Journal of Engineering and Development, Vol. ١٧, No.١, Mar. ٢٠١٣, ISSN ١٨١٣- ٧٨٢٢

Effect of Steel Shearhead on Behaviour of Eccentrically Loaded Reinforced Concrete Flat Plate

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Abstract

The aim of this study is to investigate the punching shear of reinforced concrete slabs (with steel shearhead as shear reinforcement) under eccentric load; this simulates the effect of unbalance moment on slab column connection with shearhead. The research includes testing nine specimens with dimensions (١٠٠٠ x ١٠٠٠ x ٨٠ mm) divided into three groups of specimens according to the percent of shearheads. Variables of this study are the number of stiffeners of the shearheads and the amount of eccentricity. The results show that the deformations and strength characteristic of the slab are affected by.

تأثير تسليح القص الفولاذي على تصرف البلاطات الخرسانية المسلحة المستويه تحت الأحمال اللامركزية

الخلاصة

الهدف من هذا البحث هو دراسة القص الثاقب للبلاطات الخرسانية المسلحة (الحاوية رؤوسا من فولاذ القص المطمور كتسليح قص) تحت حمل لامركزي حيث تمثل هذه الدراسة تاثير العزم الغير متوازن على منطقة الاتصال بين العمود و اللوح بوجود تسليح القص الفولاذي .يتضمن البحث فحص تسعة نماذج بابعاد (٨٠ x ١٠٠٠ x ١٠٠٠مم) مقسمه الى ثلاث مجاميع حسب وجود تسلح القص الفولاذي . متغيرات هذه الدراسة هي عدد الواح التقويه داخل تسليح القص الفولاذي و المسافة اللامركزية.اوضحت النتائج ان هذين المتغيرين لهما تأثير واضح على التشوه و مقامة بلاطات الخرسانة المسلحه.

١. Introduction

Flat plate structure has an advantage over other slab system because of the significant saving in construction work and aesthetically pleasing appearance. In addition, the elimination of beams and girders reduce the over all floor depth of multi-story buildings, thus creating additional floor space for a given building height. For this reason, flat plates are widely used for multi-story structures [١].

Concert flat plates are subjected to large bending moment and shearing force at their connections with columns. In flexure, reinforced concrete slabs exhibit a great deal of ductility; extensive deformations occur before their ultimate strength is reached. Design codes place increasing reliance on this ductile behavior which enables slab system to redistribute moments. Complete redistribution of bending moment can generally be achieved [٢].

Shearhead is a structural member embedded at the slab-column junction. In the flat plate structure, column support leads to punching shear stresses in the slab. The concrete will provide a certain level of shear resistance around the columns, but this may need to be supplemented by punching shear reinforcement arranged on concentric perimeters [٣].

The main advantage of shearheads is that they serve to spread the load of the floor on the respective columns and thereby reduce the effect of the vertical forces; i.e., push the critical section for shear farther out from the columns, thus giving a large perimeter around the column to resist the punching shear [٣].

٢. Materials

Concrete compositions, reinforcing steel bars and steel shearhead consist from steel C channel sections and Tee sections, were tested in the laboratory and showed good agreement with specifications:

- Water: tap water used.
- Cement: Ordinary Portland cement was used. The physical analysis and chemical test results conform to the Iraqi specification No. ٥/١٩٨٤ [٤].
- Fine Aggregate (Sand): The fine aggregate has ٤,٧٥mm maximum size with rounded-shape particles and smooth texture. The physical analysis test results are within the limits of Iraqi Specification No. ٤٥/١٩٨٤ [٥].
- Coarse Aggregate (Gravel): The gravel has maximum size of ٥mm. The physical analysis test results are within the limits of Iraqi Specification No. ٤٥/١٩٨٤ [٥].
- Steel Reinforcement: The steel reinforcement used to reinforce the concrete slab is deformed mesh bars ٦ mm diameter and ٧٥mm spacing. Columns reinforcement was ٧ bars ١٢ mm diameter for all slabs.
- Steel Shearheads: consist from steel C Channel sections and Tee sections plate (١).

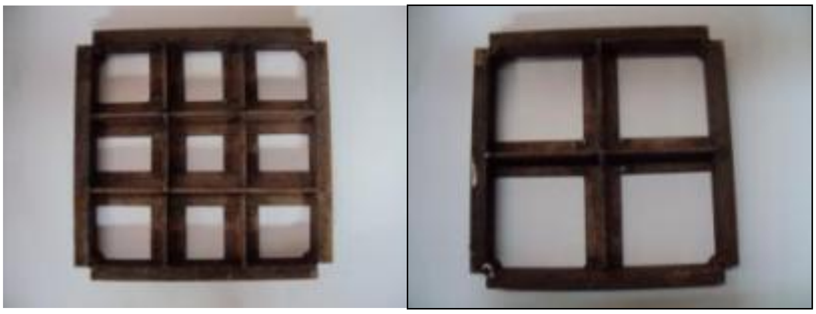


Plate (١) Shearhead Reinforcement

٣. Slabs details

This study is based on nine specimens, divided into three groups, the first group is the specimens without shearhead, the second group, is the specimens with one cross shearhead and the third group is the specimens with double cross shearhead.

