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Flexural behaviour of reinforced concrete beams with horizontal construction joints

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Abstract. In the present research, ten simply supported reinforced concrete beams having a rectangular cross- section were cast and tested up to failure under the action of two-point loads. Eight of these beams were designed to contain horizontal construction joints (HCJs) of different number and location in the beam while the other two beams had no construction joint which were referred to as reference beams for the sake of comparison of results. All the tested beams had been designed to fail in flexure and had the same amount and type of longitudinal and transverse reinforcement as well as similar concrete properties. The results of this series of tests have indicated that the presence of HCJs in reinforced concrete beams leads to a decrease in its ultimate loads and increase in its ultimate deflection. The values of the recorded ultimate loads ranged between 83% to 98% times that of the reference beam while the ultimate deflection ranged between 102% to 133% times that of the reference beam.

Keyword: cold joints, concrete interface, construction joints, flexural behaviour,

1. Introduction

Construction joints can be defined as stopping places in the process of concrete casting. They are needed as it is difficult to place concrete in a continuous process for big structures. The joint should be considered a construction joint if concrete placing is stopped for longer than the initial setting time. Generally, construction joints can be classified according to the plane of joint construction into four groups; horizontal, vertical, longitudinal and transverse joints [1,2]. In beams, there are horizontal and vertical joints, while columns and massive concrete structures have horizontal joints only. The main concern in joint placement is providing satisfactory shear transfer and flexural continuity through the joint. Flexural continuity can be achieved by ongoing the reinforcement through the joint, while the shear transfer is provided by shear friction between old and new concrete and/or dowel action in reinforcement through the joint [3–6]

Different studies were conducted to investigate the response of structural members with construction joints to the quasi-static loading. Paramasivam et al. [7] studied the tensile and flexural behaviour of various types of joints in ferrocement construction. The ultimate moment capacity is significantly reduced. Test results were presented by Djazmati et al. [8] for shear resistance of unreinforced concrete slab with construction joints. It was indicated that slabs with wetted joint have similar initial stiffness to that cast monolithically. Nagib et al. [9] carried out an experimental study to investigate the flexural behaviour of single reinforced concrete beams having vertical construction joints. Charts were proposed to predict the loss in the flexural capacity of such beams for a normal strength concrete. An experimental study was presented by Jang et al. [10] to develop construction joints using ultra-high-performance concrete (UHPC). The findings show that steel fibers and grooved geometry significantly affect shear resistance. Issa et al. [11] investigated the effect of the vertical construction joints on the modulus of rupture. It was observed that providing a vertical joint lead to a significant reduction in the modulus of rupture varies between 24 to 83%.

It can be observed that previous researches have paid little attention to the effect of construction joints on the flexural strength of reinforced concrete, but rather discussed their effect on the shear strength of such elements, therefore it is thought important to introduce this study in the research program supported by the results of a series of experimental tests. The primary objective of this research is to obtain further information on the effect of the horizontal construction joints on the flexural strength capacity of reinforced concrete beams by studying the load-deflection behaviour of such beams (containing HCJs) and the effect of the position of the joints on the behavior of these beams, then trying to limit the reduction of moment capacity of jointed beams by comparison with unjointed beams.

2. ACI Code requirements

1. ACI Committee 224 R [3] was a report which reviewed the state of the art on design, construction, and maintenance of joints in concrete structures under different conditions. The desirable location for joints placed perpendicular to the main reinforcement was at points of minimum shear or point of contra flexure. It was also stated that “Horizontal construction joints in beams and girders are usually not recommended”. The latter statement gives the motivation to the authors discussing to what extent that such joints may influence the beam behaviour.
2. ACI 318M-08 Building Code [12] gave a report for the purpose of the shear-friction, the report suggested the following;

a. The surface of the interface when concrete is placed against previously hardened concrete (i.e. construction joint) shall be cleaned and laitance removed.
b. All construction joints shall be wetted and standing water removed immediately before new concrete is placed (saturated surface dry condition).
c. Construction joints should be located where they will cause the least weakness in the strength of the structure, so in beams and slabs, construction joint shall be located within the middle third of their spans.

3. ACI-ASCE Committee 333 [13] recommended that the ultimate horizontal shear strength of a smooth contact surface with a minimum cross-sectional area of steel ties of 0.5 % in each meter (0.15 % in each foot) of a span of contact area but not less than 129 mm^2 (0.2 in^2) was 0.55 MPa and 2.2 MPa (80 psi and 320 psi) for a rough contact surface with the same minimum steel requirement. An increase of 1.03 MPa (150 psi) on a rough surface for each additional area of steel ties equal to percent of the contact area.

