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Effects of Compaction State and Position of the Cold Joints on the Flexural Capacity of RC Beams

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Abstract

Cold joints are necessary stops in the concrete placement process since pouring concrete in one continuous operation in many structures is impossible. The strength of the formwork and the batching and mixing capacities determine how much concrete can be placed at once. A well-made construction joint should have sufficient shear and flexural continuity across the interface. In this study, the effect of the position of cold joints and the compaction state of the first concrete layer on the flexural strength of reinforced concrete is experimentally investigated. Five beam specimens with dimensions of 160×100×1200 mm were tested. The variables investigated are the position of the cold joints (which were placed horizontally at compression fiber and tension fiber of the beams), and whether the first poured concrete layer is compacted or just left uncompacted until the second pour is placed To study the effect of the cold joint and compaction process on the ultimate load. The research results indicated that the ultimate load, ultimate deflection, ductility, and toughness were all reduced due to such cold joints. These behavior indices were primarily dependent on the location of the cold joint and compacted first layer. The compaction of the first layer and the location of the cold joint has a significant effect on the load-carrying capacity and the corresponding deflection of the tested beams, the decrease in ultimate load, ultimate deflection, ductility, and toughness for the beam, which was compacted, and placed horizontally at tension fiber were 13.78%, 34.95%, 32.1%, and 84.04% respectively. In contrast, for the beam which was uncompacted first layer, the decrease was 31.35%, 29.52%, 31.6%, and 61.03%. The decrease in ultimate load, ultimate deflection, ductility, and toughness for beams which was compacted and placed horizontally at compression fiber were 15.50%, 37.95%, 35.1%, and 85.575%, respectively, while for beam which was uncompacted first layer, the decrease was 40.91%, 43.76%,33.9%, and 72.7% respectively.

Keywords— Cold joint, Compaction Process, Position, Flexural Strength.

1. Introduction

Cold joints can be defined as stopping points in the concrete casting process; the necessity for such joints stems from the impracticability of casting concrete in a single continuous operation. The strength of the formworks and the mixers' capacity determines how much concrete can be produced at once. As a result, there may be delays in the concrete casting process, followed by several restarts that cause the construction joints to commence (Aziz, 2006). Construction joints can often be classified into four types according to the plane in which they are constructed: transverse, longitudinal, vertical, and horizontal joints (Dulaimi et al., 2020; Shanbara et

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al., 2020). There are both horizontal and vertical joints in beams, but only horizontal joints are found in columns and large concrete constructions. Maintaining adequate flexural continuity and shear transfer across the joint is the primary goal of joint placement. Flexural continuity can be achieved through continuous strengthening throughout the joint. Shear friction between the old and new concrete or dowel action in the reinforcing material of the joint provides shear transmission (ACI Committee 224, n.d.; Al-Husainy et al., 2020; Al-Rifaie et al., 2017, 2018). The most effective location for the construction joint is at the point of least shear, according to research on the impact of construction joint position on the performance of reinforced concrete (RC) structural elements (Abass, 2012). It was also determined that the strength of beams is noticeably decreased when inclined construction joints are present. Comparing the ultimate load capacity to the strength of the beam without construction joints, there is an 8% to 20% reduction in strength based on the unreinforced concrete test results. Testing unreinforced concrete construction joints under in-plane shear loads revealed that properly prepared and prepared members with a moist-cured joint offer an initial stiffness comparable to a member cast monolithically (Basel Djazmati & J. Pincheira, 2004). Furthermore, it has been discovered that the presence of construction joints reduces a monolithic specimen's splitting tensile strength by around 55% (Gerges et al., 2015). In the literature(Issa et al., 2014), when compared to a reference beam, it was discovered that the existence of a vertical construction junction at mid-span decreased the overall flexural strength by about 55%. The horizontal construction joints have a slight effect, while the vertical type has a great effect on the ultimate capacity of the concrete beam. The vertical construction joint is preferable to be located within the middle third of the beam span and the horizontal type in tension zone of beam (Kadhum et al., 2024). According to the findings of experiments, it has been found that the inclusion of horizontal construction joint (HCJ) in reinforced concrete beams decreases the cracking and ultimate loads of the beams and increases their ultimate deflection. Nevertheless, no discernible change in the value of the beam deflection at the first crack was reported (Hameed Naser Al-Mamoori & Hameed Naser Al-Mamoori, 2018). The literature (Abbas et al., 2018) determined that the ultimate load, first crack load, and stiffness all reduced during the course of the study, decreasing by 15.4%, 14.7%, and 28.7%, respectively, at 70 mm level in contrast to a monolithic beam. When compared to a monolithic beam, the reduction in ultimate load, first crack load, and stiffness at 210 mm level was 26.2%, 22.9%, and 66.5%, respectively. (P. Paramasivam & M. A. Mansur, 1985) investigated the flexural and tensile properties of various types of joints used in ferrocement building. Test results were presented by (Basel Djazmati & J. Pincheira, 2004) for shear resistance of unreinforced concrete slabs with construction joints. It was indicated that slabs with wetted joints have similar initial stiffness to that cast monolithically. (Gerges et al., 2016) conducted an experimental investigation aimed at the flexural behavior of single beams made of reinforced concrete with vertical construction joints. For normal strength concrete, charts were provided to forecast the reduction in the flexural capacity of such beams.