All slabs were geometrically similar, having dimensions (١٠٠٠×١٠٠٠×٨٠ mm) and loaded through a central column of dimension (١٢٠×١٢٠ mm) with corbel (١٢٠ x ٢٤٠ mm) as shown in figures (١) to (٣). The slabs have the same flexural reinforcement. The slabs are simply supported along all edges and the distance from c/c of support was (٩٠٠mm). The details of these slabs are listed in Table (١).

Table (١) Characteristics of Test Slabs

Group	Specimen	Eccentricity e [mm]	Punching reinforcement
G١	S٠	٠	Non
	S٦٠	٦٠	
	S١٢٠	١٢٠	
G٢	SHS٠	٠	Shearhead (٢٨cm×٢٨cm) With Single cross stiffener
	SHS٦٠	٦٠	
	SHS١٢٠	١٢٠	
G٣	SHD٠	٠	Shearhead (٢٨cm×٢٨cm) With double cross stiffeners
	SHD٦٠	٦٠	
	SHD١٢٠	١٢٠	

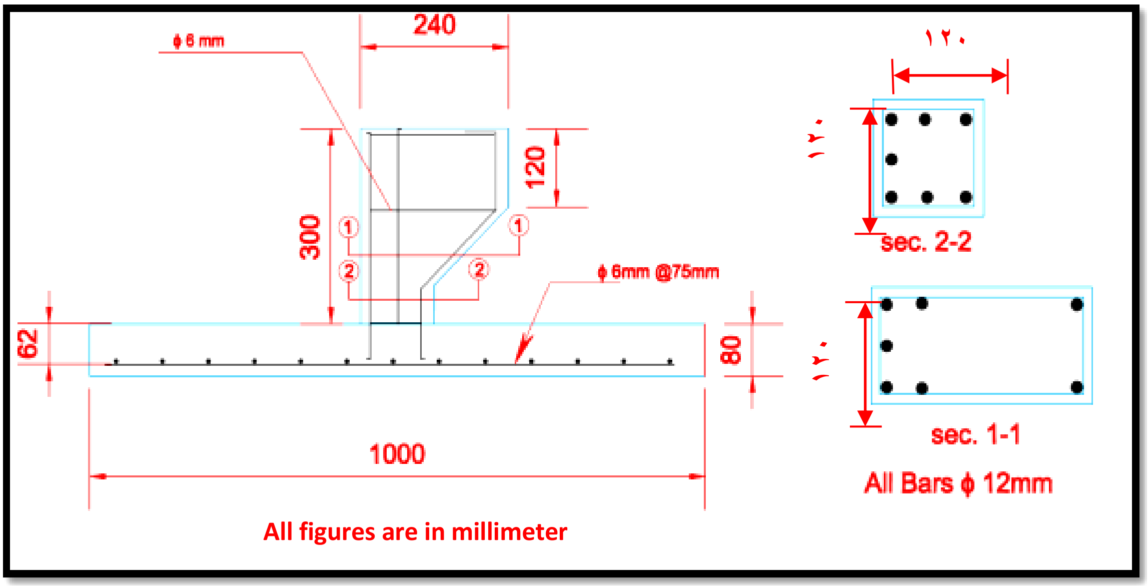


Figure (١) Dimensions and Layout of Slab without Shearhead

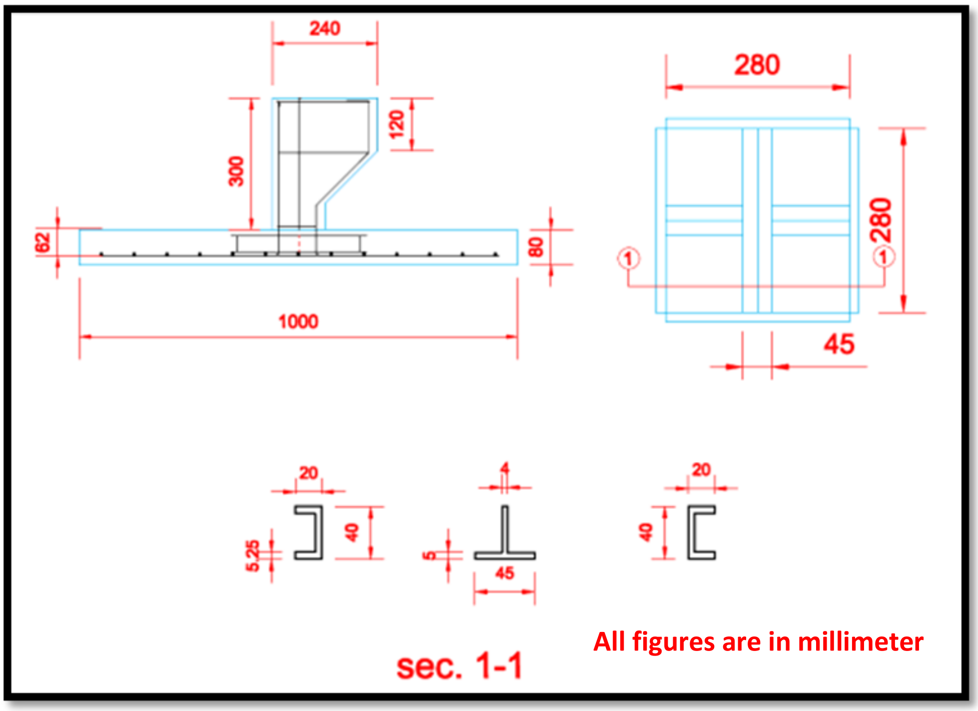