3. Experimental procedure

3.1 Materials

Ordinary Portland cement from Kubaysa complying with IQS No. 5/84 was used throughout the current investigation [14]. Natural yellow sand passing through sieve of size 4.75 mm was used. Sieve analysis was performed and the results conform to the limits specified by IQS No 45/84 for zone 2 [15]. Deformed longitudinal steel bars were used with a nominal diameter of 12 mm as tension reinforcement, and 8 mm diameter bars were used as compression reinforcement. 5 mm diameter steel bars at 100 mm spacing were provided as stirrups to prevent shear failure. The material properties were obtained by applying direct tensile test and the results are indicated in Table (1).

Table (1) Material properties of steel reinforcement

Type of reinforcement	Diameter (mm)	Fy (MPa)	Fu (MPa)	E (GPa)
Shear	5	380	425	200

Longitudinal (tension	8	420	510	200
Longitudinal (compression)	12	425	530	200

3.2 Specimens preparation

A mix proportion by weight used was 1:1.8:3.5 (cement: sand: gravel) with a water/cement ratio of 0.55 and a slump between 120-150mm. This gave an average cylinder compressive strength at age of 26 MPa. Beams were cast in moulds made up of timber forms with plywood faces. The concrete of beams having joints was cast to the decided location of the joint then vibrated. After two days, the fresh concrete of a new mix was put on the hardened old concrete and vibrated. No attempt was made to improve the construction joint. Curing of concrete was carried out for 28 days by sprinkling water every 24 hours and covering them with a wet hessian while the control specimens were cured in a water tank.

3.3 Test setup and instrumentation

The load was applied using steel I-beam to divide the total load into two equal points loads. The beams have been tested using a 2450 kN capacity hydraulic Avery type-testing machine to measure the cracking and subsequently the ultimate flexural load. Deflections were measured at the mid-span of the tested beams using a dial gauge of 0.01 mm division and 50 mm travel. Considerable attention was paid to avoid dynamic effect by applying a loading rate of 0.5 kN/m [16,17].

3.4 Matrix of tested beams

Ten beams were cast to investigate the effect of the number and location of horizontal construction joints. Two of them were cast monolithically named, B_{ref1} and B_{ref2}. Other two beams were cast with one HCJ in the middle of the beam height. Those beams were tested and the results show an acceptable correlation in terms of load-deflection relationships and deformation mode. Hence, one beam was cast for each other cases. Table (2) show the summary of the tested beams showing the number and location of the HCJs.

Table (2) Summary of the tested beams

Beam Mark	No. of joints	location of joints**	Location of center line of joints**	Beam shape
B_{ref1} & B_{ref2}	–	–	–	h
B_{1a} & B_{1b}	1	h/2	h/2	h/2, h/2
B_2	1	2/3h	2/3h	h/3, 2h/3
B_3	1	h/3	h/3	2h/3, h/3
B_4	2	h/3 2/3h	h/2	h/3, h/3, h/3
B_5	3	h/4 h/2 3/4h	h/2	h/4, h/4, h/4, h/4
B_6	2	h/2 3/4h	5/8h	h/4, h/4, h/2
B_7	2	h/4 h/2	3/8h	h/2, h/4, h/4

**The locations of joints and their centre lines are measured from bottom face of beam

4. Behaviour of Beams Under Load

In general, the structural behaviour of the beams having HCJ was similar to that of the two reference beams. All tested beams failed in flexure (ductile failure) with a pattern of uniformly distributed vertical cracks completely developing in the tension zone of the beam middle portion. In few beams (namely B5 and B7), the ultimate stage had also witnessed the development of an apparent horizontal crack running in the longitudinal direction of the beam along its middle third at the interface of the lower HCJ **Error! Reference source not found.** show the load-deflection curves for all studied cases.