The present study aims to investigate the effect of compaction of the first RC layer and the effect of joint location and alignments on the flexural behavior of RC beams.

2. Experimental Study

2.1Materials

2.1.1Cement

Ordinary Portland Cement (OPC), Type-1 was used in the concrete mixture. The physical and chemical test findings of the cement satisfy ASTM C-150 criteria (ASTM International, 2017).

2.1.2Coarse Aggregate

The durability of the concrete mixture was provided by the choice of coarse aggregate. The maximum size of coarse aggregate particles is 9.5 mm. The test results for coarse aggregate satisfy ASTM C33/C33M requirements (ASTM International, 2018).

2.1.3 Fine Aggregate

Sand, a naturally occurring fine aggregate, was utilized. The physical and chemical test results conform to the limits of the specification (ASTM C33) (ASTM International, 2018).

2.1.4 Steel reinforcement

Tension test results for the bar used are displayed in Table 1. The test results satisfy the ASTM A615 criteria. Deformed steel bars, 10 mm, and 8 mm were employed as the primary reinforcing bars and shear reinforcing stirrups for the beams (ASTM International, 2020).

Table 1 Mechanical properties of steel bars

Bar diameter(mm)	Actual diameter (mm)	Yield strength (MPa)	Ultimate tensile strength (MPa)
10	10	544.04	647.01
8	8	340.07	515.13

3. Mix design

There are 430 kg of cement, 1050 kg of gravel, 750 kg of sand, and 180 kg of water in one m3 of the concrete mixture. As specified by ASTM-C94, the mixing procedure was used. (ACI Committee 318, 2019).

4. Test Specimens

These five beams were constructed to investigate the impact of horizontal cold joints on the behavior of reinforced concrete. Their dimensions and steel reinforcement ratio were selected according to ACI 318M-2014 requirements for the reinforced concrete structures. The overall length of the tested beams was (1200) mm, and with a cross-section (b x h) of (100×160) mm, dimensions and steel reinforcement ratios of reinforced concrete structures were selected. The flexural reinforcement was composed of two deformed bars of 10mm diameter located in the beam bottom fiber, and the shear reinforcements were of 8mm diameter deformed bars forming closed stirrups spaced at 75mm. Additionally, one bar of 8mm diameter was used on the top of the beams to support the stirrups, as seen in Figure 1.

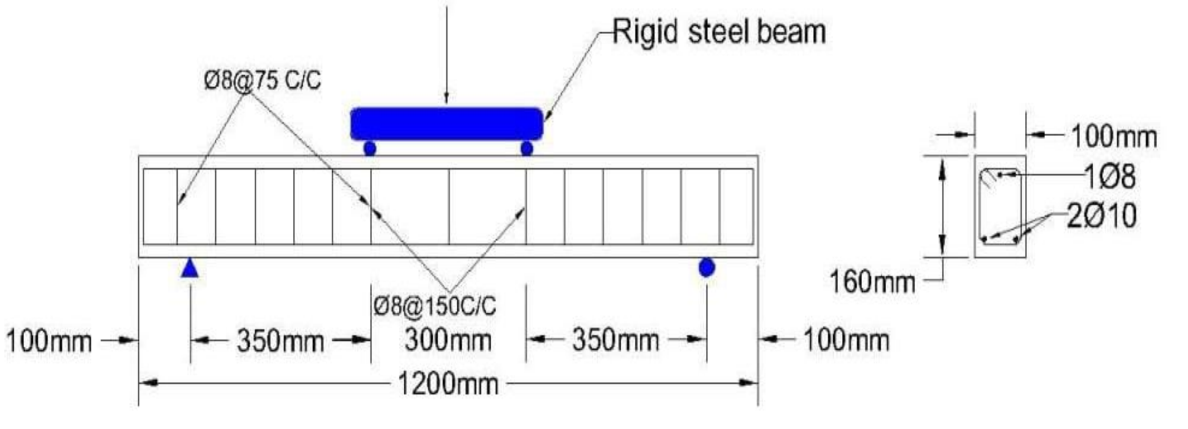

Figure 1: Sample dimensions and details of steel reinforcement

The compaction technique and the position of the cold joints served as the study parameters. Table 2 shows the description of all beams.

