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STRUCTURAL BEHAVIOR OF EMBEDDED SHEAR HEAD IN MODIFIED REACTIVE POWDER FLAT PLATE CONCRETE WITH OPENING

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Abstract: This study presents an experimental investigation on one type of embedded shearhead called (collar head reinforcement) as shear reinforcement for tow type of reinforced concrete flat plate with presence of opening on punching shear strength. This type of shearhead is one of the structural solution that are used to increase the shear strength of flat slab . In the present research , ten specimens are tested with dimensions (1000x1000x75 mm) which are divided into two groups; the first group is a normal strength concrete with a compressive strength 30MPa; the second group is modified reactive powder concrete with a compressive strength 90MPa. Each group consists of five slabs. By using collar shearhead around the column sides and extended to the opening NSC4, the cracking load can be increased to 100% solid flat slab without collar head. For serviceability of flat plate with opening, the deflection and crack width can be reduced by using collar head around the column sides extended to the opening. The reduction can be continued by increasing the compressive strength of the concrete. The losses in the critical section property in the present work do not exceed 7% in the case of specimen with opening with dimension equal to the supporting column dimensions. By concentrating on the slabs which had openings adjacent to the column but strengthened with collar head in different configurations, the percentage of the critical section perimeter was between (103.2– 119.3) % that was reflected to the capability of this type of shear reinforcement (collar shear head) in making up the shortfall in the critical section due to the presence of openings.

Keywords: *Flat Plate, Punching Shear, Modified Reactive Powder.*

التصرف الانشائي لتسليح القص الطوقي المطمور في بلاطة مستوية من خرسانة المساحيق الفعالة المعدلة بوجود الفتحات

الخلاصة: تقدم هذه الدراسة بحث عملي لاحد انواع تسليح القص للسقوف المستوية والمسمى بتسليح القص الطوقي لنوعين من الخرسانة, مع وجود فتحات ملاصقة للعمود . ان تسليح القص (التسليح الطوقي) يعتبر احد الحلول الانشائية لزيادة مقاومة القص للسقوف المستوية. ان هذا البحث يتضمن اختبار عشرة نماذج ذات ابعاد (1000*1000*75) ملم ومقسمة الى مجموعتين المجموعة الاولى تتضمن خرسانة مسلحة عادية ذات مقاومة انضغاط 30 ميكا باسكال والمجموعة الثانية تتضمن خرسانة المساحيق الفعالة المعدلة ذات مقاومة انضغاط 90 ميكا باسكال وكل مجموعة تتكون من خمسة نماذج وكل مجموعة تحتوي على مرجع بدون فتحة ملاصقة للعمود وتحتوي على نموذج يحتوي على فتحة ملاصقة للعمود ولاتحتوي على تسليح القص الطوقي وثلاثة نماذج تحتوي على فتحة ملاصقة للعمود وتحتوي على تسليح القص الطوقي . ومن الناحية الخدمية التشوه الحاصل وعرض الشق يمكن تقليله باستخدام التسليح الطوقي الفولاذي المحاط بالعمود والممتد الى الفتحة الملاصقة للعمود. ان النقص الحاصل في المقطع الحرج لا يتجاوز ال 7% يالنسبة للنماذج الحاوية على فتحات ملاصقة للعمود وباستخدام تسليح القص الطوقي تزداد النسبة (103.2-119.3)% وهذا يشير الى قدرة هذا النوع من التسليح (تسليح القص الطوقي الفولاذي)في تعويض النقص الحاصل في المقطع الحرج نتيجة وجود الفتحات.

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1. Introduction

Generally, flat plates are two-way concrete slabs having uniform depths and transfer loads directly to supporting columns without the aid of beams or column capitals or drop panels. Flat plates can construct quickly due to their simple formwork and reinforcing bar arrangements. They need the smallest overall story heights to provide specified headroom requirements and they give the most flexibility in the arrangement of columns and partitions [1]. Punching shear failure of reinforced concrete slabs occurs when concentrated loads are applied, causing very high shear- and axial stresses. At first, the combined stress performance leads to radial cracks, starting at the edge of the load application zone. Increasing the load causes tangential cracks around the load application zone. The failure state is reached when an inclined crack forms around the column, with a typical cylindrical punching failure cone, the column separates from the slab. Without shear reinforcement, the punching shear failure performs in a brittle manner within the discontinuity region of the highly stressed slab at the column [2].

Shearhead is a structural member embedded at the slab-column junction, the main use of shearhead is that to spread the load of the floor on the respective columns and increasing the critical punching shear perimeter around the column [3]. So, reduce the effect of the vertical forces, reduce the stresses in the slab. Connections of columns with flat plates should not considered in design as part of the system resisting lateral forces [4]. Reactive Powder Concrete (RPC) is a developing composite material that will allow the concrete industry to optimize material use, generate economic benefits, and build structures that are strong, durable, and sensitive to environment [5].

A treatment was invented by replacement of the fine ground quartz sand by an equal volume of well graded natural aggregate (maximum size of 8 mm) that will not change the compressive strength of the RPC at the same water-cement ratio and this is known as modify reactive powder concrete MRPC [6]. In flat plate floor systems, there is often a need to install new services that required openings in the vicinity of columns. Small openings are required in the slab to accommodate the mechanical and electrical services such as heating, plumbing and ventilating risers, air conditioning and electrical ducts [7].

2. Materials

Concrete compositions, reinforcing steel bars and steel shearhead consist from steel angles(L sections), were tested in the laboratory and showed good agreement with specifications:

- Water: tap water used.
- Cement: Bazian ordinary Portland cement type (I) was used. The physical analysis and chemical test results conform to the Iraqi specification No.5/1984 [8].
- Fine Aggregate (Sand): Al –Ukhaidher natural sand is used ,the physical analysis test results are within the limits of Iraqi Specification No. 45/1984[9]. For

MRPC,only the passing sand from sieve No.4 (600μm) was used to achieve the mixing requirements and properties.

- Coarse Aggregate (Gravel): Crushed gravel from AL–Nibaee with maximum size of (10mm) is used. The physical analysis test results are within the limits of Iraqi Specification No. 45/1984[9]. For MRPC mixes, only the passing sand from sieve No. 3 (4.75 mm) was used to achieve the mixing requirements and properties

- Steel Reinforcement: The steel reinforcement used to reinforce the concrete slab is deformed mesh bars 6 mm diameter and 75mm spacing. Columns reinforcement was. bars 6 mm diameter for all slabs.

- Steel Shearheads: consist from steel angle (L sections) .

