Effect of Construction Joints on the Behavior of Reinforced Concrete Beams

Hussain Askar Jabir
Lecture
E-mail: haskar@uowasit.edu.iq

Thaar Sauid Salman
Assistant Professor
College Engineering - University of Wassit
E-mail: thaar@uowasit.edu.iq

Jasim Mahmood mhalhal
Assistant Lecture
E-mail: eng_ jasem67@yahoo.com

ABSTRACT

In this study, the effect of construction joints on the performance of reinforced concrete beams was experimentally investigated. Seven beam specimens, with dimensions of 200×100×1000 mm, were fabricated. The variables were considered including; the location and configuration of the joints. One beam was cast without a joint (Reference specimen), two specimens were fabricated with a one horizontal joint located either at tension, or compression zone. The fourth beam had two horizontal joints placed at tension, and compression area. The remaining specimens were with one or two inclined joints positioned at the shear span or beam's mid-span. The specimens were subjected to a monotonic central concentrated loading until the failure. The results of the experimental program indicated that the best location of the construction joint is at the compression zone. The presence of the horizontal construction joint at tension zone resulted in a reduction in strength of beams, about 5% - 7.5%, relative to the reference beam. However, the inclined construction joint had a little effect on the collapse load of beams, about 1.25% - 2.5%.

Key words: construction joint, cold joint, reinforced concrete, beams, crack, monotonic.

تأثير المفاصل الانشائية على تصرف العتبات الخرسانية المسلحة

حسين عسكر جابر
مدرس
كلية الهندسة-جامعة واسط

ثائر سعود سلمان
استاذ مساعد
كلية الهندسة-جامعة واسط

جاسم محمود مهلهل
مدرس مساعد
كلية الهندسة-جامعة واسط

الخلاصة

في هذا البحث تم دراسة تأثير المفاصل الانشائية على اداء العتبات الخرسانية المسلحة عن طريق فحص النماذج عمليا في المختبر.تم أنشاء سبعة نماذج بأبعاد (100×200×1000) ملم. ان المتغيرات التي تم اعتمادها هي مواقع و تشكيل المفاصل الانشائية. النموذج المصدري لم يحتوي على مفصل و نموذجين حتوى على مفصل افقي في منطقة الشد أو الضغط. النموذج الرابع أحتوى على مفصلين افقيين في منطقتي الشد والضغط. النماذج المتبقة تم أنشائها مع مفصل او مفصليين افقيين تقع في منطقة القص او في منتصف العتبة. بينت النتائج العمليه الى ان افضل موقع للمفصل الانشائي هو في منطقة الانضغاط، وتشير ايضا الى ان المفصل الافقي ذو تأثير واضح على مقاومة النماذج حيث ان نسبة الانخفاض جاءت بين (5%-7.5%). بينما يوجد نقصان طفيف على مقاومة النماذج ذات المفصل الانشائي المائل بحدود (1.25%-2.5%).

الكلمات الرئيسية: المفصل الانشائي، العتبات الخرسانية المسلحة، التشقق، التحميل الساكن.

1. INTRODUCTION

Construction joints (or cold joints) can be defined as stopping positions in the concrete casting, and they are needed because of impracticality to cast concrete in one continuous process. The concrete quantity, produced at one time, is dominated by the capacity of mixers and the formworks' strength. Thus, the concrete casting process may be stopped and resumed several times leading to initiate the construction joints **Aziz, 2006**.

Clark and **Gill, 1985** investigated the shear capacity of 60 plain concrete prisms having smooth construction joints at their mid-span. These joints were inclined at various angles ranged from 13.9^o and 75.1^o. The results showed that the shear resistance was developed by a combination of friction and cohesion. The specimens were failed either by sliding over the cold joint or by crushing monolithically if the joint is very strong. Moreover, an empirical equation for estimating the shear strength was presented.

Mo and **Lai, 1995** evaluated experimentally the influence of the casting procedure on the structural response of nine reinforced concrete beams. The beams were (300×500mm) in the cross section, and their compressive strength was 34 MPa. Two-step casting procedures (two layers) were achieved. Three specimens were concreted monolithically; the others were concreted to the high of (360mm) on the first day and the remaining part of (140mm) on the next day. An inconsiderable difference between the two casting procedures was observed.