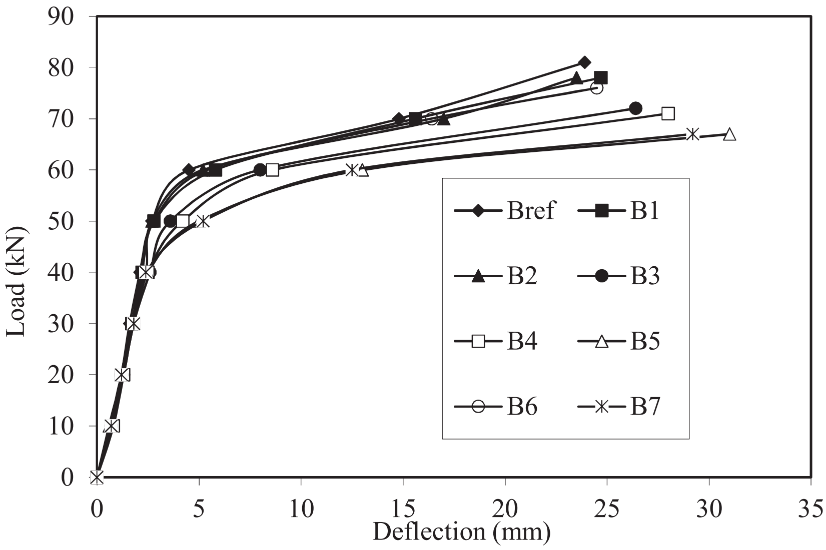


Figure 1. Load-deflection curve for the tested specimens

4.1 Effect of Number of Joints

Four cases of study were chosen to examine the effect of number of joints on the behaviour of reinforced concrete beams. These four cases were the unjointed reference beam (Bref) in addition to the jointed beams (B1), (B4) and (B5) which contain one, two and three joints, respectively. All these three jointed beams had their centre line of joints located at the middle of cross section depth of the beam (i.e at h/2). The effect of number of joints on the load-deflection behaviour of the beam can be summarized as follows:

- Effect on ultimate deflection (δu): Fig. 2 shows that increasing number of joints will increase the ultimate deflection (δ u) as follows; (i) The presence one HCJ in the beam results in ultimate deflection 108%of that of the reference beam. (ii) The presence of two HCJ in the beam results in the ultimate deflection 122%of that of the reference beam. (iii) The presence of three HCJ. in the beam results in the ultimate deflection 133% of that of the reference beam
- Effect on ultimate load (Pu): Fig. 3 shows that increasing number of joints will decrease the ultimate load (Pu) as follows; (i) The presence of one HCJ in the beam results in ultimate load 97%of that of the reference beam. (ii) The presence of two HCJ in the beam results in ultimate load 88%of that of the reference beam. (iii) The presence of three HCJ in the beam results in ultimate load 83%of that of the reference beam.

4.2 Effect of joint location

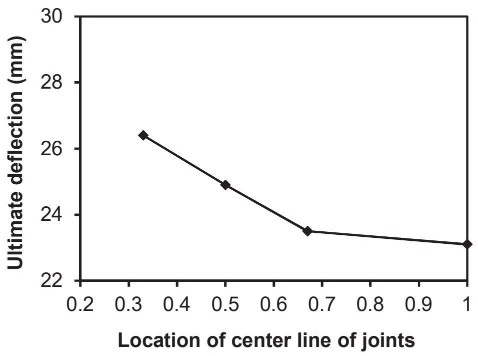


Figure 2. Effect of location of centre line of joints on ultimate deflection

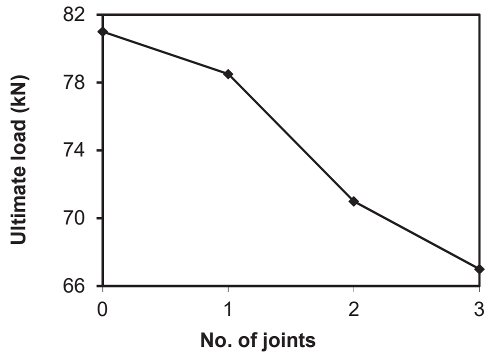


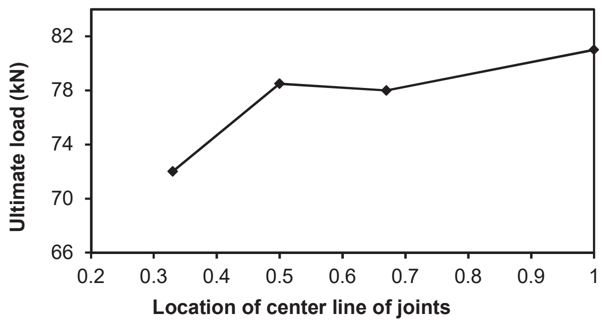
Figure 3. Effect of No. of joints on ultimate load