Figure (٢) Dimensions and Layout of Slab with Shearhead of Single Cross Stiffener

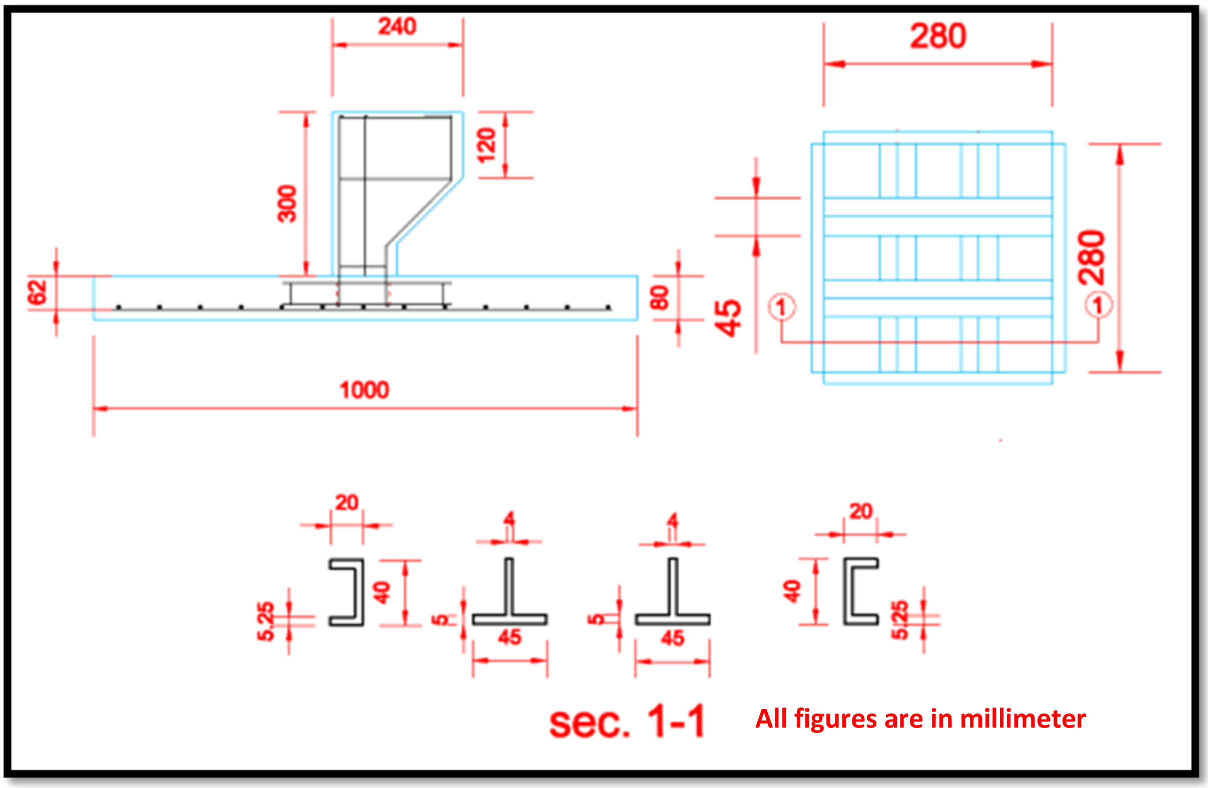


Figure (٣) Dimensions and Layout of Slab with Shearhead of Double Cross Stiffeners

٤. Concrete Mix, Casting and Curing

The following steps are followed before mixing;

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

٢. The coarse aggregate is sieved on (١٠mm) sieve size to remove the large size aggregate particles. Then, the aggregate is also washed and dried.

٣. Preparing the weights.

Mixing method is important to obtain the required workability and homogeneity. A (٠,١٢٥m³) drum mixer is used. Coarse and fine aggregates are poured into the mixer, and mixed together. The cement is then added to the mixer, and then water is added gradually to the mix. The total mixing time is (٦-٨ min).