Patnaik, 2001, presented an experimental study of the behavior of composite concrete beams of a smooth interface. The beams were fabricated in the T and rectangular cross- sectional area. The cold joints were located between the web and the flange in the T-beams. In the rectangular beams, construction joints were positioned at (150mm) below the upper face. The specimens were constructed with effective depth (d) ranged from (277mm) and (317mm). The compressive concrete strength of the specimens was varied from (17MPa) to (38MPa). The tests showed that the concrete strength of a composite concrete beam with a smooth interface and that the effective depth to tie spacing ratio (d/s) did not influence the horizontal shear strength of such beams.

The influence of construction joints and the existing flange openings on strength of reinforced concrete T-beams was studied by **Aziz** and **Ajeel, 2010**. Eight T-specimens of simply supported were tested under a concentrated loading applied at their mid-span. The test's parameters were the position and number of construction joints and flange openings. The results observed that the shear strength dropped about (27%) for the specimen having cold joint.

Camille A. Issa et. al., 2014, correlated experimentally the concrete compressive strength to the modulus of rupture for plain concrete beams with a vertical construction joint placed at their center. The experimental results indicate that for monolithic beams, the ACI Code always underestimates the modulus of rupture. The presence of a vertical construction joint yielded a significant loss in the modulus of rupture of concrete varying between 24% and 83%.

2. RESEARCH SIGNIFICANCE

The purpose of this experimental study is to understand the effect the construction joints on the structural behavior beams. Seven beam specimens were fabricated and subjected to a three-point loading until failure. The tests focused on the influences of the types and locations of the construction joints.

3. TEST SPECIMENS

Seven reinforced concrete beams were manufactured to study the effect the construction joints on behavior of RC beams. They were similar in the geometry and reinforcement ratio. Their dimensions and steel reinforcement ratios were selected according to **ACI 318M-2014** requirements for the reinforced concrete structures. The total length of the tested beams was (1000) mm and with cross-section of (100×200) mm. The flexural reinforcement composed of two deformed bars of 10mm diameter located in the beam bottom, and the shear reinforcements were 6mm diameter deformed bars forming closed stirrups spaced at the 75mm center to center. Two bars of 6mm diameter were used in the top of the beams to support the stirrups as shown in **Fig. 1**.

The study parameters were the locations and the types of the construction joints. One beam was fabricated without construction joint (Reference specimen) as shown in **Fig. 2**. Other six specimens had the construction joints with various types and locations as shown in **Fig. 3**. Four of them were made with one construction joints and concreted into two layers. The primary layer was cast on a first day, and a second one was done on the next day. The other two specimens were with two joints and cast in three layers on three consecutive days.

A total of seven specimens (**SR**, **SHT**, **SHC**, **SHTC**, **SIM**, **SIS**, and **SISM**) were tested as a simply supported and subjected to a concentrated loading applied at their mid-span. The specimen's designation can be explained as follows; the first symbol indicates the (Specimen); the second one refers to the type of construction joint (R=reference without construction joint, H= horizontal construction joint, I=inclined construction joint); and the third and fourth symbols indicate the location of construction joint (T= tension zone, C= compression zone, M= maximum moment (mid-span) and S= shear span). The entire characteristics and details of the tested specimens are listed in **Table 1**. Finally, the beams were categorized into two groups depending on the joints' type as shown in Table **2**.

The properties of steel used in the reinforcing of the beams are listed in **Table 3**. One specimen for each bar size was tested according to **ASTM A 615M- 2005.** The samples were produced using a normal density concrete with 30 MPa target compressive strength. The concrete mixing consisted of; ordinary Portland cement, sand, and 12mm maximum size crushed coarse aggregate in the following weight proportion 1; 2.05; 2.2, respectively. The water to cement ratio was 0.55 for all specimens. These raw materials were mixed using a mechanical mixer according to the procedure of **ASTM C192-2002**. **Table 4** lists the final strengths based on the average values from the tests performed on at least three 150 x 300mm cylinders for each test specimen. The tensile strength of concrete was determined by performing the split cylinder tests.

