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EFFECT OF TYPE AND POSITION OF CONSTRUCTION JOINT ON BEHAVIOR AND CAPACITY OF REINFORCED CONCRETE ONE WAY SLABS

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Abstract: This work involves experimental study for the effect of construction joint on behavior of R.C. one way slabs. Eight slabs of 1000×450×70 mm were tested. One of them is cast monolithically while the other seven were cast by two stages with presence of construction joints. Different types of joints were considered (vertical, inclined and key) with different forms and locations for these types. The results indicated that these joints have different effects on cracking and ultimate capacities and on load deflection response. Transversal inclined joint has the largest effect on ultimate capacity (reduction is 24.6 %), while long key joint has smallest effect (reduction is 1.8 %). The slab involved inclined in plane joint has the closest load deflection response to the reference slab response and has few and narrow final cracks. Slabs of vertical middle and transversal inclined joints have stiff behavior in earlier loading stages but becomes more soft in advanced stages. Side joint caused sudden shear failure on contrast for the other slabs failed by flexure. Inclined in plane joint, key in plane joint and long key in plane joint are the best types of construction joints due to their smallest effects on slabs behavior.

Keywords: *slab, one way, concrete, construction joint.*

تأثير نوع وموقع المفصل الانشائي على سلوك وتحمل البلاطات الخرسانية المسلحة ذات الاتجاه الواحد

الخلاصة: يتضمن البحث دراسة مختبرية لتأثير المفصل الانشائي على سلوك البلاطات الخرسانية المسلحة ذات الاتجاه الواحد. تم فحص ثمانية بلاطات بأبعاد 1000×450×70 ملم. أحد البلاطات تم صبها بمرحلة واحدة بينما البلاطات السبعة الاخرى تم صبها على مرحلتين بوجود مفصل انشائي. تم اعتماد انواع مختلفة من المفاصل (شاقولي، مائل، مفتاح) بأشكال و مواقع مختلفة. بينت النتائج ان هناك تأثيرات مختلفة لهذه المفاصل على مقاومة التشققات والمقاومة القصوى وعلاقة الحمل بالهطول. كان للمفصل المائل عرضياً التأثير الاكبر على المقاومة القصوى (الانخفاض كان 24.6 %) بينما مفصل المفتاح الطويل في مستوى البلاطة كان له التأثير الاصغر (الانخفاض كان 1.8 %). علاقة الحمل بالهطول للبلاطة المتضمنة المفصل المائل في المستوي كانت الاقرب للعلاقة في البلاطة المرجعية وكانت تشققاتها النهائية قليلة وضيقة. البلاطات ذات المفصل الشاقولي الوسطي والمفصل المائل عرضياً كان لها سلوك جاسئ في مراحل التحميل المبكرة لكنه يصبح ضعيفاً في المراحل المتقدمة. المفصل الجانبي سبب فشل قص مفاجئ ومغاير لفشل الانثناء في البلاطات الاخرى. المفصل المائل في المستوي ومفصل المفتاح في المستوي ومفصل المفتاح الطويل في المستوي هي افضل انواع المفاصل نتيجة تأثيراتها الاقل على سلوك البلاطات.

1. Introduction

A construction joint is a plane surface between two sections of concrete that are not placing monolithically [1] and it represents the stopping places in the process of placing

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*Corresponding Author wisamhulail78@gmail.com concrete [2]. Many reasons leads to the stopping in concrete placing such as: insufficient amount of fresh concrete supplied to placing the structure continuously, or sudden breaking down of some machines (mixer or pump or vibrator….etc), or the large amount of concrete required to placing some large structural members such slabs or foundations so that their placing cannot complete at one day, or when weather conditions do not allow casting operations to continue at the same time [2,3].

Commonly, concrete structures must be are cast monolithically to ensure that they are sufficiently rigid and that they satisfy the strict vibration and deformation requirements. Construction joints are, however, potential planes of weakness where slip, dilation, and, ultimately, delamination can occur [4]. The effect of this weakness on the structural behavior differs according to type of the joint. A good construction joint should provide adequate flexural and shear continuity through the interface at the joint [5], therefore, the optimum type and location of construction joint must be chosen so that the structural members involved construction joints exhibit higher strength and lower deformation .

Many types of joints may be made in construction process of concrete structures such as horizontal joint, vertical joint, longitudinal joint, inclined joint, key joint, or composite type of any two types of them [1,2].

2. Literature Review

Generally, few works were made for studying the effect of construction joints on behavior of concrete structural members. In this paragraph some modern experimental works on this topic will be reviewed.

In 2010, Aziz [3] performed 16 push-off tests to quantify the shear strength capacity at the interface between old and new concretes. Test parameters included different interface surfaces: smooth and rough with and without shear keys and presence of shear reinforcement across the interface surfaces. The results indicated that using rough concrete surface with shear keys is essential to restore significant part of shear capacity. Presence of shear reinforcement further improves interface shear resistance.

In 2011, Abass [2] studied the effect of location of construction joints on the performance of R.C. beams. Nineteen beams with dimensions of 950×200×200 mm were tested. The variables are location of the joint (at midspan or at third point of the beam), type of joint (vertical, inclined, and key joints). The results indicated that the best location of the joint is at the point of minimum shear. Using of vertical and key joints has little effects on the overall behavior of beams. While inclined joints results in a noticeable reduction (in range of 8% - 20%) in strength of beams.