After (٢٤) hours, the control specimens were stripped from the moulds and cured (kept) in water bath for (٢٨) days with almost constant laboratory temperature. Before (٢٤) hours from test date, they were taken out of the water bath and then tested in accordance with the standard specifications after painted by using white washer.

٥. Testing Machine

The machine which was used in the tests is a universal hydraulic machine with (٣٠٠ ton) capacity available in the structural engineering laboratory, in the College of Engineering, Al-Mustansiriya University. The loading arrangement with loading frame is shown in plate (٢).

Plate (٢) Testing Machine with Loading Frame

٥.١. Loading Caps (Eccentricity Apparatus)

A new steel loading cap was designed to provide eccentric loading. The loading cap has a rectangular section (١٢٠×٢٤٠mm) and thickness ٢٠mm and can give three values of eccentricity. The eccentric load was exerted on the loading cap via a wedge plate that was positioned into the ٠mm, ٦٠mm or ١٢٠mm grooves, respectively. It is manufactured in the structural Laboratory at the University of AL-Mustansiriyha from high strength steel. The method of loading is shown in plate (٣)

a- Axial Loading

b- Eccentricity at ٦٠mm

c- Eccentric at ١٢٠mm

Plate (٣) Loading Caps

٦. Discussion and Results

٦,١. Crack Pattern

Test results show that the punching crack tends to be at one side of slab with the increase of eccentricity of loading form (٠ to ١٢٠ mm) for slabs with or without shear reinforcement, due to presence of unbalance bending moment Plates (٤) to (١٢) show tension face for all tested slabs. In general, the failure pattern for all specimens shows that shearheads are sufficient stiff to push the critical punching shear perimeter outside the shearhead.