4. TEST PROCEDURE

The beam samples were tested using a testing rig at Engineering College of Wasit University. The specimens were positioned inside the testing rig and supported simply as shown in **Fig. 4**. They were subjected to a centrally concentrated loading, three-points loading, applied gradually at an increment of 5 kN until specimens' failure. The loading was subjected through a hydraulic jack of 500 kN capacity, and its value was recorded using a load cell that inserted between the jack strike and specimen's surface. A dial gauge of 0.01 mm accuracy was located directly under the bottom beam surface at mid-span to measure the maximum deflection at each a loading increment.

At each loading stage, the test measurements included the magnitude of the applied load and deflection of the beam at mid-span was recorded. At the end of each test, the cracks developed were marked and the crack pattern and mode of failure for each specimen were carefully investigated.

5. TEST RESULTS AND DISCUSSION

5.1 General Behavior and Crack Patterns

For all specimens except for **SIS** and **SISM,** the first crack initiated from the bottom of the beam in the mid-span where the maximum bending moment occurred, just the tensile stresses exceeded the concrete rupture modulus. In samples **SIS** and **SISM,** the primary crack was observed at the inclined construction joints in the shear span, and in the maximum moment region, respectively.

As the applied loading increased, the first cracks widened and propagated vertically upward. Moreover, other flexural cracks also developed and separated along the beam's length. Diagonal cracks were noticed near the supporting points, some of these cracks connected with the flexural cracking shaping the shear-flexural cracks. It is worth mentioning that horizontal cracks were noted at the horizontal cold joints in the beams **SHT** and **SHTC.**

In general, all specimens were failed in a ductile mode by an excessive yielding of tension steel reinforcement and a concrete crushing at the top surface. **Fig. 5** shows the crack patterns of the testing specimens.

5.2 Cracking and Failure Loads

The experimental results for cracking and ultimate loads of all specimens are listed in **Table 5**. The test results show that the cracking loading was (20.5% to 25.6%) of the ultimate load capacity of these specimens.

The existing of a cold joint in the horizontal form in the tension zone decreased the cracking load about 15% to 20% for specimens **SHT** and **SHTC**, respectively with respect to the beam **SR**. Whereas it had no effect on the cracking load of specimens whose horizontal joint positioned at the compression zone. Furthermore, the inclined joint constructed at the specimens' mid-span led to a considerable dropping in the cracking load, reached 20% comparing with specimen **SR**. On the contrary, the inclined joints, located at the shear span, did not affect the cracking load as shown in specimen the **SIS**.

Generally, the construction joint leverage on the ultimate load was more tenuous than that on the cracking load. For specimens with horizontal construction joints, the joints influenced the ultimate load only when they located in a tension zone near the flexural reinforcement. However, the reduction in the ultimate load was relatively slight about 5%, and 7.5% for specimens **SHT**, and **SHTC,** respectively compared to the control one **SR**. The beam **SHC** with joint, located in the compression fiber, failed at the same load of the specimen **SR**.

The beams, made with inclined joints, showed the smallest drop in the failure load compared with the reference beam without joints. Where the specimens SIM**, SIS** and **SISM** collapsed at loads 1.25%, 2.5% and 2.5% less than that of the control sample **SR**, respectively. The limited effect of the inclined joints was due to the flexural failure of these beams.

5.3 Load-Deflection Response

Vertical deflection at the mid-span was recorded at each load step of the test program. Two groups were adopted in the presentation of the load-deflection relations as described in **Table 2**. The load-deflection response of the specimens is compared to that of the reference specimen, at two loading levels as listed in **Table 6**: a service load level and the failure load level. The

