6.62	1.11	35.1

4.0 CONCLUSION

This research intended to study the behavior of RC beams containing cold joints formed by pouring the concrete in two layers at intervals between pours of 1.5, 3.0, and 4.5 hours. The cold joints investigated were located at the tension and compression fibers. The results obtained showed that the cracking load has not been impacted by the existence of cold joints, regardless of the position of the joint and the time between pours. On the other hand, cold joints have significantly affected the ultimate load, location of the joint (i.e., at the tension or compression side of the beam) and the time elapsed between concrete pours. For the beams with cold joints at the tension side, it has been found that when the period between concrete pours increases, the ultimate strength decreases proportionately with the decrease in flexural strength was 4.93, 9.03, and 13.78% similarly for B1.5, B3.0, and B4.5. Again, for beams with cold joints, the % decrease in strength at the compression side was 5.36, 10.22 and 15.58% for beams B1.5, B3.0 and B4.5, respectively.

Additionally, the studied structural indices such as stiffness, toughness and ductility were also decreased as the time between pours is increased. In the worst scenario when h=110mm and t=4.5 hrs, the reduction percentages of stiffness, toughness and ductility reached 41.2, 85.57, and 35.1% respectively, compared to the reference beam. Similarly, the presence of cold joints has also negatively affected the ultimate deflection at failure and, therefore, caused the tested beams to fail in a more brittle mode in contrast to the reference beam. For example, the percentage reduction in the mid-span deflection of beam "B4.5-0.7h" reached 38% compared to the reference beam. With respect to the location of cold joints, test results showed that the presence of cold joints in the compression zone (h=110mm) is most critical than joints in the tension zone (h=50mm) of the beam. This is because concrete material is the normally the only material on the compression zone of the beams' cross-section responsible for resisting flexural stress, and any inconsistency in its properties may negatively influence the overall behavior of the beam.

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Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper.

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