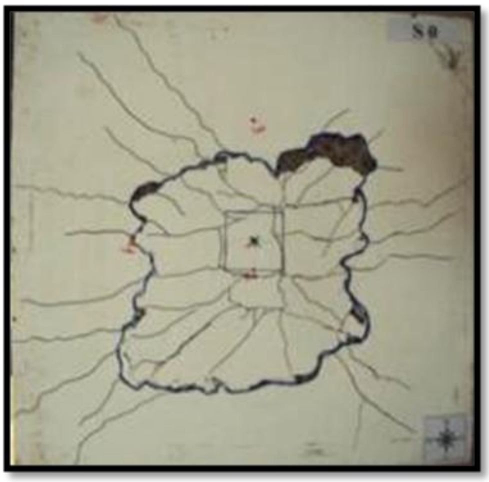


Plate (٤) Tension Face for Slab S٠

Plate (٥) Tension Face for Slab S٦٠

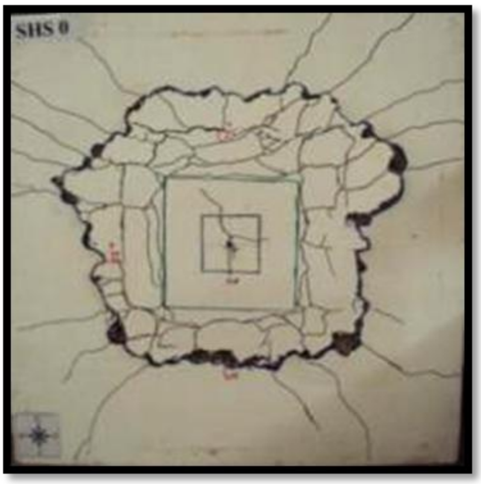


Plate (٦) Tension Face for Slab S١٢٠

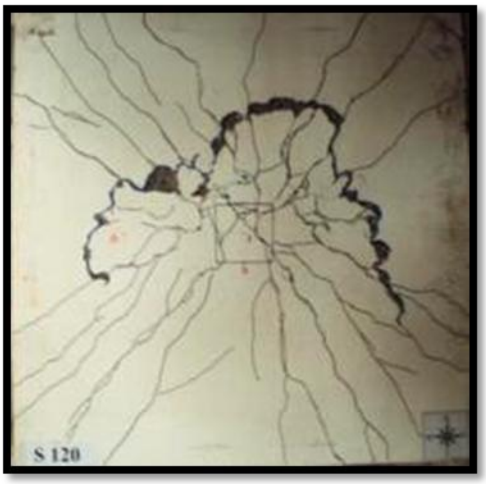


Plate (٧) Tension Face for Slab SHS٠

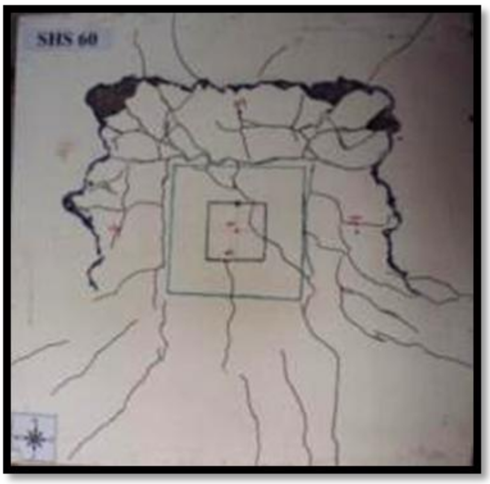


Plate (٨) Tension Face for Slab SHS٦٠

Plate (٩) Tension Face for Slab HS١٢٠

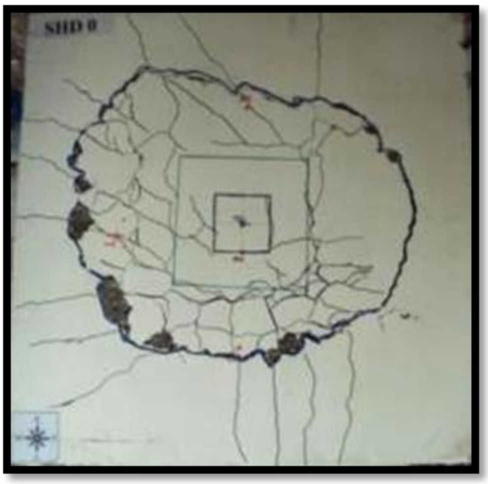
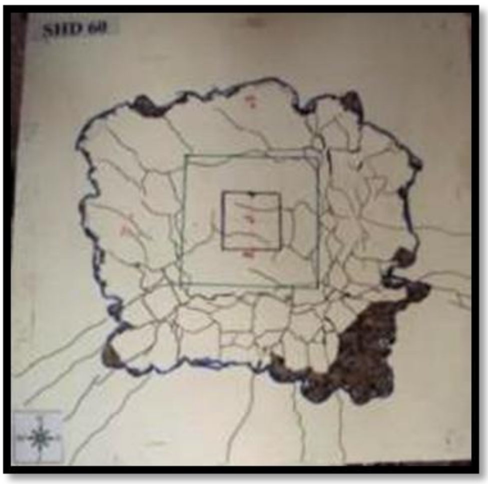


Plate (١٠) Tension Face for Slab SHD٠



Plat (١١) Tension Face for Slab SHD٦٠

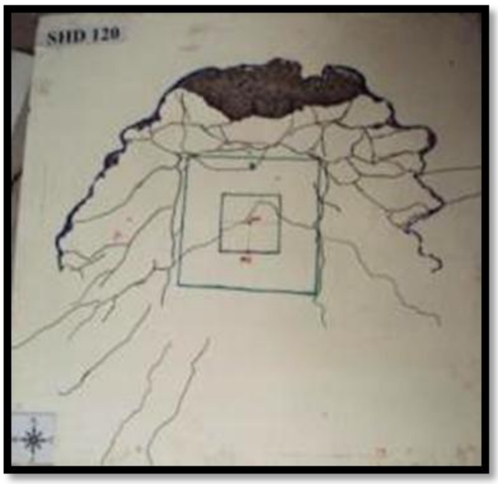


Plate (١٢) Tension Face for Slab SHD١٢٠

٦,٢. Ultimate Load Capacity

The primary aim of this study is to determine the ultimate load capacity of specimens reinforced for punching shear caused by eccentric loading and shearheads reinforcement then compare it with the reference specimen (without punching shear reinforcement). The observed failure loads of the tested slabs are shown in Table (٢).

Table (٢) Cracking and Ultimate Loads

Group	Specimen	Ultimate Load (Pult) (kN)	Ultimate unbalance moment (Mult) (KN.m)	% Decrease in Ultimate Load Relative to zero eccentricity specimen	% Increase in Ultimate Load Relative to G١	Type of Failure
G١	S٠	٧٤	٠	---	---	Punching
	S٦٠	٧١,٥	٤,٢٩	٣,٤	---	Punching
	S١٢٠	٦٥,٧٥	٧,٨٩	١١,١	---	Incomplete punching
G٢	SHS٠	٨٤	٠	---	١٣,٥	Punching
	SHS٦٠	٧٧	٤,٦٢	٨,٣	٧,٨	Incomplete punching
	SHS١٢٠	٧٢,٥	٨,٧	١٣,٧	١٠,٣	Incomplete punching
G٣	SHD٠	٩٦,٥	٠	---	٣٠,٤	Punching
	SHD٦٠	٨٩	٥,٣٤	٧,٨	٢٤,٥	Punching
	SHD١٢٠	٨١,٧٥	٩,٨١	١٥,٣	٢٤,٧	Incomplete punching

Test results are listed below:

Group G١: (Specimens without shear reinforcement)

In (S٠), the punching shear failure occurs at the higher loads than the other slabs (with eccentricity). The test results show that the slabs (S٦٠ and S١٢٠) give decrease in strength over the reference slab (S٠) by about (٣,٤ and ١١,١٪) respectively.