In 2014, Issa et al [6] made experimental work to correlate the compressive strength (f'_c) of concrete to the modulus of rupture (f_r) for plain concrete beams with a vertical construction joint placed at their center. The results indicated that the presence of a vertical construction joint leads to a significant loss in the modulus of rupture. The equation

$f_r = 0.28\sqrt{f'_c}$ is suggested for modulus of rupture of concrete with presence of construction joint.

In 2015, Gerges et al [7] made experimental work to correlate the compressive strength (f'_c) of concrete to the splitting tensile strength (T) for plain concrete in the existence of a construction joint. The results showed that having a construction joint reduces the splitting tensile strength of a monolithic specimen by 55%. The equation $T = 0.25\sqrt{f'_c}$ is suggested for splitting tensile strength of concrete with presence of construction joint.

In 2016, Bin Osman et al [5] studied the effect of type of construction joints on the performance of concrete structural slabs. Six slabs with dimensions of 700×400×150 mm with different types of construction joints were tested. The results indicated controlled sample have the maximum applied load, deflection, stiffness and energy absorption. Sample of inclined joint has the higher applied load, deflection and energy absorption compare to other joint samples. Using Hy-Rib Mesh to form the joint has the highest stiffness compare to other joint samples.

In 2017, Jabir et al [8] investigated the effect of construction joints on the performance of R.C. beams. Seven beams with dimensions of 1000×100×200 mm, were fabricated. The variables were considered including; the location and configuration of the joints. The results indicated that the best location of horizontal 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 joint had a little effect on the collapse load of beams, about 1.25% - 2.5%.

3. Research Significant

The little attention in study of the important effect of construction joint on behavior of different structural members indicates the need to additional researches for this important topic especially its effect on concrete slabs that is often station to occurrence the problems of construction joint due to large amount of concrete needed to cast them.

Based on this need, this work takes care the study of the effect for different types and configurations of construction joints on behavior of one way reinforced concrete slabs. Therefore, this study my contributes to provide more universality vision on this important effect, then arriving to some recommendations that are beneficial in design and construction fields.

4. Experimental Program

The experimental program consists of testing eight simply supported reinforced concrete one way slabs . All slabs have the same dimensions and flexural reinforcement. They have an overall length of 1000 mm, a width of 450 mm and a height of 70 mm. All slabs were reinforced by 6 ϕ 5 mm bars (ρ = 0.004545). The parameters of the study are type and location of construction joint were the first slab are cast monolithically, while the other remaining slabs are cast with presence of construction joints where each slab contain a certain type of the joint. The details of these slabs and types of used joints are illustrated in Table (1).

5. Materials

Ordinary Portland cement (type I), natural fine aggregate (sand) with 4.75 mm maximum size and crushed coarse aggregate (gravel) with 10 mm maximum size are used to make the concrete that is used for casting specimens of the study.

6. Concrete Mix Proportions

The quantities by weight of materials used in preparation of concrete per cubic meter were as follows: cement: 400 kg, sand: 600, gravel:1200 kg, and water: 200 liters. This proportions were used in some previous works for the same materials [9].

7. Steel Reinforcing Bars

Deformed steel bars are used in this work with nominal diameters of 5 mm for longitudinal reinforcement in tension side (bottom side) and plain bars of diameter 3 mm are used for longitudinal reinforcement in compression side (top side) without stirrups except two of 3 mm plain bar stirrups used for fixing the bars in their positions during the casting as shown in Fig. (1). The concrete cover for reinforced bars was 10 mm. The laboratory tensile tests on bars of 5 mm diameter showed that the average yield stress of it was 607 MPa.

8. Casting of the Specimens

To make the construction joints, the slabs (except the reference specimen S_N) were cast in successive two days. In the first day, the first part of each slab is cast using insulator made from cork to prevent fresh concrete from flowing to another part . In next day, this part would be fairly hardened, then the second part of the specimen is cast. Therefore, the construction joint will be form as an interface region between old and new concrete parts as shown in Fig. (2). This state is based on assumption that the provided amount of concrete is about half of the required amount for casting the whole slab monolithically.

Table (1) Details of tested slabs and types of construction joint

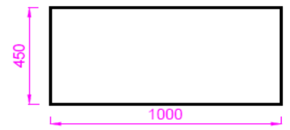
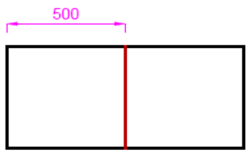
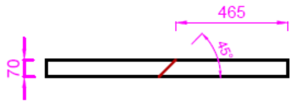
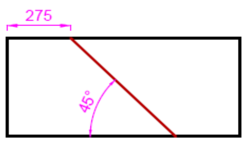
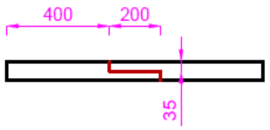
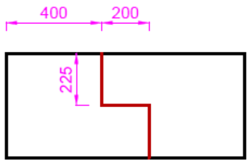
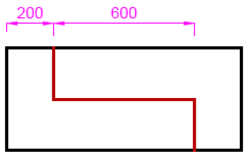
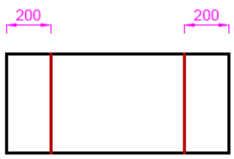
Slab Name	Joint Type	Description of Construction Joint	Details of slabs and Construction Joints
S_N	N	Without joint (**N**o - joint)	
S_M	M	Vertical joint at **M**id-section of the slab	
S_{IT}	IT	**I**nclined joint by 45 deg. in **T**ransversal manner at mid region of the slab	
S_{IP}	IP	**I**nclined joint by 45 deg. in **P**lane manner at mid region of the slab	
S_{KT}	KT	**K**ey joint made in **T**ransversal manner at mid region of the slab	
S_{KP}	KP	**K**ey joint made in **P**lane manner at mid region of the slab	
S_{KLP}	KLP	**K**ey **L**ong joint made in **P**lane manner so that the vertical part of it distribute at two sides region of slabs (shear zones) and the longitudinal part extends within mid region of it (bending zone)	
S_S	S	Vertical joints at **S**ides regions of the slabs (shear zone)	