Table 2: Details of Tested Beams

Beam ID	Time (Hours)	No of specimen	Position of cold joint	Compaction state
CB	----	1	----	----
B4.5-0.3h-C	4.5	1	Tension fiber	The first layer had been compacted
B4.5-0.7h-C		1	Compression fiber	
B4.5-0.3h-NC		1	Tension fiber	The first layer had not been compacted
B4.5-0.7h-NC		1	Compression fiber	

4.1 Experimental Work

To achieve the goals of the study, five RC beams have been cast and tested under a four-point load. where the beams were divided into two groups to investigate the effects of the location of the joint (i.e., at the tension side of the section at 0.3h and at the compression side of the section at 0.7h), and whether the first pour had been compacted before pouring. The second pour in each group was done after 4.5 hours after pouring the first pour. Therefore, each beam of this group, excluding the reference beam, has a horizontal cold joint with different joint characteristics as compared to other specimens.

4.2 Casting and curing

Before casting, all molds had been thoroughly cleaned, and their surfaces inside were lightly oiled to avoid the hardened concrete from being adhered to the inside surface. Before the concrete was poured into the mold, the steel reinforcement was held in place inside the mold. After the end of mixing, the concrete was poured into the standard mold for casting the beams in two layers. The control beam was compacted by using an electric vibrator. It should be noted here that the compaction process is an experimental variable and not all beams have been compacted. The vibrator was used to be sure that enough amount of concrete got into all small regions and to eliminate the voids. The samples were immediately covered with polyethylene sheets to reduce shrinkage and limit the hydration loss of water during hardening. Following casting, the specimens were kept in the lab for 36 hours under a plastic sheet. The molds are then opened, samples are taken out, labeled, stored, and given a full 28 days to cure before testing.

5.Result

5.1 First crack load and ultimate load

The load at which the first visible crack has been noticed for each beam is listed in Table 3. Generally, it can be noted that the cold joint had no noticeable effect on the first cracking load and the corresponding deflections of the tested “RC” beams and the variations in the reported cracking loads (i.e. $\pm 4\text{kN}$) is due to the heterogeneous nature of concrete, the accuracy of the testing machine, and the method used to capture the crack.

Table 2 Results of the tested beams

Beam	Cracking load, Pcr (kN)	Ultimate load, Pu (kN)	Pu Decreasing percentage(%)	Ultimate deflection, Δu (mm)	Δu Decreasing percentage (%)
CB	18	84.23	---	10.67	----
B4.5-0.3h-C	20	72.62	13.78	6.94	34.95
B4.5-0.7h-C	18	71.16	15.50	6.62	37.95
	15	57.82	31.35	7.52	29.52
B4.5-0.7h-NC	18	49.77	40.91	6.0	43.76

In comparison to the control beam (CB), the tested beams (B4.5-0.3h-C and B4.5-0.7h-C) showed a drop in strength of 13.78 and 15.50 after 4.5 hours of pouring the first layers and compacting them. The tested beam's strength decreased to (31.35 and 43.76) when it cast 4.5 hours after the initial layers were poured and without the first layers compressed, which clearly shows the location of the joint, and leaving the first layer uncompacted prior to pouring the second layer have significantly affected the overall results of this group.

5.2 Load versus deflection

For every tested beam, the load-deflection relationships can be divided into the following three stages: During the first stage, all beams have the same beginning slope, which is linear, and the deflections are related to the loads. The behavior is linear once more in the second stage, although the gradients are less, which could be the result of cracking starting. In the final stage, when the cracks spread, the horizontally cold beams become less stiff and fail without deflecting greatly in relation to the other beams. Nonlinear relationships have been observed throughout this stage. Additionally, when compared to the control beam, BC, it was shown that the maximum deflection of cold joint specimens with and without a compacted initial layer decreased by 34.95%, 37.52%, 29.52%, and 43.76%, respectively**.** The applied load versus deflection relationships of tested beams are shown in Figure 2 and Figure 3.