-Admixture: For the production of MRPC mix, superplasticizer (high range water reducing agent HRWRA) based on poly carboxylic ether is used.

One of the new generation of polymer based super plasticizer designed for the production of MRPC, Glenium 51 is used. The normal dosage for Glenium 51 is (0.5-0.8) L/100 kg of cement mass.

-Silica Fume: Silica fume is a highly reactive material that is used in relatively small amount to enhance the properties of concrete.it was generally used at 5 to 12 % by mass of cementitious materials as a partial replacement for concrete structure that need high strength or significantly reduced permeability to water [10].

3. Slabs details

This study is based on ten specimens, divided into two groups, the first group is consist of normal strength concrete slabs with a compressive strength 30MPa; the second group is consist of modified reactive powder concrete slabs with a compressive strength 90MPa. Each group consists of five specimens and each group contains reference specimen, specimen with opening adjacent to the column but without collar head , three specimens with opening and with collar head, the details of these slabs are listed in "Table 1". All slabs were geometrically similar, having dimensions (1000×1000×75 mm) and loaded through a central column of dimension (150×150 mm) as shown in "Fig. 1 and Fig.2. The slabs which have shear head {collar head) as shown in "Fig. 3"and "Fig. 4"and"Fig. 5". The slabs have the same flexural reinforcement. simply supported along all edges and the distance between center lines of support was (900mm).

Table 1. The Characteristics of Test Slabs.

Group No	Specimens	Opening and Dimension	Collar Head Reinforcement
G1	NSCR	-----	-----
fć=30MPa	NSC1	150*150	-----
	NSC2	150*150	On both sides of the col towards the opening
	NSC3	150*150	On both sides of the col away from the opening
	NSC4	150*150	Entire the col (all sides of col) and extend to the opening
	MRPCR	-----	-----
G2	MRPC1	150*150	-----
fć=90MPa	MRPC2	150*150	On both sides of the col towards the opening
	MRPC3	150*150	On both sides of the col away from the opening
	MRPC4	150*150	Entire the col(all sides of col) and extend to the opening

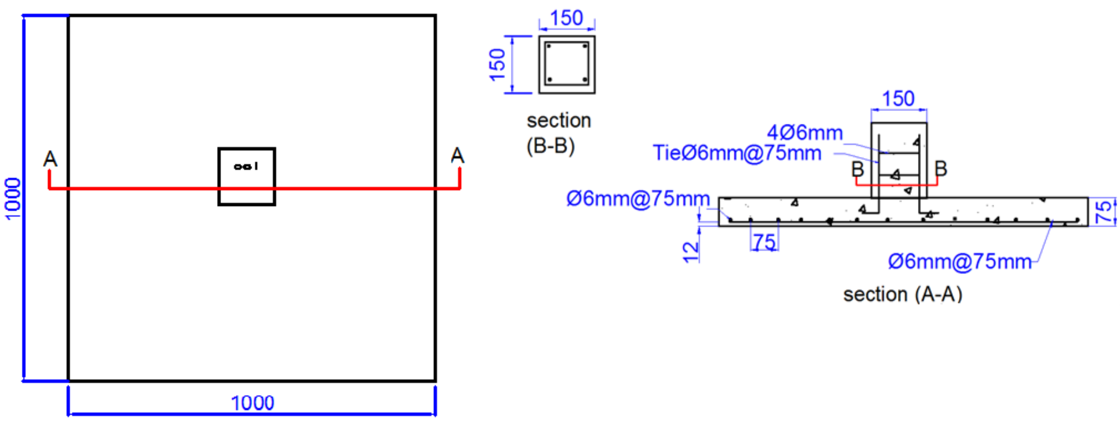


Figure 1. Dimension and Layout of Slab Without Shearhead (NSCR,MRPCR)

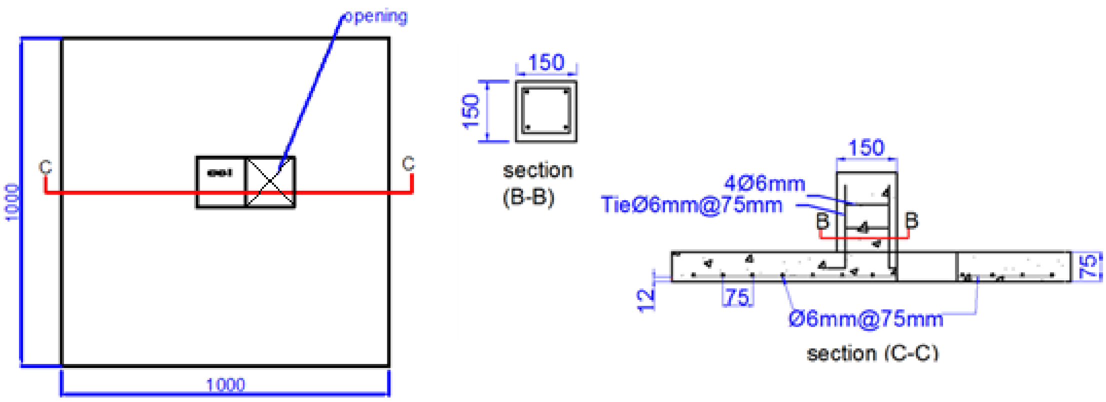


Figure 2. Dimensions and Layout of Slab with Opening(NSC1,MRPC1)