Figure (1) Steel reinforcement cage and formworks

Figure (2) Casting of slabs with presence of construction joints

9. Hardened Mechanical Properties Results

Table (2) shows test results of mechanical properties obtained for hardened concrete. These properties are concrete compressive strength (f'_c), splitting tensile strength (f_t), modulus of rupture (f_r). Each value presented in this table represents the average value of three specimens.

Table (2) Tests results of mechanical properties for hardened concrete

f'_c (MPa)	f_t (MPa)	f_r (MPa)
32.6	2.95	3.91

10. Tests and Measurements of Slabs

All slabs were tested using a hydraulically universal testing machine of 3000 kN capacity under monotonic loads up to ultimate load at the Structural Laboratory of the Faculty of Engineering of Al-Mustansiriya University as shown in Fig. (3).

The slabs are supported with distance of 900 mm between supports. The load was applied by two line loads through two steel bars with distance 300 mm between them at mid of slab span (the distance between the support and the load arm is 300 mm). Vertical deflections are measured at mid of slab span using dial gauge of (0.01 mm) accuracy as shown in Fig. (4). Loading was applied at increments of 1 kN. At each load stage the deflection readings were recorded. When the first crack appears, the load corresponding to it was recorded.

Figure (3) Slab inside testing machine

Figure (4) Dial gauge position

11. Results of Tested Slabs

Table (3) summarizes results of first cracking load (P_{cr}), ultimate load (P_u), reduction ratio in P_{cr} and P_u due to presence of construction joint and ratio between them for all tested slabs.

Table (3) Results of Tested Slabs

Slab Designation	Type of joint	P_{cr} kN	Reduction in (P_{cr})	P_u kN	Reduction in (P_u)	$\frac{P_{cr}}{P_u}$
S_N	N	9.0	---------	28.5	-------	0.32
S_M	M	5.5	38.9 %	24	15.8 %	0.23
S_{IT}	IT	7.0	22.2 %	21.5	24.6 %	0.33
S_{IP}	IP	8.0	11.1 %	26.5	7.0 %	0.30
S_{KT}	KT	6.0	33.3 %	25	12.3 %	0.24
S_{KP}	KP	7.0	22.2 %	27.5	3.5 %	0.25
S_{KLP}	KLP	8.5	5.6 %	28	1.8 %	0.30
S_S	S	9.0	0 %	25	12.3 %	0.36

12. Discussion of Results

12.1 First Cracking Loads

From Table (3), one can note that presence of joint lessen first cracking load especially for some types of it where the reduction is significant. The reduction for all types ranges from 0 % to 38.9 %. Minimum reduction (0 %) was in case of (S) joint because the joint lies outside maximum bending zone, therefore, it does not affect the flexural cracking capacity. Maximum reduction (38.9 %) was in case of (M) joint. Also, (KLP) joint has small effect on first cracking load (the reduction is 5.6 %).

12.2 Ultimate Loads

From Table (3), it can be noted that presence of the joint reduces the ultimate load especially for some types of it where the reduction is significant. The reduction in ultimate loads for all types ranges from 1.8 % to 24.6 %. Minimum reduction (1.8 %) was in case of KLP joint, because the vertical part of the joint lies outside bending zone while the longitudinal part of it lies within bending zone so that it has no effect on flexural capacity. Maximum reduction (24.6 %) was in case of (IT) joint. Also, using of (KP) joint and (IP) joints have small effects on ultimate load (the reductions are 3.5 % and 7 % respectively).

12.3 Cracking to Ultimate Loads Ratio

From Table (3) it is seems that the presence of joint reduces the ratio of cracking to ultimate loads for the slabs (S_M, S_{IP}, S_{KT}, S_{KP} and S_{KLP}) where the ratios range from 0.23 to 0.3 in comparison with the ratio of reference slab (S_N) (0.32), while it rises this ratio for the slabs (S_{IT} and S_S) where the ratios are 0.33 and 0.36 respectively. Maximum ratio was 0.36 for slab (S_S), while minimum ratio was 0.23 for slab (S_M).

12.4 Failure Modes

All slabs were failed by flexural mode except the slab (S_S) which was failed by shear mode. The flexural failure occurs within bending zone especially when the joint locates within it where the fracture position lies near joint location. Slab (S_S) fails by shear due to presence of the joint within shear zone. Although part of (KLP) joint lies in shear zone, it fails by flexural because the vertical parts of this joint extend to half width of the slab at its two sides so that the shear capacity of it is larger than shear capacity of slab (S_S), and that prevents the earlier failure by shear and allow to flexural failure to take place.