serviceability load is approximately (70-75%) of the peak load **Tan** and **Zhao**, **2004**. In the current illustration of deflections, the service loads are assumed to be 70% of the collapse load of reference specimens. The failure loads of samples are equal to the recorded load, in **Table 5**.
Generally, when a beam is progressively loaded, the deflection linearly augmented at an elastic juncture. Thereafter, the first crack appeared; the deflection rose rapidly. After developing of cracks in the beam, the load-deflection response remained somewhat linear even yielding of tensile reinforcement. Beyond this, the deflection largely grew without a considerable boost in applied load.
The influence of the horizontal and inclined construction joints on load- central deflection behavior is demonstrated in **Fig. 6** and **Fig. 7,** respectively. As shown in the figures, there is a significant effect for inclined joints on the deflection measured at the service stage. Since it reduced the inertia moment of the specimens, the deflection increased compared with the specimen **SR**. The increments in the deflection were 22.2%, 43.7% and 29.6% for the specimens **SIM**, **SIS** and **SISM** respectively. It is worth mentioning that the reduction in the deflection was trivial (4.8%, 1.9%) for one horizontal joint specimens **SHT**, and **SHC**, correspondingly. The specimen SHTC, which had two horizontal joints at tension and compression zones, exhibited 16.7% rising in the deflection compared with the reference beam.
Finally, at failure all specimens showed ultimate deflection smaller than that of the control specimen (specimen without construction joint).

6. CONCLUSIONS

The major conclusions of current experimental investigation are listed as follows;

1. All specimens exhibited a ductile failure. The first cracks developed at a load range of about (20.5% to 25.6%) of the ultimate load capacity of the specimens.
2. The beams, having construction joints at the compression zone parallel to the main reinforcement, performed structurally better than the beams with construction joints at the tension zone.
3. The load carrying capacity of specimens with horizontal construction joints at a tension zone was reduced about (5% -7.5%) with respect to the reference specimen.
4. The location of horizontal joints at a compression zone did not influence the ultimate strength of specimens.
5. Inclined construction joints had a trivial effect on the overall behavior of reinforced concrete beams displayed the flexural failure. The load carrying capacity for the tested beam with inclined construction joints dropped about (1.25% - 2.5%) comparing to the reference specimen.
6. The existing of construction joints led to a reduction in the inertia moment of beams, and therefore, dropping in the beams’ stiffness.
7. If the existing of construction joints is impossible to avoid in beams, the best location for joints is at the compression zone in the horizontal configuration. For beams, designed to fail in the flexural, the presence of inclined construction joints does not affect the beams strength.

REFERENCES

- ACI Committee 318, 2014, *Building Code Requirements for Structural Concrete ACI 318M-14 and commentary*, American Concrete Institute, Farmington Hills, 519 pp.

- ASTM Designation A615, 2005, *Standard Specification for Testing Method and Definitions for Mechanical Testing of Steel Products*, Annual Book of ASTM Standards, American Society for Testing and Material, Philadelphia, Pennsylvania, Section 1, Vol. 1.01, pp. 248-287.

- ASTM Designation C192/C192M-02, 2002, *Making and Curing Concrete Test Specimens in Laboratory,* Annual Book of ASTM Standards, American Society for Testing and Materials, Philadelphia, Pennsylvania, Vol. 4, 02.

- Aziz, A. H., (2006), *Flexural and Shear Behavior of Hybrid I-Beams with High - Strength Concrete and Steel Fibers,* Ph.D. Thesis, Department of Civil Engineering, Al-Mustansirya University, (10) p.

- Aziz A. H. and Ajeel A. E. 2010, *Effect of Existing Flange Opening and Cold Joints on Strength of RC T-Beams*, Journal of Engineering, Collage of Engineering, University of Baghdad, Iraq, Volume 16, Number 1, March, pp. 4535-4546.

- Camille A. Issa , Nagib N. Gerges , Samer Fawaz, 2014, *The Effect of Concrete Vertical Construction Joints on the Modulus of Rupture*, Construction Materials Jornal, Vol.1, pp. 25–32.

- Clark, L. A. and Gill, B. S., 1985, *Shear Strength of Smooth Unreinforced Construction Joints*, Magazine of Concrete Research, V. 37, No. 131, June, pp. 95-100.

- Mo, Y. L. and Lai, H. C., 1995, *Effect of Casting and Slump on Ductilities of Reinforced Concrete Beams*, ACI Structural Journal, V. 92, No. 4, July-August, pp. 419-424.