It is clear that increasing the number of HCJ in a reinforced concrete beam reduces its load- carrying capacity and increases its deflection. To enable a close study of the effect of changing the position of the effect of varying the number of joints, cases of beams having only one HCJ located at different depths will be considered here. This gives four beam cases according to the performed experimental tests of the present research which are namely beams (B1), (B2), (B3) in addition to the unjointed reference beam (Bref). The effect of varying the location of the HCJ on the load-deflection behaviour of the beam can be summarized as follows:

- Effect on ultimate load: From Fig. 4, it can be seen that the presence of HCJ above or at or below beam mid-depth decreases the value of the ultimate load such that Pu is (96%) or (97%) or (89%) times that of the reference beam, respectively.
- Effect on ultimate deflection (δ u): From Fig. 2, it can be seen that the presence of HCJ above or at or below beam mid-depth increases the value of the ultimate deflection such that δ u is (102%) or (108%) or (114%) times that of the reference beam, respectively.

Figure 4. Effect of location of centre line of Joints on ultimate load

4.3 The Combined effect of varying both the number and location of Joints



In this text, a study is given to the combined effect of both increasing the number of joints and varying the location of their centre line on the behaviour of reinforced concrete beams, so all beam cases were chosen except (B5).
- Effect on ultimate load (Pu): From Fig. 5, it can be seen that placing two HCJ in the beam instead of one decreases the value of the ultimate load (Pu) as follows;
- from (96%) to (94%) times that of the reference beam for beams having the centre line of joints located at the beam mid-depth.
- from (97%) to (88%) times that of the reference beam for beams having the centre line of joints located at the beam mid depth - from (89%) to (83%) times that of the reference beam for beams having the centre line of joints located below the beam mid-depth.

-Effect on ultimate deflection (δu): From Fig. 6, it can be seen that placing two HCJ in the beam instead

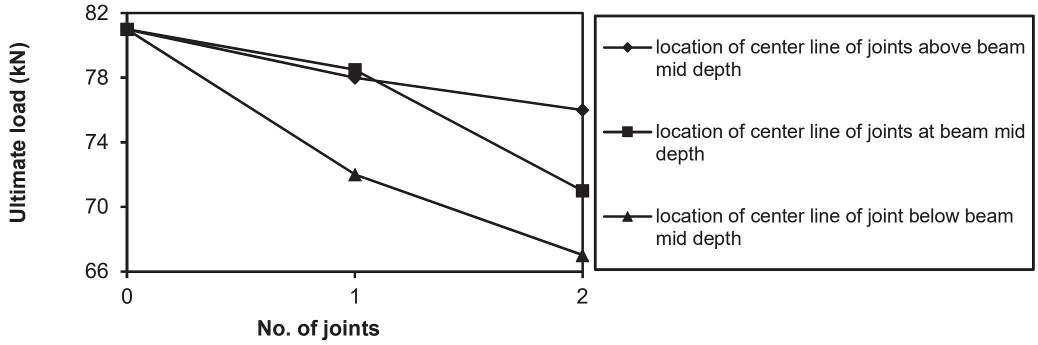


Figure 5. Effect of No. of joints on ultimate load for various locations of centre lines of joints

of one increases the value of the ultimate deflection (δ u) as follows;
- from (114%) to (126%) times that of the reference beam for beams having the centre line of joints located below the beam mid depth.
- from (108%) to (122%) times that of the reference beam for beams having the centre line of joints located at the beam mid depth.
- For beams having the centre line of joints located above the beam mid-depth, the ultimate deflection (δ u) seem to be unaffected by changing the number of joints and has a value 102% times that of the reference beam.

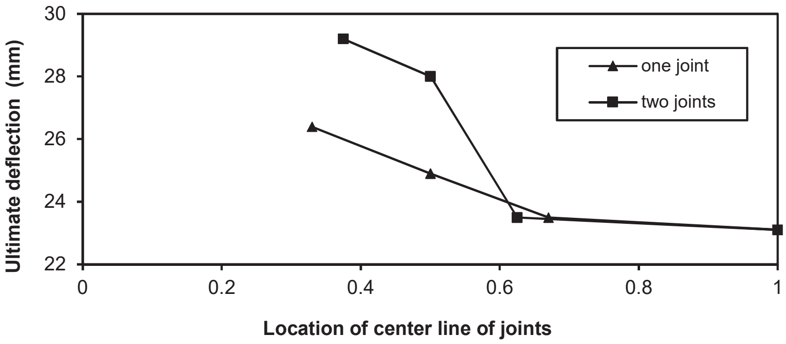


Figure 6. Effect of No. of joints on ultimate deflection for various locations of centre lines of joints