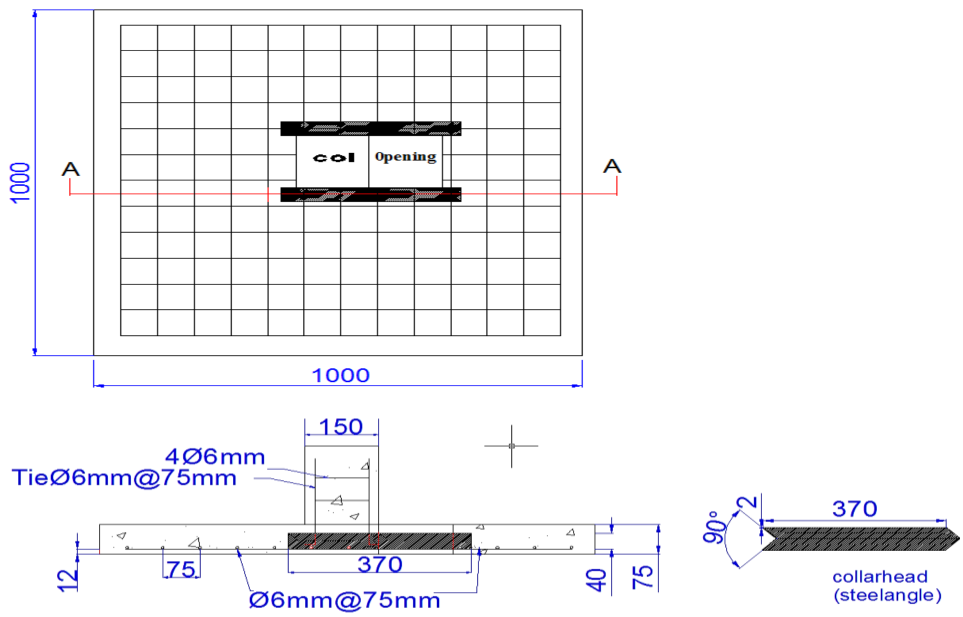


Figure 3. Dimensions and Layout of Slab with Collar Head on both sides of the col towards the opening(NSC2,MRPC2)

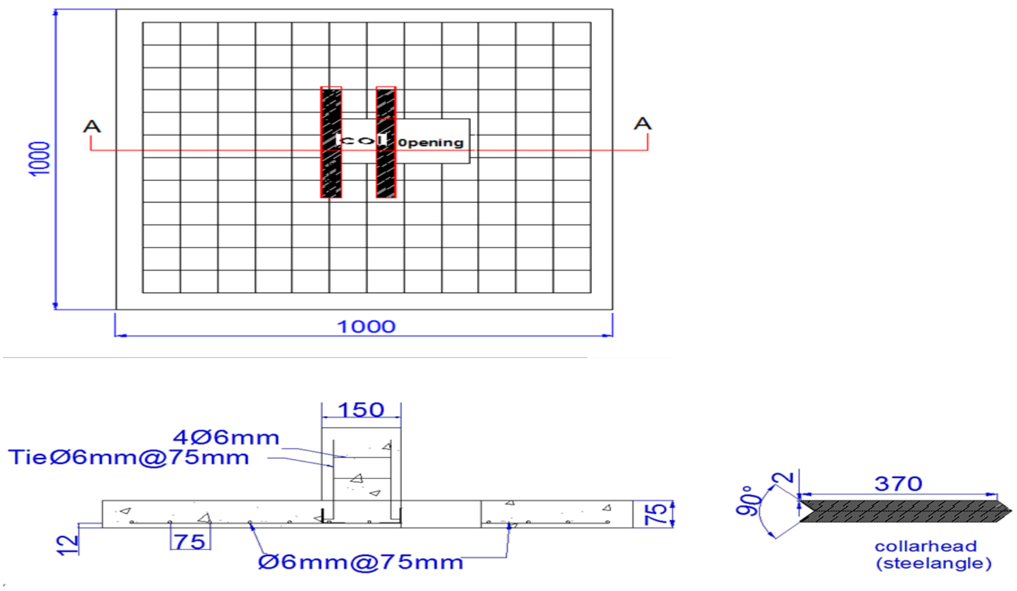


Figure 4. Dimension and Layout of Slab with Collar Head on both sides the col away from the opening(NSC3,MRPC3)

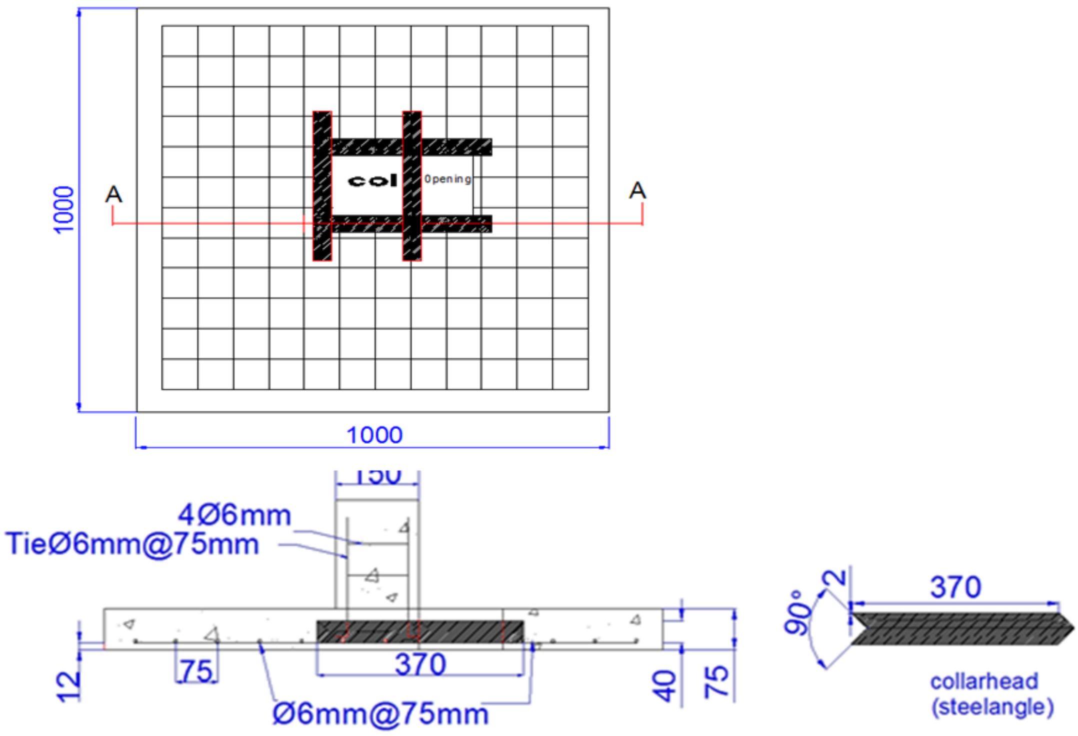


Figure 5. Dimension and Layout of Slab with Collar Head all sides of col and extend to the opening(NSC4,MRPC4)

4. Concrete Mix, Casting and Curing

The following steps are followed before mixing;

1. The fine aggregate is washed and dried to remove any clay particles.

2. The coarse aggregate sieved on (10 mm) sieve size to remove the large size aggregate particles. Then, the aggregate also washed and dried.
3. Weights preparation.