- Patnaik, A. K., 2001, *Behavior of Composite Concrete Beams with Smooth Interface*, ASCE-Journal of Structural Engineering, V. 127, No. 4, April, pp. 359-366.

- Tan, K. G. And Zhao, H. , 2004, *Strengthening of Openings in One-Way Reinforced-Concrete Slabs Using Carbon Fiber-Reinforced Polymer Systems*, Journal of Composites for construction ,ASCE, Vol. 8, No. 5, pp. 393-402.

Table 1. Characteristics of the tested beams.

No.	Specimen designation	Beam depth (mm)	Beam width (mm)	Tension steel ratio (ρt)	Shear reinforcement details	Location of construction joint
1	SR	200	100	0.0092	$\emptyset 6\ mm\ at\ 75\ mm\ c/c$	Without construction joint
2	SHT	200	100	0.0092	$\emptyset 6\ mm\ at\ 75\ mm\ c/c$	Tension zone
3	SHC	200	100	0.0092	$\emptyset 6\ mm\ at\ 75\ mm\ c/c$	Compression zone
4	SHTC	200	100	0.0092	$\emptyset 6\ mm\ at\ 75\ mm\ c/c$	Tension and compression
5	SIS	200	100	0.0092	$\emptyset 6\ mm\ at\ 75\ mm\ c/c$	Shear span (min. moment)
6	SIM	200	100	0.0092	$\emptyset 6\ mm\ at\ 75\ mm\ c/c$	Maximum moment (mid-span)
7	SISM	200	100	0.0092	$\emptyset 6\ mm\ at\ 75\ mm\ c/c$	Shear span & maximum moment

Table 2. Details of beams groups.

Group	Description	Specimens
I	$b = 100mm, \quad h = 200mm$ $\rho t = 0.009$ Horizontal Construction Joint (Variable)	1. SR 2. SHT 3. SHC 4. SHTC
II	$b = 100mm, \quad h = 200mm$ $\rho t = 0.009$ Inclined Construction Joint (Variable)	1. SR 2. SIM 3. SIS 4. SIMS

Table 3. Properties of steel reinforcement.

Nominal diameter (mm)	Measured diameter (mm)	Yield stress fy MPa	Ultimate strength fu MPa	Elongation %
6	5.83	724.4	777.4	16
10	9.87	648.2	721.34	13

Table 4. Mechanical properties of concrete.

Specimen ID	Layer Description	Compressive Strength at Time of Specimen Testing (MPa)		Modulus of rupture (MPa)	Splitting tensile strength (MPa)
		f_{cu}	f'_c	fr	ft
SR	Casting one part	44.72	36.76	4.03	3.72
SHT	The first layer of beam	44.72	36.76	4.03	3.72
	The second layer of beam	41.87	33.16	3.64	3.13
SHC	The first layer of beam	43.35	33.92	3.7	3.42
	The second layer of beam	41.87	33.16	3.64	3.13
SHTC	The first layer of beam	44.72	36.76	4.03	3.72
	The second layer of beam	41.87	33.16	3.64	3.13
	The third layer of beam	38.86	30.82	3.36	3.32
SIS	The first part of beam	45.84	35.82	3.92	3.18
	The second part of beam	43.15	35.68	3.73	3.44
SIM	The first part of beam	45.84	35.82	3.92	3.18
	The second part of bean	43.15	35.68	3.73	3.44
SISM	The first part of beam	45.84	35.82	3.92	3.18
	The second part of beam	43.15	35.68	3.73	3.44
	The third part of beam	41.02	31.64	3.45	3.22