12.5 Crack Pattern

Fig. (5) shows crack patterns for all tested slabs and effect of construction joint type on number and width of cracks and their propagation way along the tension sides of slabs.

From this figure, it was noted that for reference slab (S_N) without joint, there are many cracks distributed within bending zone without major crack. Maximum crack width was 0.8 mm at failure. For slab (S_M), the cracks are fairly lesser than these in reference slab because of concentration the cracks at major large crack that appeared at the location of the joint with a width reaches to 2.4 mm at failure.

Figure (5) Pictures of crack pattern for all tested slabs

For the slab (S_{IT}), the cracks are very few yet one major crack appears under the joint with 1 mm width at failure. This is because earlier failure, in comparison with the reference slab, that does not allow to further propagation of cracks. The earlier failure was happened due to the weakness of compression ability for the concrete in presence of this type of joint due to slipping of the two parts of jointed slab above them when they are compressed in above region of slab due to flexural stresses.

For the slab (S_{IP}), the cracks are lesser and narrower than those in slab (S_M). The vertical cracks are discontinuous because they are cutting by the diagonal major crack that extend along the inclined joint. Also, these vertical cracks appears corresponding about the major diagonal crack. Maximum width is 0.5 mm for vertical cracks and 0.7 for diagonal cracks at failure.

For the slab (S_{KT}), many cracks were propagated within bending zone that generally were narrower than those in slabs (S_N) and (S_M). Maximum crack at failure was parallel to joint line extended in above part of it with 9 mm width, while the crack propagated in location of below part of this joint has 0.4 mm width.

For the slab (S_{KP}), there are many cracks within the bending zone that generally were narrower than those in slabs (S_N) and (S_M) except the major crack that was very wide (10 mm) and locates at failure region in position of one of key joint legs.

For slab (S_{KLP}), there are many cracks within the bending zone and they were wider than those in slab (S_N) but narrower than those in slab (S_M). Major crack rapidly expands at failure and it was very wide (12 mm) and locates within bending zone under the load arm.

For slab (S_S) involved S joint (within shear zone), the cracks within the bending zone were lesser than those in slabs (S_N) and (S_M) because the failure take place by shear instead of bending. Also, there are some cracks in sides (shear zones) near the joints with major crack locates at failure region near the joint with maximum width about 3.7 mm.

12.6 Load Deflection Response

Fig. (6) shows the response relationship between applied load and deflection at mid of slab span. From this figure, it is noted that the presence of construction joint increases the deflection for all types of joint and for all stages of loading in comparison with deflection values of the reference slab. Generally, the differences in deflection are larger with increasing the applied loads and become more pronounced in last stages. The response of slab (S_{IP}) is the closest to the response of reference slab.

The responses of slabs (S_{KT}), (S_{KP}), (S_{KLP}) and (S_s) are the farthest from the reference slab in earlier stages of loading. The curve of all slabs, excepting slab (S_{IP}), become more farthest from curve of the reference slab in last stages especially slabs (S_M) and (S_{IT}). This means that presence of construction joint weaken the stiffness of the slab and increase its ability to exhibit the deformations under application of loads. The Slabs (S_M), (S_{KP}), and (S_{IT}) have the largest value of deflection at ultimate load.

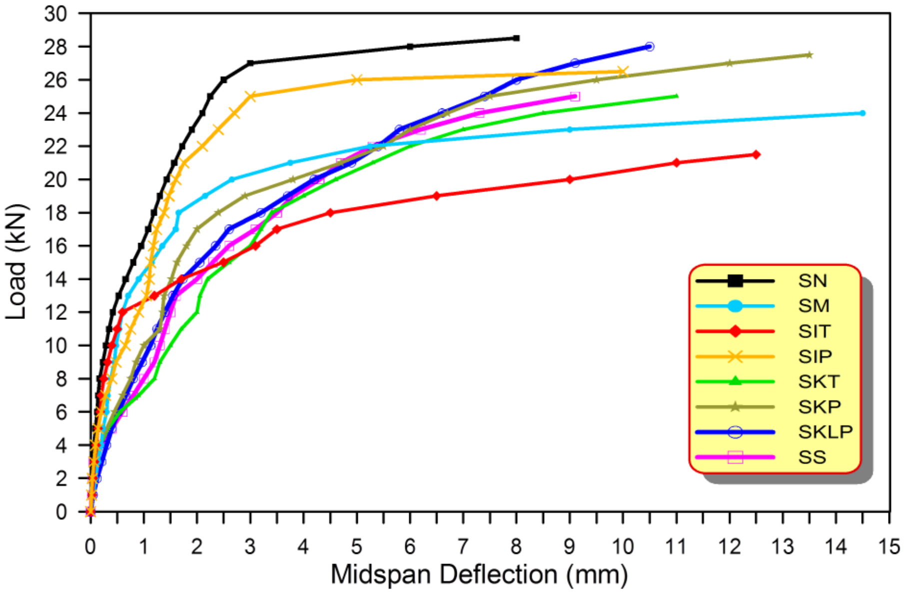


Figure (6) Load –deflection plot for all slabs

12.7 Effect of Vertical Joint at Mid of Slab Span

Effect of this type of joint (M) joint on behavior of slab can be clear from comparison between the results of the slabs (S_N) and (S_M). Using this type of joint reduces the cracking capacity by ratio of 38.9 % and the ultimate capacity by ratio of 15.8 % as shown in Table (3). This means that its effect on the cracking capacity is significantly larger than its effect on the ultimate capacity.