Fig. 7 shows how the ultimate load Pu can be increased by shifting the centre line of joints away from the beam bottom face.
- For one HCJ the ratio Pu /Puref (as percent) for cases where the joint is placed below, at, and above the beam mid-depth is respectively, 89%, 97% and 96% - For two HCJ the ratio Pu /Puref (as percent) for cases where the centre line of joints is located below, at, and above the beam mid-depth is respectively, 83%, 88%, and 94%.
Fig. 8 shows how the ultimate deflection (δ u) can be reduced by shifting the centre line of joints away

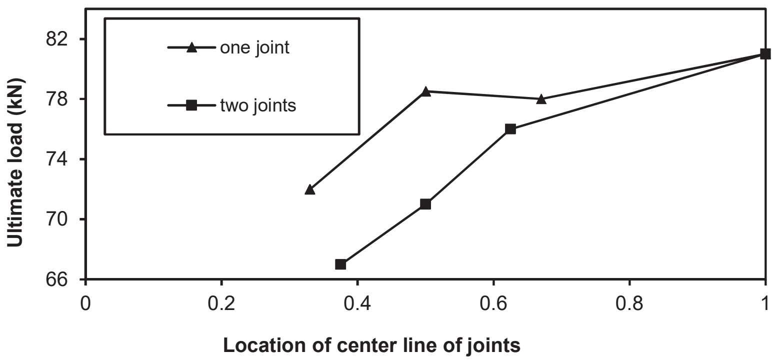


Figure 7. Effect of location of centre line of joints on ultimate deflection for various No. of joints

from the beam bottom face.
- For one HCJ the ratio δ u / δ uref (as percent) for cases where the joint is placed below, at, and above the beam mid-depth is respectively, 114%, 108% and 102%. - For two HCJ the ratio δ u / δ uref (as percent) for cases where the centre line of joints is located below, at, and above the beam mid-depth is respectively, 126%, 122%, and 102%.

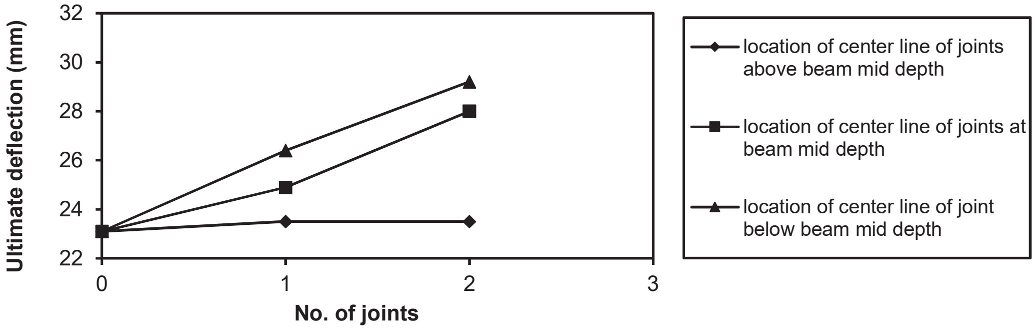


Figure 8. Effect of location of centre line of joints on ultimate load for various No. of joints

5. Conclusions and recommendations

From the present experimental investigation on the behaviour of reinforced concrete beams containing HCJs, the following points can be concluded within the limitations of the tests of the current study;

1. The presence of one, two or three HCJ in a reinforced concrete beam under flexure gave respectively,

(i) a decrease in the value of the ultimate load such that (Pu) was (97%, 88% or 83%) times that of the reference beam.

(ii) An increase in the value of the ultimate deflection such that (δ_u) was (108%, 122% or 133%) times that of the reference beam.

2. Providing HCJ above, at, or below beams mid-depth gave respectively,

(i) a decrease in the value of the ultimate load such that (P_u) was (96%,97% or 89%) times that of the reference beam for beams having one HCJ and (94%, 88% or 83%) times that of the reference beam for beams having two HCJs.

(ii) an increase in the value of the ultimate deflection such that (δu) was (102%,108% or 114%) times that of the reference beam for beams having one HCJ and (102%, 122% or 126%) times that of the reference beam for beams having two HCJs.

From the experimental results obtained, It is recommended to improve the strength of construction joints using materials, in which bond strength between old and new concrete is enhanced [18–20] or materials with high strength such as CFRP [21,22] to improve joint strength.

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