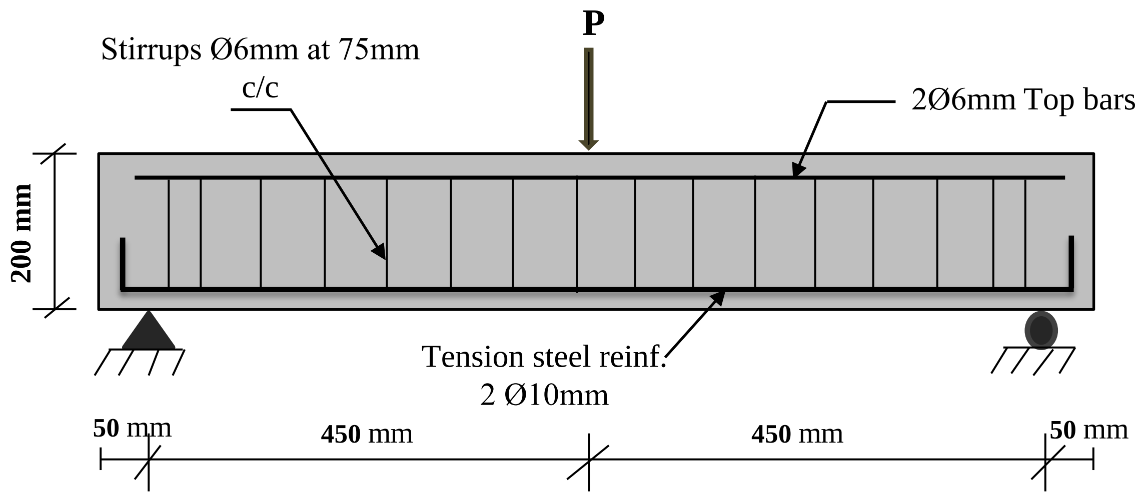
Table 5. Cracking and ultimate loads of the tested beams.

Specimens		First crack load (Pcr) (kN)	Ultimate load (Pu) (kN)	% Pcr/Pu	%Decrease in first cracking load with respect to Ref.	%Decrease in ultimate load with respect to Ref.
Group I	**SR**	20	80	25	Ref.	Ref.
	SHT	17	76	22	15	5
	SHC	20	80	25	0.0	0.0
	SHTC	16	74	21.6	20	7.5
Group II	**SR**	20	80	25	Ref.	Ref.
	SIM	17	79	21.5	15	1.25
	SIS	20	78	25.6	0	2.5
	SISM	16	78	20.5	20	2.5

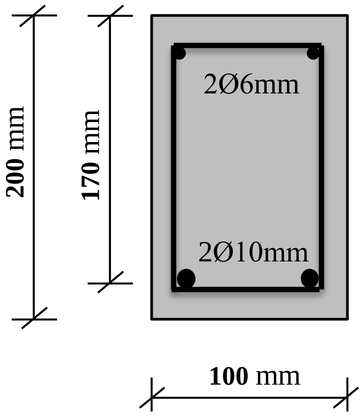
Table 6. Central deflections of the tested beams at service and ultimate loads.

Specimens		**Deflection at Service Load of Ref. Specimen (mm)**	**% Increase in Deflection at Service Load**	**Deflection at Ultimate Load of Ref. Specimen (mm)**	**% Decrease in Deflection at Ultimate Load**	**Ultimate Deflection of each Specimens (mm)**
Group I	**SR**	2.7	Ref.	16.98	Ref.	16.98
	SHT	2.83	4.8	**	**	11.98
	SHC	2.75	1.9	15.99	5.8	15.99
	SHTC	3.15	16.7	**	**	13.69
Group II	**SR**	2.7	Ref.	16.98	Ref	16.98
	SIM	3.3	22.2	**	**	13.26
	SIS	3.88	43.7	**	**	14.8
	SISM	3.5	29.6	**	**	14.47