Also using this type of joint increase value of deflections for all loading stages, i.e. it makes the load – deflection response softer as shown in Fig. (7). The differences are very small for the earlier stage of loading, then these become larger as load increases reaching to ultimate load stage where the differences are very large. This means that this type of joint decreasing the slab stiffness.

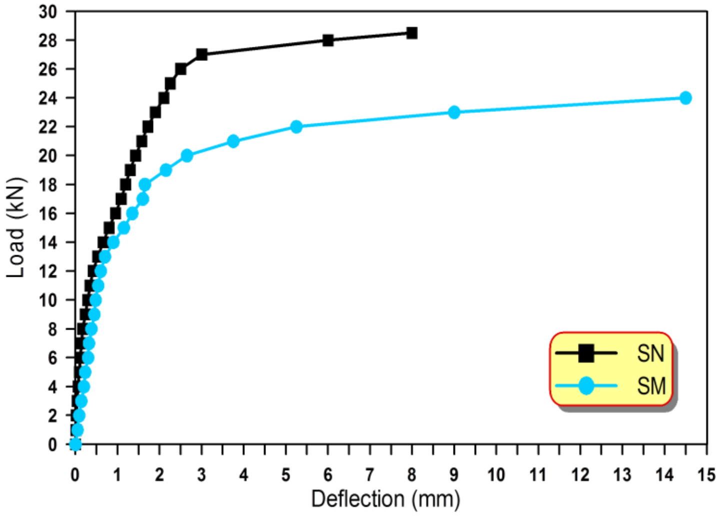


Figure (7) Load – deflection plot for slabs (S_N) and (S_M)

12.8 Effect of Inclined Joints

Two types of inclined joints were used in this study: (IT) joint and (IP) joint. Effect of these types of joints on behavior of slab can be noted from comparison between results of the slabs (S_{IT}) and (S_{IP}) with results of reference slab (S_N) as detailed in Table (4) and Fig. (8). Effect of (IP) joint was smaller than effect of (IT) joint on cracking and ultimate capacities as shown in Table (4).

Table (4) Effect of inclined joints on P_{cr} and P_u

Slab Name	Joint Type	Reduction in P_{cr}	Reduction in P_u
S_{IT}	IT	22.2 %	24.6 %
S_{IP}	IP	11.1 %	7.0 %

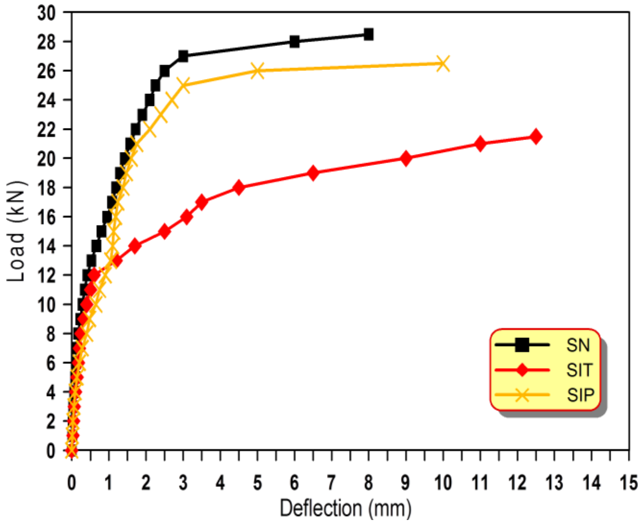


Figure (8) Load – deflection plot for Slabs (S_N), (S_{IT}) and (S_{IP})

Also, using (IP) joint does not significantly effect on load – deflection response where the curves of slabs (S_N) and (S_{IP}) are convergent for all loading stages. This indicate the small effect of (IP) joint on slab stiffness. While, using (IT) joint does not significantly effect on load – deflection response for the earlier stage of loading and its response is more convergent to response of reference slab (S_N) than slab (S_{IP}), but this effect becomes very significant in the advanced stage of loading where the deflection values of slab (S_{IT}) are debilities the deflection values of reference slab (S_N). This indicate the small effect of (IT) joint on slab stiffness in the earlier stages of loading while very high effect of it for the advanced stages.

Eventually, (IP) joint is more efficient than (IT) joint.

12.9 Effect of Key Joints

Three types of key joints were used in this study: (KT), (KP) and (KLP). Effect of these types of joints on behavior of slab can be noted by comparison of results of the slabs (S_{KT}), (S_{KP}) and (S_{KLP}) with results of reference slab (S_N) as detailed in Table (5) and Fig. (9). Effect of (KLP) joint was smaller than effects of (KT) and (KP) joints on cracking and ultimate capacities as shown from ratios of reduction for them in Table (5). Also, Effect of using (KP) joint was smaller than effect of using (KT) joint on cracking and ultimate capacities as detailed in Table (5).