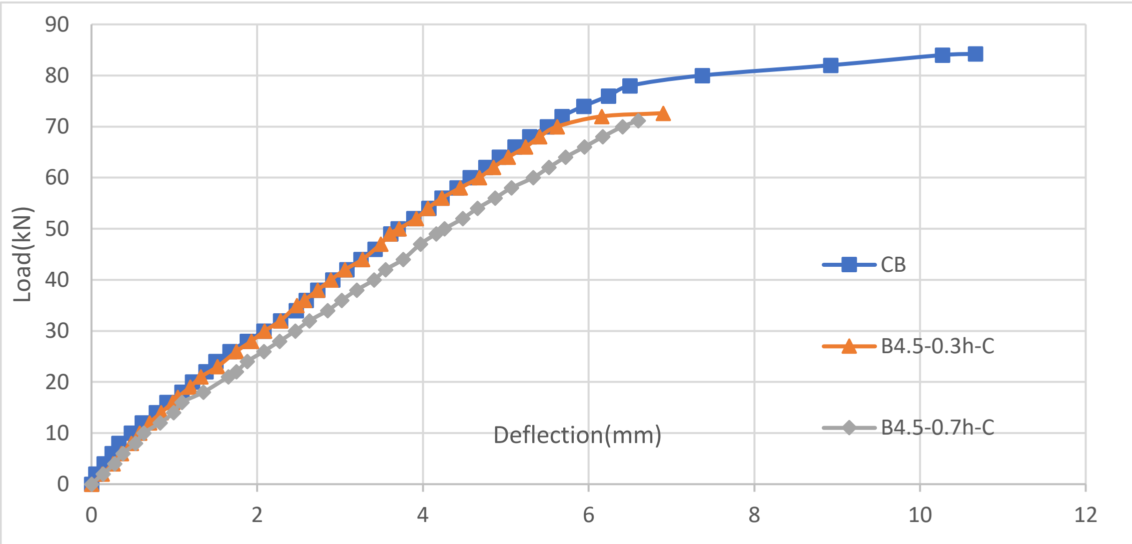

Figure 2: Load-deflection for beams which had compacted first layer

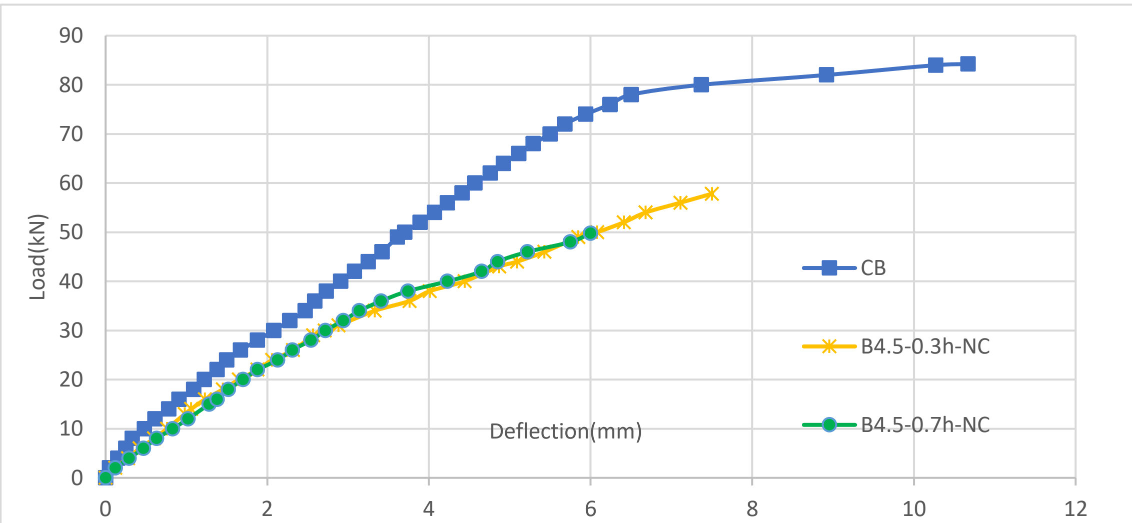

Figure 3: Load-deflection for beams which had not compacted first layer

5.3 Crack and Failure Patterns

Figure 4 shows the crack pattern of tested beams. All beams failed due to extensive flexural stresses as expected**.** All beams failed in flexural. At load level 18kN under the point load, the control specimen (CB) had the first noticeable crack. The initial cracks grew wider and spread upward in a vertical direction as the applied loading increased. Along the length of the beam, other flexural cracks also appeared and cracked. Diagonal cracks were seen around the supporting points; some of these cracks were connected to the flexural cracking that formed the shear-flexural cracks. It is noteworthy to emphasize that horizontal cracks were discovered at the horizontal cold joints of the beams.