**Ultimate load of control specimen SR (80 kN) is beyond the failure load of these specimens.



a. Longitudinal section of the beams



b. Cross Section in Beams

Figure 1. Typical dimensions and reinforcement details of the beams

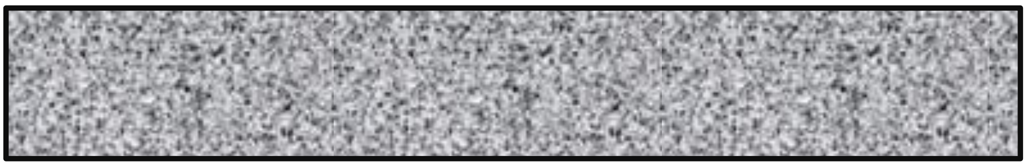
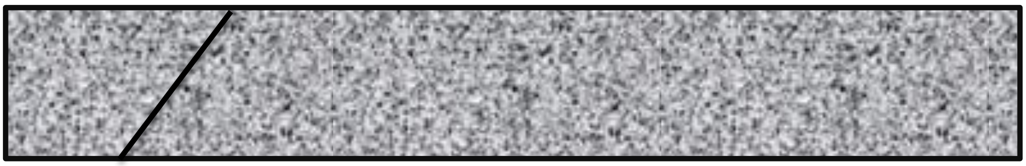


Figure 2. Longitudinal section of the control specimen (without construction joint)

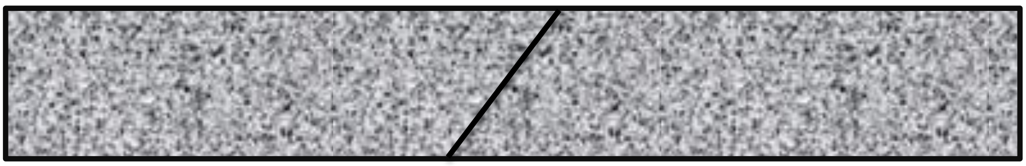
a. SHT specimen

b. SHC specimen

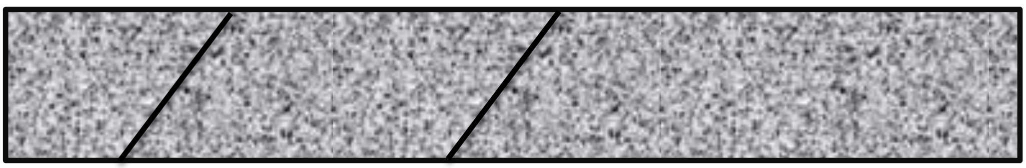
c. SHTC specimen



d. SIS specimen



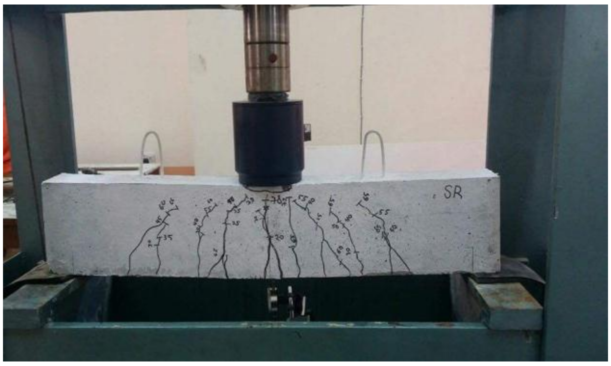
e. SIM specimen



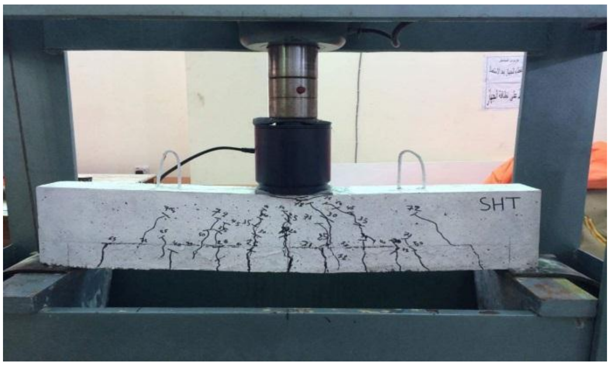
f. SISM specimen

Figure 3. Locations of the construction joints for the tested specimens.