Table (5) Effect of key joints on P_{cr} and P_u

Slab Name	Joint Type	Reduction in P_{cr}	Reduction in P_u
S_{KT}	KT	33.3 %	12.3 %
S_{KP}	KP	22.2 %	3.5 %
S_{KLP}	KLP	5.6 %	1.8 %

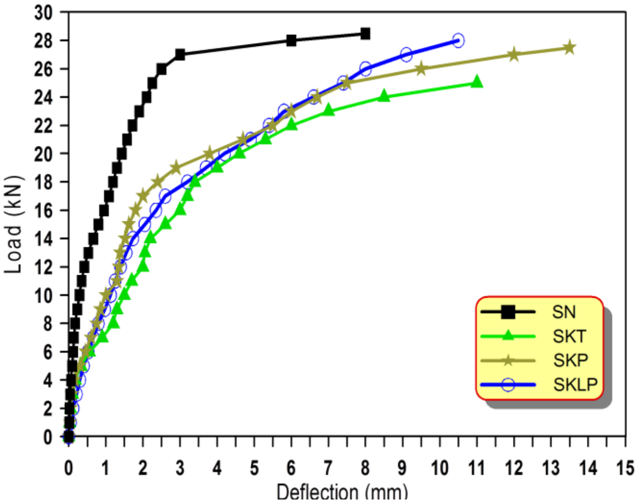


Figure (9) Load –deflection plot for Slabs (S_N), (S_{KT}), (S_{KP}) and (S_{KLP})

Using of these types of joint effects on load – deflection response where the deflection values of the slabs (S_{KT}), (S_{KP}) and (S_{KLP}) are larger than deflection values of reference slab (S_N) for all loading stages. These differences become larger as the loading progresses. This means that these types of joints makes the load deflection response of the slab more softer because these joint have considerable effects on slab stiffness.

Generally, the load deflection responses for slabs (S_{KP}) and (S_{KLP}) are fairly convergent for all stages of loading. Also, the response of the slab (S_{KT}) is slightly softer than response of the slabs (S_{KP}) and (S_{KLP}).

Eventually, (KLP) joint is more efficient than (KT) and (KP) joints. Also, (KP) joint is more efficient than (KT) joint.

12.10 Effect of Joints in Side of Slab (Shear Zone)

Two types of side joints were used in this study: (S) joint and (KLP) joint that the vertical parts of it extended in side of the slab (shear zone). Effect of these types of joints on behavior of slab can be noted from comparison between results of the slabs (S_s), (S_{KLP}) with results of reference slab (S_N) and slab (S_M) (to study effect of moving the joint from mid to side of slab span on its behavior) as detailed in Table (6) and Fig. (10).

Table (6) Effect of Side joints on P_{cr} and P_u

Slab Name	Joint Type	Reduction in P_{cr}	Reduction in P_u
S_M	M	38.9 %	15.8 %
S_{KLP}	KLP	5.6 %	1.8 %
S_S	S	0 %	12.3 %

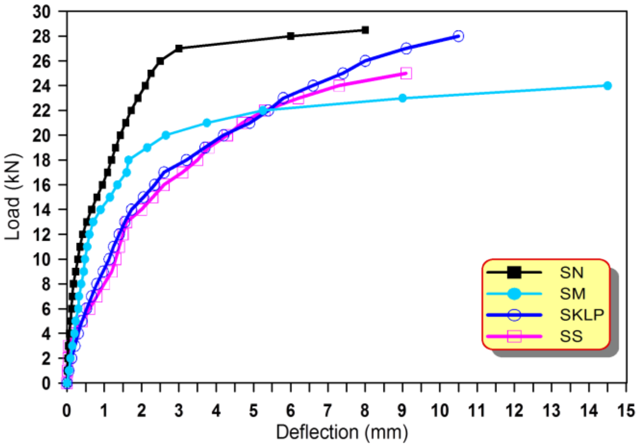


Figure (10) Load –deflection plot for Slabs (S_N), (S_M), (S_{KLP}) and (S_S)

(S) joint has not effect on cracking capacity because there is no joint in bending zone. Also, its effect on ultimate capacity was smaller than effect of using (M) joint. The failure of the slab (S_S) differs from failure of the slab (S_M) where the first fails by shear while the second fails by flexural. This difference in failure due to presence of (S) joint in shear zone that weakens shear capacity of the concrete.

(KLP) joint has very slight effect on cracking and ultimate capacities because the bending zone involves only the longitudinal part of it while the vertical parts of it distribute on shear zones. The failure was by flexural rather than shear because the vertical part of the joint extend to only half of slab width so that the concrete keeps its shear capacity in the other half.

Using of (S) and (KLP) joints significantly affects load – deflection response where deflection values of the slabs (S_S) and (S_{KLP}) are larger than deflection values of reference slab (S_N) for all loading stages. These differences become larger as the loading progresses.

This means that these types of joints makes the load deflection response of the slab softer because these joints can be consider as hinge regions that give different structural behavior from that for ordinary simply supported slabs, therefore these regions cause marked increase in deflection values from these in reference slab.

Generally, the load deflection responses for slabs involved (S) and (KLP) joints are fairly convergent for all stages of loading. In most of loading stages, response of the slab (S_M) is stiffer and closer to response of reference slab than responses of the slabs (S_S) and (S_{KLP}), but it becomes softer and farthest from response of reference slab in last stages of loading.