The mixing procedure is an important thing to obtain the required workability and homogeneity. A horizontal rotary mixer of (0.19 m3) capacity was used, and the following sequence is adopted after a number of trial mixes have been done

Mixing of NSC

Before starting to mix NSC, it was necessary to keep the mixer clean and moist but free of water. First, the gravel and sand were poured in the mixer, with the addition of (1/3) of the mixing water to wet them, and then they were mixed for (1 min). Cement is added at this stage and mixed for (1/2 min), then followed by (1/3) of mix water and mixed for (1min), and then the remaining water is added gradually and mixed for (1.5 min). The total mixing time is (4 min)

Mixing of MRPC

In Mixing MRPC , 50% of very fine sand (0.6mm) was replaced by fine gravel of(4.75mm) The procedure used for production of the MRPC was briefly stated in the following points: First, cement and silica fume were mixed together carefully to obtain dry cementitious material (powder), the fine aggregate was added to the mixer with 1/3 water, and mixed for 1 minute. Following, the powder (cement + silica fume) is added with another 1/3 mixing water, and mixed for 1 minute. After that, the coarse aggregate was added with the last 1/3 mixing water and 1/3 of superplasticizer, and mixed for (1.5) minute then the mixture was left for (1.5) minutes for rest. Then, the remaining 2/3 of the super plasticizer is added and mixed for (1.5) minutes. The mixture is then discharged, casted and tested. The total time of mixing was (5 min).

5. Testing Machine

Testing is conducted by using MFL system of hydraulic universal testing machine type EPP300, with a maximum capacity of (3000 kN) as shown in Plate .1 Before testing, a thin layer of white emulsion paint is applied onto the surface of the specimen to aid the detection of cracks, the rate of loading was 10 KN.

Plate 1. Testing Machine with Loading Frame.

6. Discussion and Results

6.1 Cracking Load, Ultimate load and Crack Pattern

6.1.1 Group One (NSC)

The test results of cracking and ultimate loads of slab in group G1 are illustrated in "Table 2" and show in" Fig. 6"," Fig. 7", the first crack is formed at about (40 - 48.27) % of the ultimate load for each slab. The first crack appears around the sides of the column on the tension face of the slab. The specimens which have openings adjacent to the column and without collar head the first crack also appears around the sides of the column on the tension face , and extend to include the edge far from the column , and in the specimens with collar head the cracks attach the corners of the opening in the tension face of the slab near one or more of the corners of collar head .

The cracks development delineates cracking area surrounding the project of supporting column at the tension face of the tested specimens, as shown in Plate 2. to Plate 6. below. When failure becomes more prepositioning to start out, crack appears around the sides of the column on the compression face of the slab and the column begins its diving to punch the slab downward.

Table 2. Characteristics of cracking load of the Tested Slabs

Group No.	Specimens	First Crack load (Pcr)KN	Ultimate Load (Pu)KN	$\frac{Pcr}{Pu}$ %	Maximum Crack Width (w)mm	$\frac{Pcr}{PcrRefere}$ %	Mode of Failure
G1 fć=30MPa	NSCR	40*	90	44.4	2.60	-	Punching+flexure
	NSC1	30	70	42.85	2.85	75.0	Punching
	NSC2	35	72.5	48.27	2.45	87.5	Punching
	NSC3	35	82.5	42.42	2.35	87.5	Punching
	NSC4	40	87.5	40	2.20	100.0	Punching
G2 fć=90MPa	MRPCR	100**	215	46.5	2.15	-	Punching+flexure
	MRPC1	50	120	41.67	2.25	50	Punching
	MRPC2	60	127.5	47.06	2.00	60	Punching
	MRPC3	75	145	51.72	1.95	75	Punching
	MRPC4	90	180	50	1.85	90	Punching

* Reference cracking load for G1

**Reference cracking load for G2

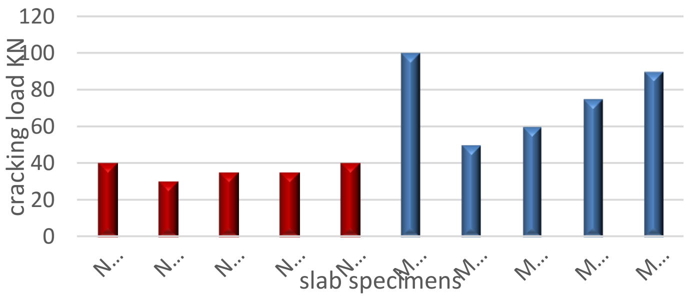


Figure 6. Cracking Load for all tested specimens

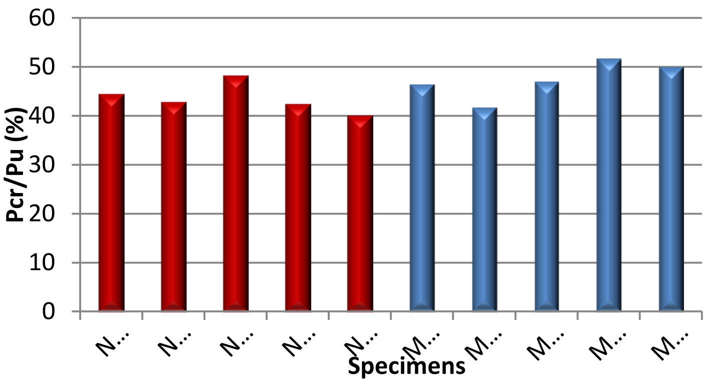
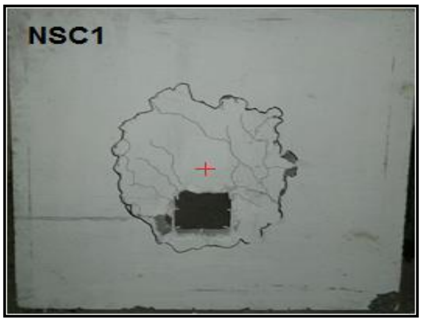


Figure 7. Percentage of cracking load to ultimate load for all tested specimens

Plate 2. Tension Face for Slab NSCR



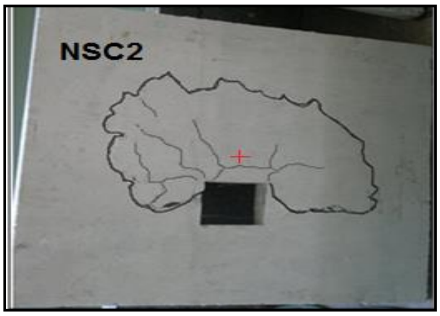
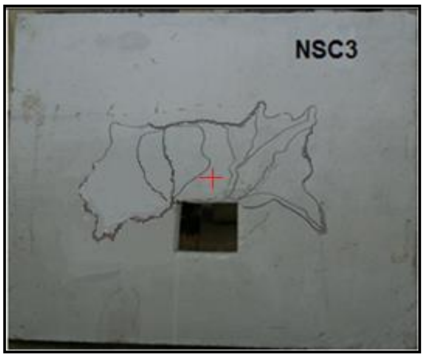