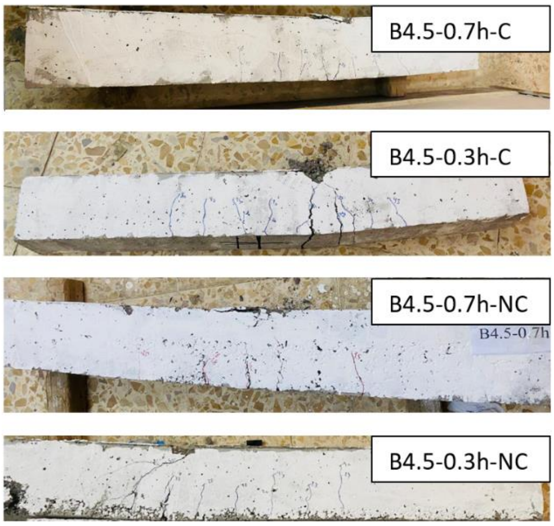

Figure 4: Crack patterns of all beams

5.4 Ductility

Ductility is the capacity to experience inelastic deformation before failing. By increasing energy dissipation and minimizing damage, it lowers dynamic load demand and serves as a warning mechanism before final failure. The ratio of ultimate displacement to yielding displacement was designated as the ductility index (Yoo & Yoon, 2015). The definition of deflection ductility is investigated in this study. As defined by Pam (Pam et al., 2001), the deflection ductility index (μΔ) is the ratio of maximum deflection (Δu) to yield deflection (Δy). Several various definitions have been suggested by Park (Park, 1989). The ductility of all tested beams has been computed and is presented in Table 4.

Table 4: Effective ductility of Tested Specimens

Specimen	Δu (mm)	Δy (mm)	μ (ductility index)	Decrease in ductility
CB	10.67	6.24	1.71	-----------
B4.5-0.3h-C	6.94	5.70	1.16	32.1%
B4.5-0.7h-C	6.62	5.95	1.11	35.1%
B4.5-0.3h-NC	7.52	6.41	1.17	31.6%
B4.5-0.7h-NC	6	5.31	1.13	33.9%

5.5 Toughness

The concrete specimen's energy absorption capacity can be assessed using the area defined by the load-displacement curve up to the ultimate condition, which indicates potential energy absorption before a significant decrease in load-bearing capacity (Yu et al., 2016). Energy absorption capacity has been shown in earlier research to be the best measure of a concrete building's ability to resist seismic motion and the impact load resulting from terrorist attacks or accidents. (Yu et al., 2016). toughness indices of all tested beams have been computed and are presented in Table 5.

Table 5: Effective Toughness of Tested Beams

Beam	Toughness	Degrease in toughness
CB	651.95	-------------
B4.5-0.3h-C	104.01	84.04%
B4.5-0.7h-C	94.05	85.57%
B4.5-0.3h-NC	254.04	61.03%
B4.5-0.7h-NC	177.43	72.7%

6. Conclusion

This research was intended to investigate the behavior of RC beams containing horizontal cold joints formed by pouring the concrete in two layers at the time interval between pours and 4.5 hours. The following notes can be reached:

- The presence of cold joints has not affected the cracking load regardless of the position of the joint and compacting process.
- The presence of a horizontal cold joint in tension fiber is more critical than the joint in compression fiber. For the beams with cold joints at the tension side due to the fact that the concrete in the tension zone has little contribution to the strength of beams and therefore, any inconsistencies in the concrete quality at the tension side would result in an insignificant effect on the overall flexural behavior of RC beams
- Compacting the first layer prior to pouring the second layer has the most significant effect on the results. Where the percentage decrease in flexural strength was 13.78, 15.50% for beams that had compacted the first layer, but the decrease for beams that had not compacted the first layer was 31.35%,40.91
- Performance structural indicators, such as ductility and toughness, have been significantly impacted by the presence of cold joints. The ductility and toughness lower the percentages attained to 35.1% and 85.57%, respectively, compared to the control beam.
- In general, a beam with a cold joint is less stiff after the first crack load than a beam without a cold joint, and before the first crack, the effect is very little.

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