Eventually, (KLP) joint is more efficient than (M) and (S).

12.11 Effect of Joints Extended in Transversal Manner

Two types of joints were made in transversal manner in this study: (IT) and (KT) joints. Effect of these types of joints on behavior of slab can be noted from comparison between results of the slabs (S_{IT}), (S_{KT}) with results of reference slab (S_N) and slab (S_M) (to study effect of changing configuration of joint from the vertical form to transversal form on its behavior) as detailed in Table (7) and Fig. (11).

Table (7) Effect of Transversal joints on P_{cr} and P_u

Slab Name	Joint Type	Reduction in P_{cr}	Reduction in P_u
S_M	M	38.9 %	15.8 %
S_{IT}	IT	22.2 %	24.6 %
S_{KT}	KT	33.3 %	12.3 %

Effect of (IT) joint was smaller than effects of (KT) and (M) joints on cracking capacity but its effect on ultimate capacity was significantly larger than effects of the other two joints as detailed in Table (7). Effect of (KT) joint was slightly smaller than effect of (M) joint on both cracking and ultimate capacity.

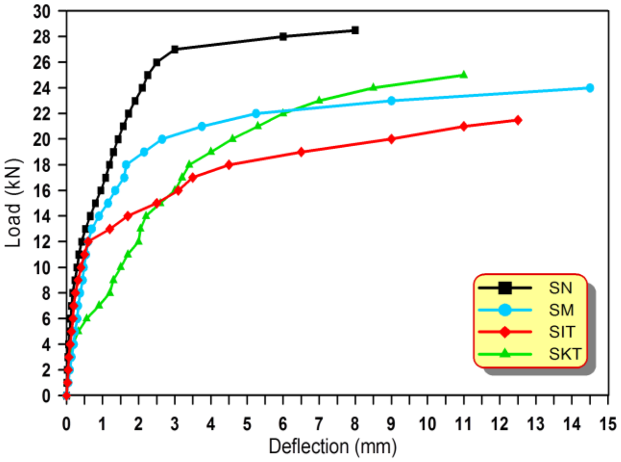


Figure (11) Load –deflection plot for Slabs (S_N), (S_M), (S_{IT}) and (S_{KT})

Load – deflection responses of the slabs (S_M) and (S_{IT}) are close to response of (S_N) for earlier stage of loading, then they suddenly left away from it and become more softer than it in advanced stage of the loading, where the differences in deflections become larger with advancing the loads. The response of (S_{KT}) slab was softer than the others in earlier stage of loading, then it becomes stiffer than the response of the slab (S_{IT}) in advanced stage of loading. Also it becomes stiffer than the response of the slab (S_M) in last stages of loading.

Eventually, (KT) joint is more efficient than (M) and (IT) joints.

12.12 Effect of Joints Extended in Plane Manner at Bending Zone

Two types of joints were made in plane manner within the bending zone in this study: IP and KP joints. Effect of these types of joints on behavior of slab can be noted from comparison between results of the slabs (S_{IP}), (S_{KP}) with results of reference slab (S_N) and slab (S_M) (to study effect of changing configuration of joint from the vertical form to in plane forms on its behavior) as detailed in Table (8) and Fig. (12).

Table (8) Effect of in plane joints on P_{cr} and P_u

Slab Name	Joint Type	Reduction in P_{cr}	Reduction in P_u
S_M	M	38.9 %	15.8 %
S_{IP}	IP	11.1 %	7.0 %
S_{KP}	KP	22.2 %	3.5 %

Effect of (IP) joint was smaller than effects of (KP) and (M) joints on cracking capacity while effect of KP joint was smaller than effects of (IP) and (M) joints on ultimate capacity. Also, effects of (IP) and (KP) were significantly smaller than effect of (M) joint for both cracking and ultimate capacities.

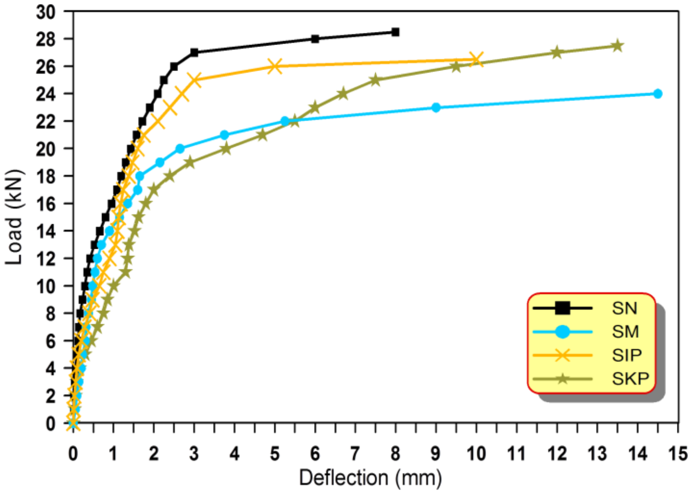


Figure (12) Load – deflection plot for Slabs (S_N), (S_M), (S_{IP}) and (S_{KP})

Load – deflection response of the slab (S_{IP}) is approximately similar to response of reference slab (S_N) for all stages of loading and stiffer than other responses. Response of the slab (S_{KP}) softer than responses of the slabs (S_N) and (S_{IP}) with convergence between the slabs (S_{KP}) and (S_{IP}) in final loading stages. Also, response of the slab (S_{KP}) is softer than response of the slab (S_M) but becomes stiffer at final stages due to the rapid failure of the slab (S_M).