Plate 3. Tension Face for Slab NSC1

Plate 4. Tension Face for Slab NSC2



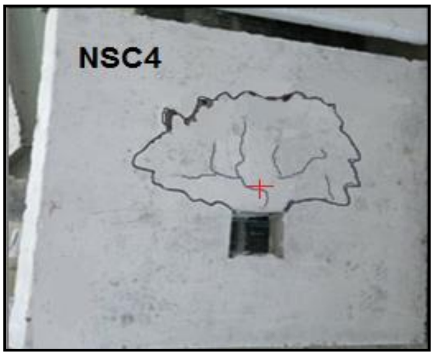


Plate 5. Tension Face for Slab NSC3

Plate 6. Tension Face for Slab NSC4

6.1.2 Group Two (MRPC)

The test results of cracking and ultimate loads of slab in group G2 are illustrated in "Table 2 " above and show in " Fig. 6"and" Fig. 7" above. When the load was applied to these slab specimens, the first crack was formed at about (41.67-51.72) % of the ultimate load.

The specimens which have openings adjacent to the column and without collar head the first crack also appears around the sides of the column on the tension face as reference slab , and extend to include the edge far from the column in the specimen at cracking load (41.67)% of the ultimate load capacity and in the specimens with collar head the cracks attach the corners of the opening in the tension face of the slab near one or more of the corners of collar head.

The cracks propagation continue with increase of loading and the cracks development delineates cracking area surrounding the project of supporting column at the tension face of the tested specimens, as shown in Plate 7. To Plate 11. below.

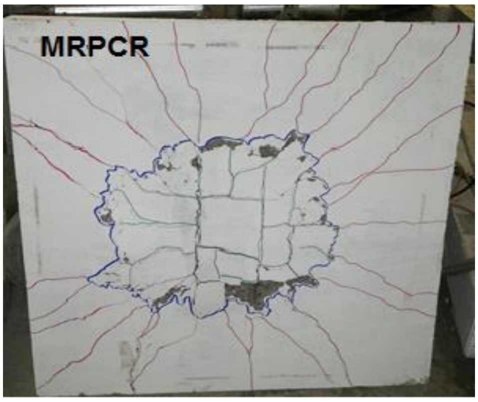


Plate 7. Tension Face for Slab MRPCR

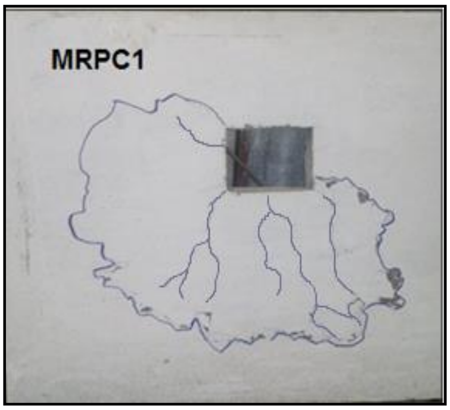


Plate 8. Tension Face for Slab MRPC1

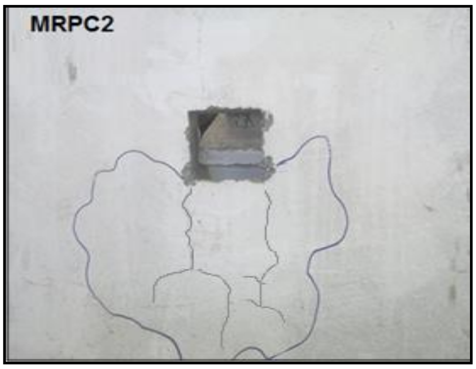


Plate 9. Tension Face for Slab MRPC2

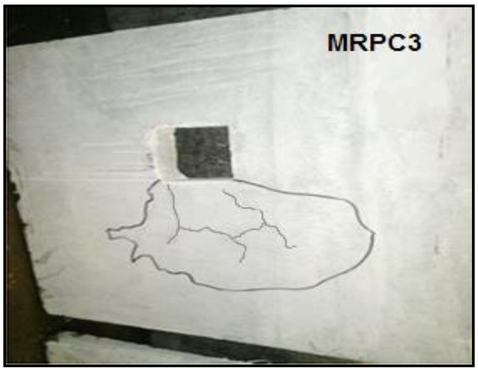


Plate 10. Tension Face for Slab MRPC3

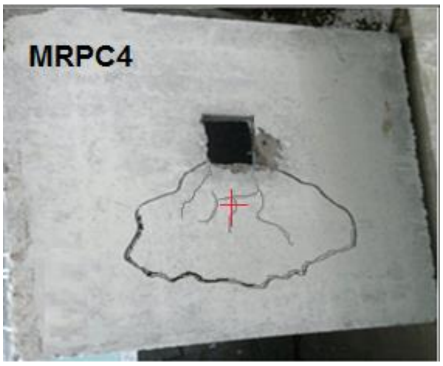


Plate 11. Tension Face for Slab MRPC4

6.2 Crack Width

In general, crack width is measured using special crack measuring instrument having a minimum thickness of 0.05 mm. At early stages of loading cracks widen slowly when loading continues until yield at reinforcement cracks become wider with excessive widening at small increments of loads.

The test results show that the maximum crack width decreases when compressive strength of reinforced concrete slabs increases and for specimens which have openings, is higher than reference slab, and the specimens which have openings that reinforced by collar head the maximum crack width decreases relative to specimens without collar head." Fig. 8" and "Fig. 9 " show the load-crack width curve for each group of specimens to illustrate the general crack width development of the work specimens.

The figure below reflects the approximate similar trend in cracks widening or cracks width increase in value. Also, the figure illustrates the differences in the tensile stress resistance among the tested specimens through the observed values of the cracking appearance or the first recorded value of the crack width. Delaying of crack appearance or increasing the cracking load value exhibits the strength of the section in tensile stress resistance, so that , at a specific stage of loading or load value, when the applied tensile stress on the specimen exceed its tensile strength, crack can be formed at a stage of loading called cracking load, and higher value of cracking load means high strength against tensile stresses and specimen increased capability to delay the cracks forming and propagation for increasing the slab serviceability.