Figure 4. Photograph of specimen setup.



a. SR specimen

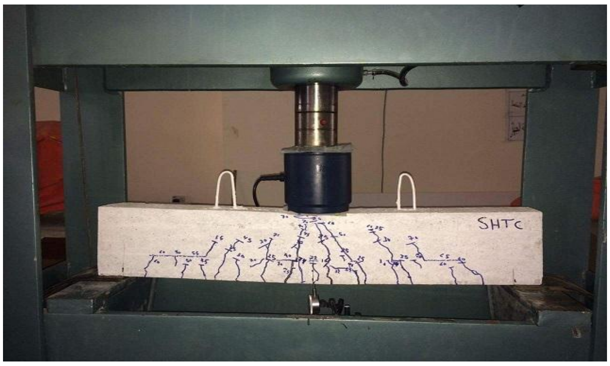


b. SHT specimen

e. SIS specimen

c. SHC specimen

f. SIM specimen



d. SHTC specimen

g. SISM specimen

Figure 5. Cracks pattern for the specimens tested after failure.

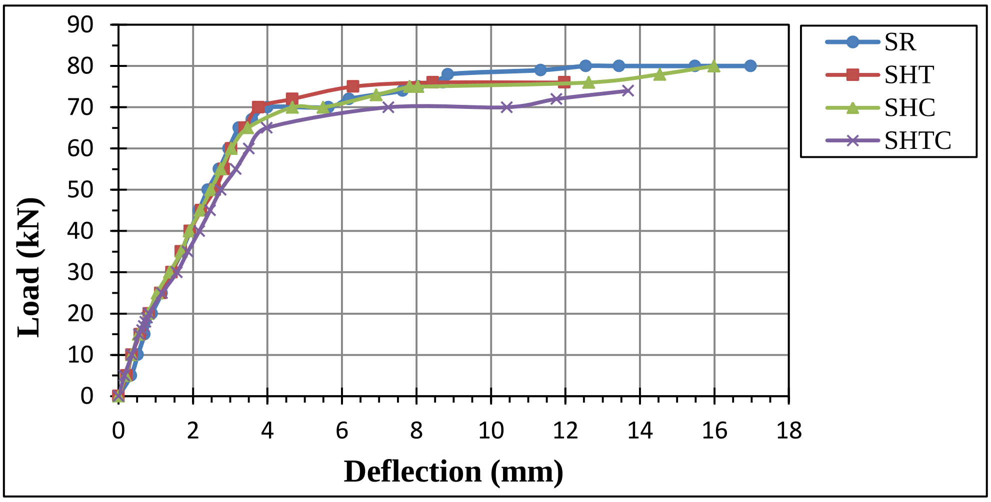


Figure 6. Influence of the horizontal construction joint on load-central deflection behavior of the specimens of group (I).

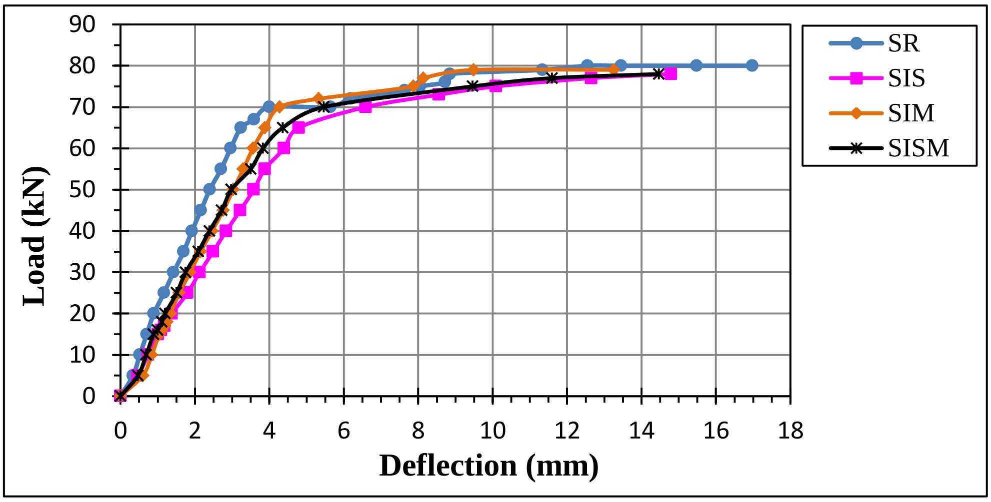


Figure 7. Influence of the inclined construction joints on load-central deflection behavior of the specimens of group (II).