Eventually, (KP) and (IP) joints are more efficient than (M) joint.

12.13 Deflection and stiffness Values at Cracking and Service Stages

Table (9) shows the details of the deflection and stiffness values for all slabs at cracking and service stages. Stiffness values express slab rigidity at a stage of loading. Stiffens value approximately is calculated by division of load value by deflection value at a point of load – deflection curve, i.e. it represents the slope of the line extended from origin to that point. Service stage is considered at point of 20 kN loading that represents about 70 % of ultimate capacity of reference slab (S_N). These values aids to understand the effect of construction joint type on deflection and stiffness values at these important stages of loading (cracking and service stages).

For cracking stage results, from ratios of deflection values, it is noted that (M) and (IT) joints have slight effect on deflection values where deflection ratios of the slabs (S_M) and (S_{IT}) converge from unity (deflection ratio of S_{IT} smaller than 1 due to smaller cracking load by comparison with cracking load of S_N). (IP), (KT) and (KP) joints have moderate effect on deflection values. While (KLP) and (S) joints have significant effect on deflection values. Also, from stiffness values, it is noted that the slab (S_{IT}) has the largest stiffness of the other jointed slabs. The slabs (S_M) and (S_{IP}) have moderate stiffness values, while the slabs (S_{KT}), (S_{KP}) and (S_{KLP}) have small stiffness values and the stiffness for slab (S_s) is the smallest.

Table (9) Deflection and stiffness values at cracking and service stages

Slab Name	Δ_{cr} mm	$\frac{\Delta_{cr\ joint}}{\Delta_{cr\ None}}$	Cracking Stiffness (P_{cr} / Δ_{cr}) kN/mm	$\Delta_{20\ kN}$ mm	$\frac{\Delta_{20\ joint}}{\Delta_{20\ None}}$	Service Stiffness ($20 / \Delta_{20}$) kN/mm
S_N	0.23	---------	39.13	1.43	-------	13.99
S_M	0.27	1.17	20.37	2.65	1.85	7.55
S_{IT}	0.2	0.87	35	9	6.29	2.22
S_{IP}	0.4	1.74	20	1.6	1.12	12.5
S_{KT}	0.56	2.43	10.71	4.6	3.22	4.35
S_{KP}	0.6	2.61	7.87	3.8	2.66	5.26
S_{KLP}	0.89	3.87	9.55	4.2	2.94	4.76
S_S	1.2	5.22	7.5	4.3	3.01	4.65

For service stage results, from ratios of deflection values, it can be noted that (IP) joint has slight effect on deflection values where deflection ratio of the slab (S_{IP}) converges from unity. (M) joint has moderate effect on deflection values while (KT), (KP), (KLP) and (S) joints have significant effect on them. (IT) joint have very high effect on deflection values. Also, from stiffness values, it is noted that the slab (S_{IP}) has the larger stiffness of the other jointed slabs. The slab (S_M) have moderate stiffness value, while the slabs (S_{KT}), (S_{KP}), (S_{KLP}) and (S_s) have small stiffness values. The stiffness for slab (S_{IT}) is the smallest.

Based on these results,(IP) joint is more efficient than other types of joint.

13. Conclusions

1-All tested slabs were failed by flexural except the slab (S_S) that were failed by shear because its construction joint extends through shear zone (side region) of the slab.

2- (M) joint has the largest effect on cracking capacity (reduction is 38.9 %) while (S) joint has no effect on it because it fails by shear. (KLP) joint has small effect (reduction is 5.6 %).

3- (IT) joint has the largest effect on ultimate capacity (reduction is 24.6 %) while (KLP) joint has the least effect on it (reduction is 1.8 %).

4- Presence of (M), (KT), (KP), (KLP) and (S) joints in slab results in propagation of very wide crack at failure extends along or near line of the joint, while (IT) and (IP) joints result in propagation of narrow final crack along of joint line.

5- Load deflection response of slab (S_{IP}) is the closest to the response of reference slab. The responses of slabs (S_{KT}), (S_{KP}), (S_{KLP}) and (S_s) are softer than the reference slab for all stages of loading, while the responses of the slabs (S_M) and (S_{IT}) are close to response of reference slab in earlier stages of loading while they become the farthest and the softest than the all other slabs in advanced stages of loading.

6- At cracking stages, (IT) joint has the smallest effect on deflection values and results in the largest stiffness for the jointed slab, while (S) joint has the largest effect on deflection values and results in the smallest stiffness for the jointed slab.

7- At service stages, (IP) joint has the smallest effect on deflection values and results in the largest stiffness for the jointed slab, while (IT) joint has the largest effect on deflection values and results in the smallest stiffness for the jointed slab.

8- (KLP), (KP), (IP) can be considered as the best types of the construction joints due to their small effects on ultimate capacity and because they result in reasonable load – deflection responses by comparison with the reference slab.

9 – It is not preference to use (M) and (S) joints due to the rapid failure for the slab (S_M) and the catastrophic shear failure for the slab (S_S).

10- (IT) joint is not desirable due to its small capacity and probability of incidence of compression failure (brittle failure) especially when the reinforcement ratio is high.

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