In general

In the reference slab NSCR, the first crack load occurs at 40KN and this value decreases in the specimens which have openings adjacent to the column NSC1 to be 30 KN. When used collar head in its sides of column toward the opening NSC2, this percentage increases to be 35KN and also it is the same percentage in NSC3, and reach to 40KN at NSC4 which is the collar head in the entire column and extend to opening.

In the reference slabs NSCR, the maximum crack width is 2.6mm and increases in specimen which has opening NSC1 to (2.85) mm and in NSC2,NSC3 the value decreases until to(2.2) in NSC4and this value is less than the reference and this belongs to the presence of collar head .

In the reference slabs MRPCR, the first crack load is the higher value in the group (100)KN and this value decrease in the specimens which have openings adjacent to the column MRPC1to reach 50KN .When is used collar head in the sides of column toward the opening MRPC2 this load increase to be 60KN and also the cracking load increases in MRPC3 and reaches to 90KN at MRPC4 which the collar head in all sides of column and extends to opening.

The maximum crack width in the reference slabs MRPCR is 2.15mm and this value is less than NSCR that belong to high strength compressive of MRPC and increases in specimen which has openingMRPC1 to (2.25) mm and in MRPC2, MRPC3 the value decreases until to(1.85) in MRPC4and this value is less than the reference and this belong to presence of collar head .

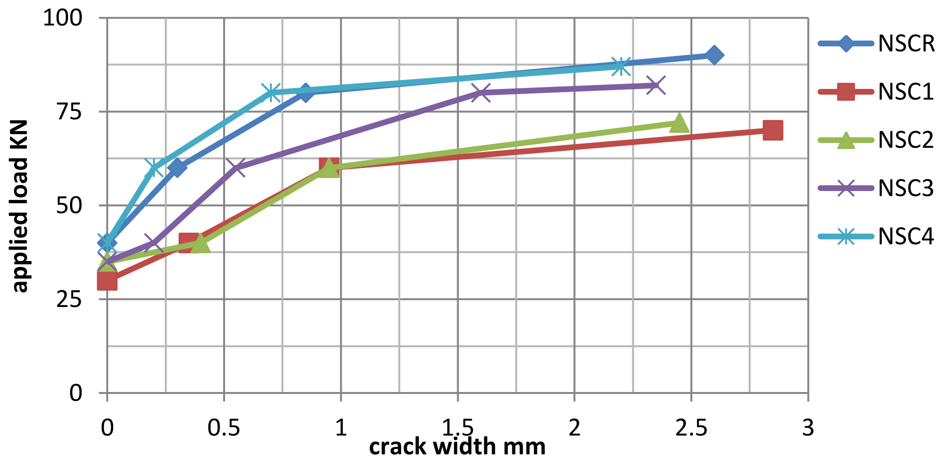


Figure 8. Maximum Crack Width for G1

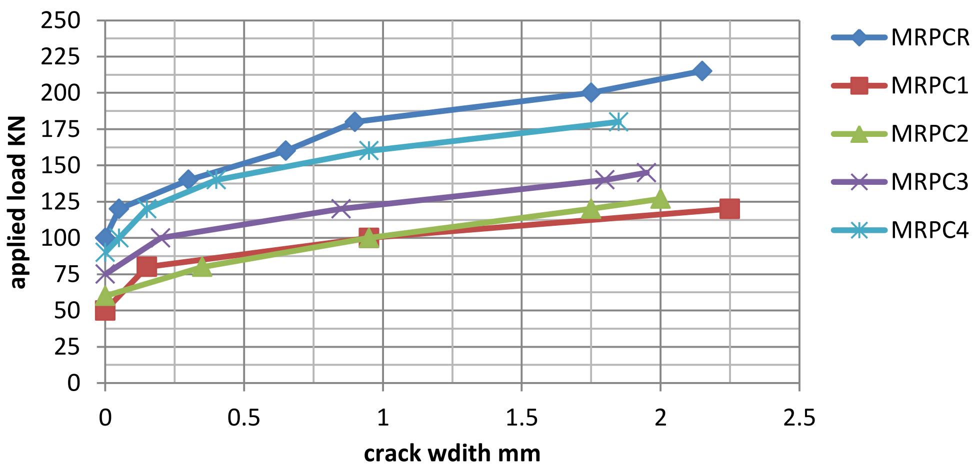


Figure 9. Maximum Crack Width for G2

6.3 Ultimate Load Capacity

The test results of ultimate loads of slab in group G1 ,G2 are illustrated in "Table 3" ,and show in "Fig. 10".

In G1, the reference slabs NSCR ultimate load capacity is the highest value 90KN, relative to other slabs in that group and this value decreases in NSC1 because of openings to be (77.78) %. When collar head are used in NSC4, the ultimate load increases to be (97.22) % of its reference.

In G2, the reference slabs MRPCR, ultimate load capacity is the highest value 215KN relative to other slabs, and this value is more larger relative to NSCR, it belongs to high strength compressive of MRPC, and this value decreases in MRPC1 because of openings to be (55.8)% . When collar head are used in MRPC4 , the ultimate load increases to be (83.7) % of its reference.

Table 3. Ultimate Load Capacity and Central Deflection for all Tested Specimens

Group No.	Specimens	Ultimate Load (Pu)KN	$\frac{Pu}{PuReference}$ %	Deflection at Ultimate Load (mm)
G1 fć=30MPa	NSCR	90*	-	6.14
	NSC1	70	77.78	5.05
	NSC2	72.5	80.56	5.88
	NSC3	82.5	91.67	5.12
	NSC4	87.5	97.22	6.52
G2 fć=90MPa	MRPCR	215**	-	*8.75*
	MRPC1	120	55.8	*5.11*
	MRPC2	127.5	59.1	*8.08*
	MRPC3	145	67.4	*8.52*
	MRPC4	180	83.7	*9.36*

* Reference ultimate load for G1
** Reference ultimate load for G2

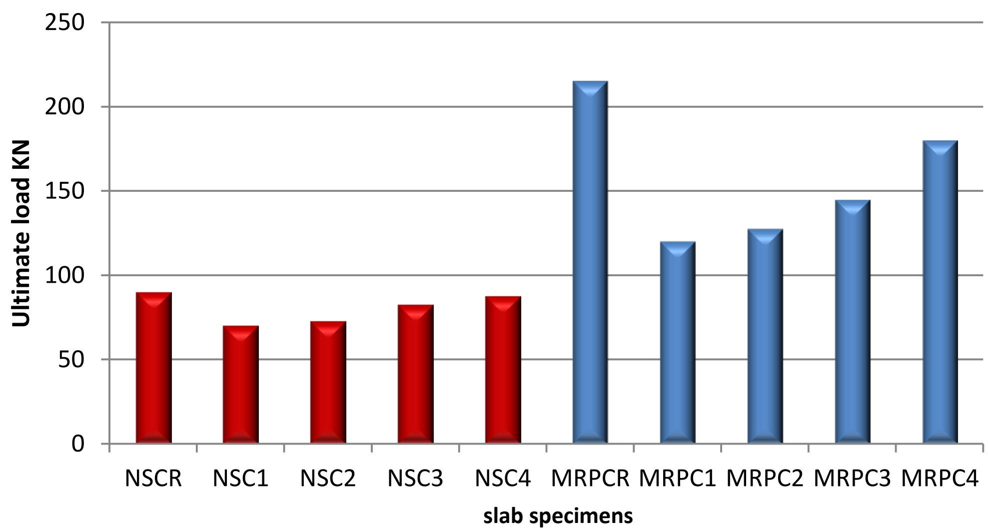


Figure 10. Ultimate load capacity for all tested specimens

6.4 Load-deflection Relationship

The test results of central deflection of slab in group G1,G2 are illustrated in "Table 3" above , "Fig.12" and "Fig.13" show the central load-deflection curve for all tested slabs of each group. The figures reflect the structural behavior of the specimens. Also, the figures illustrate the different in the stiffness value among the tested specimens through the observed values of the deflection.

In general, the test results show that when compressive strength of the specimen increases the central deflection will increase too, therefore, the central deflection in (G2) MRPC is the greatest and the central deflection of the (G1) NSC.

By concentrating for each group, the specimens with collar shearhead strengthening the entire column sides and extended to the opening and denoted with the number4 is the most stiffness specimen in its entire group and follow by the reference slab , and follow by specimens with the number(3), where the collar shearhead strengthening the columns sides away from the opening, and after that the specimens with the number(2), where the collar shearhead around the columns sides toward the opening and last specimens with the number(1), where the specimen which has opening and no collar shearhead presence.

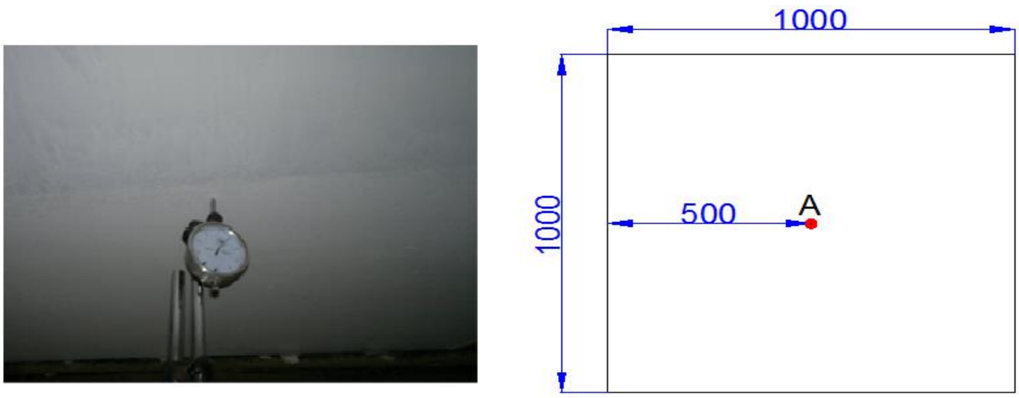


Figure 11. The Deflection Measurement

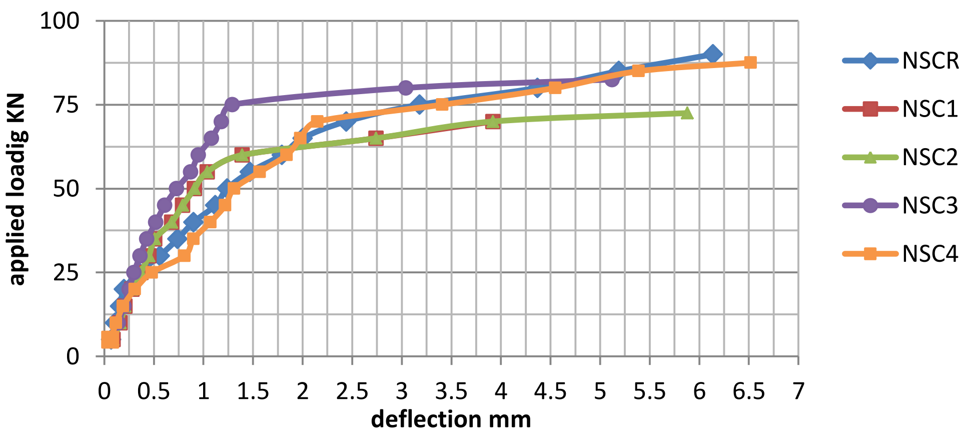


Figure 12. Central Deflection for Group One G1

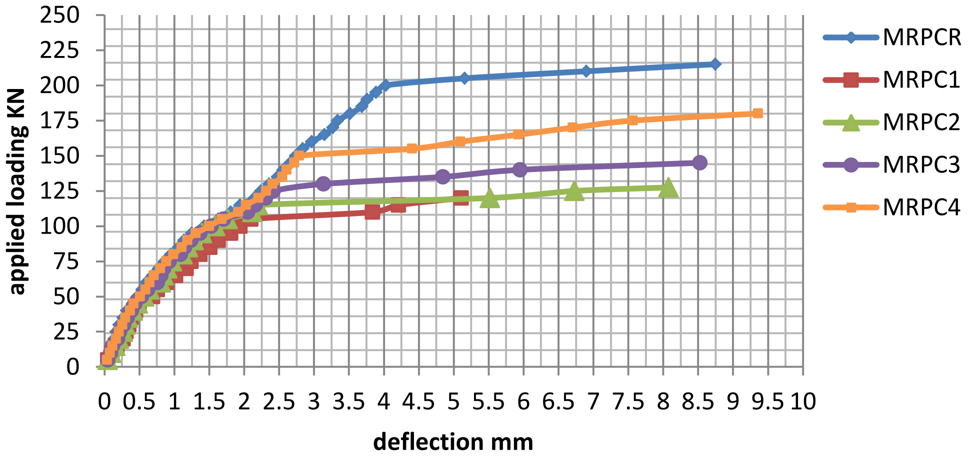


Figure 13. Central Deflection for Group One G2

6.5 Critical Section Perimeters

According to ACI (318-11) [11], the critical section perimeter is assumed to be at (d/2) from the column face. The calculated value of the critical section perimeter in the present work equals (840 mm) according to the ACI specification and this value will be compared with all the specimens to investigate the effect of the concrete type and collar head configuration on this structural property.

For the references slabs without openings, the critical section perimeter is considered as the distance (x/2) between the column side face and the end of the experimentally measured actual punching failure surface (area) on the tension face of the slab as shown in "Fig 14". For the rest slabs with openings, the same approach is adopted for determining the critical section perimeter but with considering the effect of opening in decreasing the value of the critical section perimeter.

In general:

In G1, the calculated critical section perimeters values for the reference specimen is (1152) and decreases in the specimen which has opening adjacent to column NSC1 to (890) . When collar head is used as shear reinforcement this value increases to 1002 in NSC2 and 984 in NSC4

In G2, the calculated critical section perimeters values for the reference specimen is (1052) and decreases in the specimen which has opening adjacent to column MRPC1 to (830). When collar head is used as shear reinforcement this value increase to 897 in MRPC3 and 867 in MRPC4.

The calculated critical section perimeters values for the references specimens where the solid slabs are between (1052 – 1152) mm with percentages between (125.24 – 137) % in comparison with the value calculated according to ACI code.

For the specimens which have opening adjacent to column and without collar head, the percentage of the critical section perimeter is between (98.8 – 105.9) % to reflect that the losses in this property do not exceed (7%) in the present work. By concentrating on the specimens which have opening adjacent to column but strengthened by collar head in different configurations, the percentage of the critical section perimeter is between (103.2– 119.3) % to reflect the capability of this type of shear reinforcement in making up the shortfall in the critical section due to the presence of openings.

Table (4) Characteristics of Critical Section Perimeter

Group No.	Specimens	Calculated Failure Area (A)mm^2	Calculated Distance of Failure Face (x) mm	Calculated Critical Section Perimeter mm	Percentage of distance of failure face calculated according ACI%	Percentage of Critical Section Perimeter calculated according ACI%
G1 fć=30MPa	NSCR	164675	138	1152	230	137.0
	NSC1	152910	110	890	183	105.9
	NSC2	211125	184	1002	306.7	119.3
	NSC3	187990	169	975	281.7	116
	NSC4	202445	178	984	269.7	117.14
G2 fć=90MPa	MRPCR	130575	113	1052	188.3	125.24
	MRPC1	139650	95	830	158.3	98.8
	MRPC2	159485	145	885	241.7	105.35
	MRPC3	133605	149	897	248.3	106.78
	MRPC4	145835	139	867	231.7	103.2

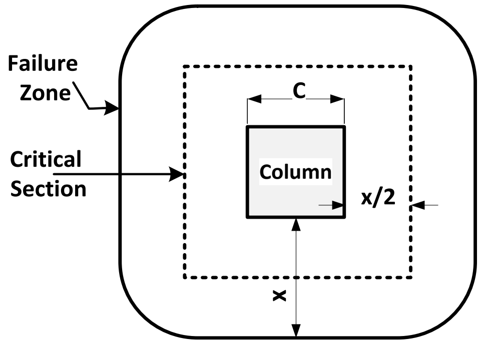


Figure 14. Method used to Calculate Critical Sections for Solid Slab

For solid slabs:

$$A = C^2 + 4Cx + \pi x^2 \quad (1)$$

$$\pi x^2 + 4Cx + (C^2 - A) = 0 \quad (2)$$

$$x = \frac{-4C + \sqrt{(4C)^2 - 4\pi(C^2 - A)}}{2\pi} \quad (3)$$

Critical section is assumed at a distance (x/2) from face of column lies in solid side of tested specimen.

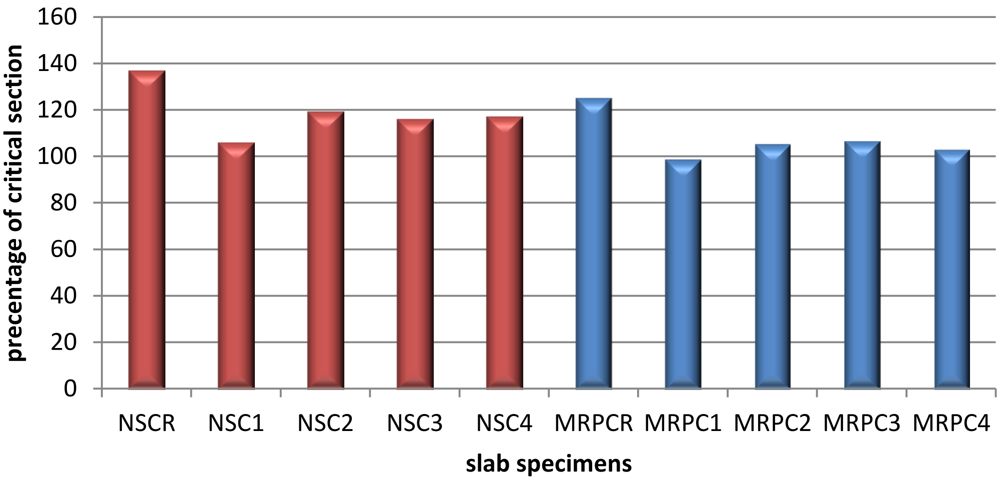


Figure 15. Percentage of critical section for all tested specimens

7. Conclusions

According to the test results found in the present study, the following conclusions can be drawn :-

1-The configuration of the collar head is considerably effective in enhancing the structural behavior of the flat plate slab with opening.

2-In general, collar head is strengthening the entire column sides and extending to the opening achieve the better results

3-The concrete type has also a considerable activity on the behavior of the flat plate with opening, that increases the compressive strength of the section means improvement in structural behavior of the flat plate with opening.

4-For serviceability of flat plate with opening, the deflection and crack width can be reduced by using collar head around the column sides extended to the opening. The reduction can be continued by increasing the compressive strength

5-For the specimens which have opening adjacent to column and without collar head, the percentage of the critical section perimeter is between (98.8 – 105.9) % to reflect that the losses in this property do not exceed (7%) in the present work

6-For the specimens which have opening adjacent to column but strengthened by collar head in different configurations, the percentage of the critical section perimeter is between (103.2– 119.3) % to reflect the capability of this type of shear reinforcement in making up the shortfall in the critical section due to the presence of openings.

7- The ultimate load increase when collar head is used as shear reinforcement and when compressive strength increase.

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