Group G٢: (Specimens with shearhead reinforcement having single stiffener)

In (SHS٠), the punching shear failure occurs at the higher loads than the other slabs (with eccentricity). The test results show that the slabs (SHS٦٠ and SHS١٢٠) give decrease in strength over the reference slab (SHS٠) by about (٨,٣ and ١٣,٧ %) respectively.

Group G٣: (Specimens with shearhead reinforcement having double stiffeners)

In (SHD٠), the punching shear failure occurs at the higher loads than the other slabs (with eccentricity). The test results show that the slabs (SHD٦٠ and SHD١٢٠) give decrease in strength over the reference slab (SHD٠) by about (٧,٨ and ١٥,٣ %), respectively.

In general:

١. The increase of ultimate load in (G٢ and G٣) over (G١), by adding shearhead reinforcement can be explained by the increase in critical shear perimeter of punching shear in slab, the ratio of increasing is (١٣,٥ and ٣٠,٤ %) for slabs (SHS٠ and SHD٠) respectively.

٢. The effect of the shearhead on slabs with eccentricity (S٦٠, SHS٦٠, SHD٦٠, S١٢٠, SHS١٢٠ and SHD١٢٠) give lower strength ratio, as compared with reference specimen (S٠, SHS٠ and SHD٠) because of the eccentric loading that causes unbalance bending moment .

٣. Slabs with shearhead reinforcement and eccentrically load gives higher ultimate load capacity than those without shear reinforcement by (٧,٨, ١٠,٣, ٢٤,٥ and ٢٤,٧) for slabs (SHS٦٠, SHS١٢٠, SHD٦٠ and SHD١٢٠).

٤. Using shearheads with double cross stiffeners give more ultimate load capacity than single cross stiffener cause the load will distribute on more steel area.

٥. The maximum increase in the ultimate strength of (SHD٠) is about (٣٠,٤٪) as compared with (S٠).

٦. The eccentricity in all cases decreases the ultimate load as shown in Figure (٤).

٦,٣. Load - Central Deflection

Figures (٥) through (١٠) show the load- central deflection curves for tested slab. They show a linear relationship up to the first crack but after which, the deflection increases until failure associated with an increase in the number of cracks.

The test results show that:

١. The increases of eccentricity decrease the central deflection for all slabs with or without shearheads.

٢. The presences of shearhead increase the deflection as function of increasing in ultimate load capacity.

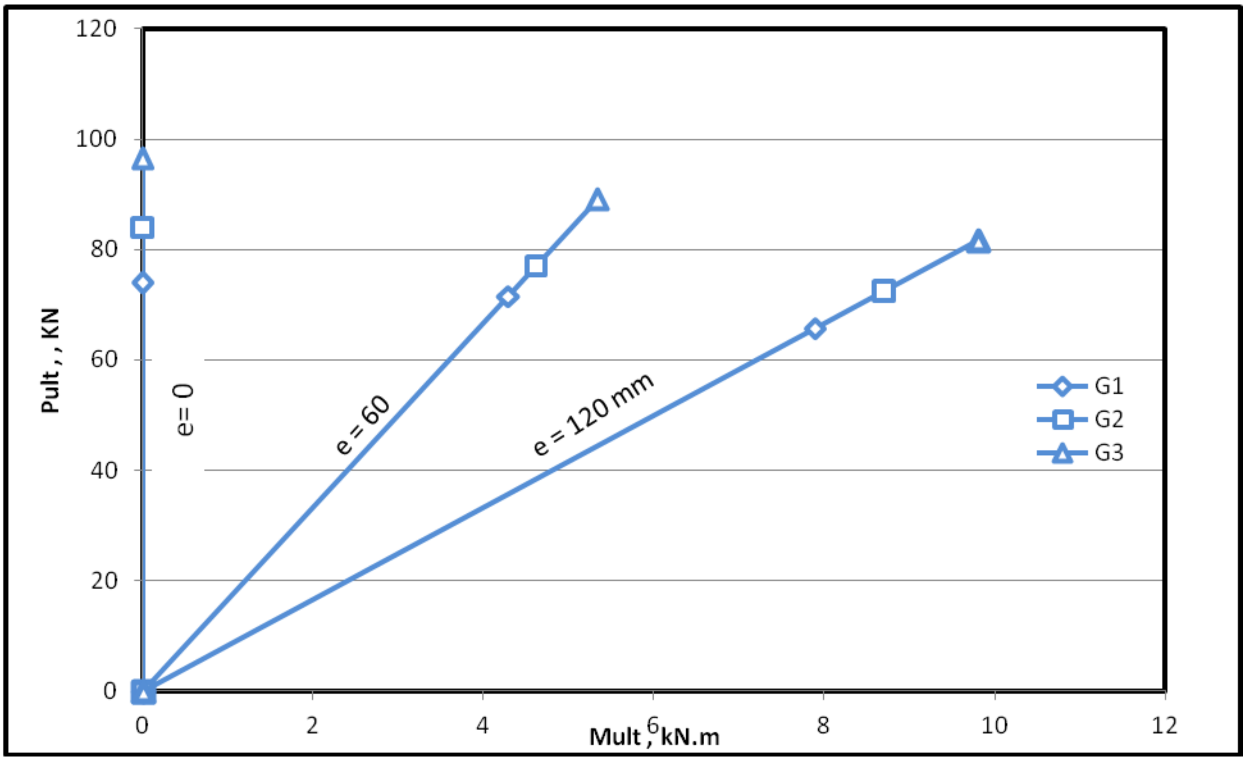


Figure (٤) Decreases in Ultimate Load with Increase of Eccentricity

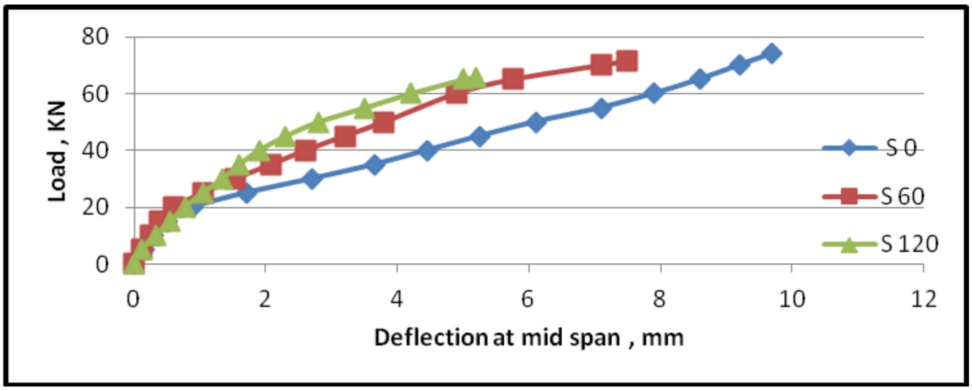


Figure (٥) Load-central Deflection Curve for G١

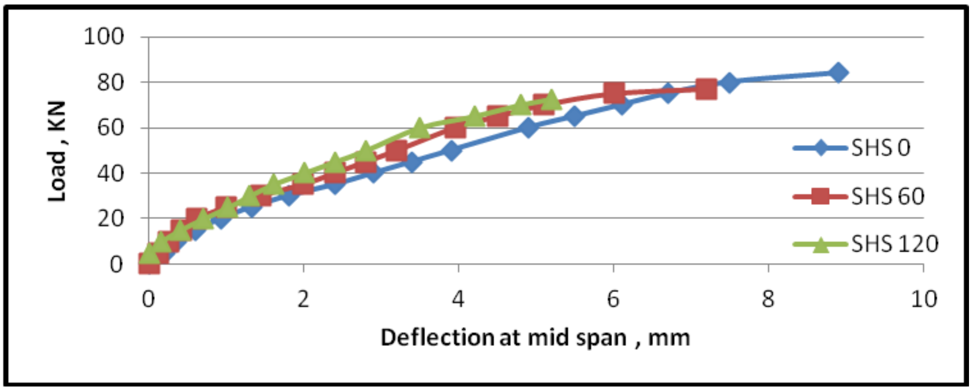


Figure (٦) Load-central Deflection Curve for G٢

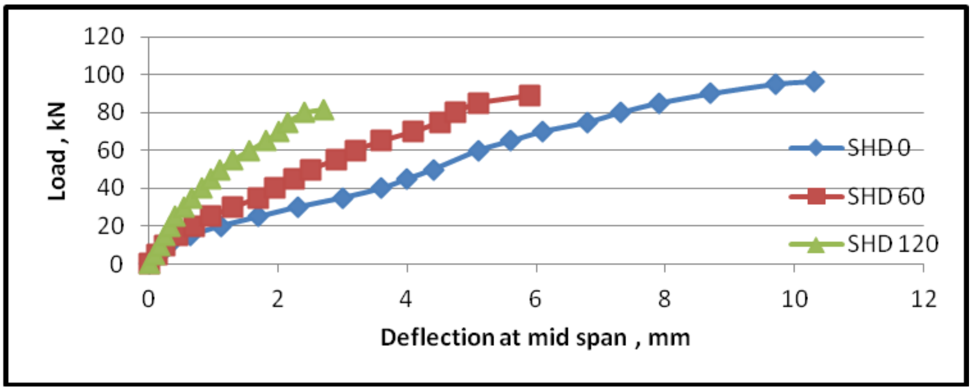


Figure (٧) Load-central Deflection Curve for G٣

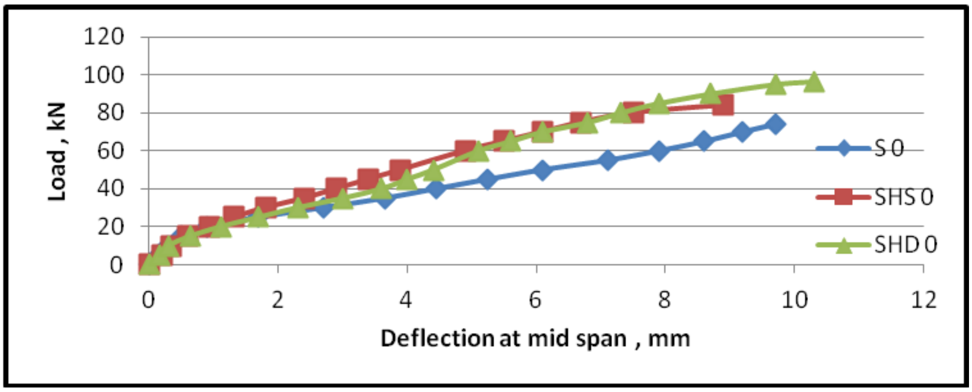


Figure (٨) Load-central Deflection Curve for e = ٠

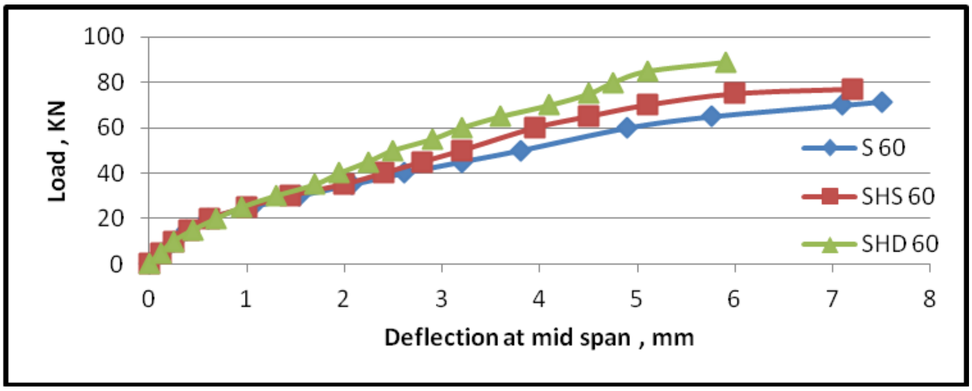


Figure (٩) Load-central Deflection Curve for e = ٦٠ mm

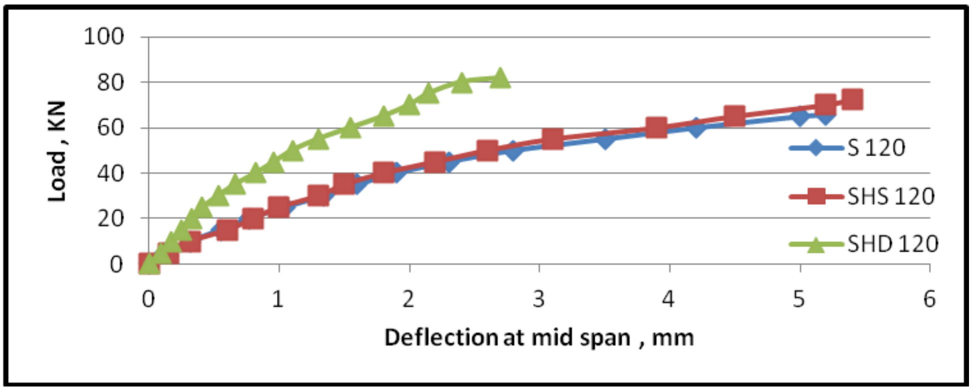


Figure (١٠) Load-central Deflection Curve for e = ١٢٠ mm

٦,٤. Critical Section Perimeter

According to ACI (٣١٨-١١) [٦] code, the critical section perimeter is assumed to be at (d/٢) from the column face. For the slabs without shearhead, the critical sections for slab with shearheads calculate according to ACI (٣١٨-١١). Table(٣), shows critical section of punching pyramid which are measured by indicating dimensions of the crushed zone at the center line passing through the loaded area.

١. The results show that, using shearhead increases the critical section of punching by (٣٢,٢, ٢٩.٥, ٤٢,٧, ٣٧,١, ٤٣,٨ and ٣٦,٨ %) for (SHS٠, SHS٦٠, SHS١٢٠, SHD٠, SHD٦٠ and SHD١٢٠) in comparison with specimens without shearhead (S٠, S٦٠ and S١٢٠).
٢. It is found that, shearhead (in all cases), increases the critical section perimeter. This is attributed to the inclined cracks that develop first along the column corner and then extend laterally. Due to the presence of shearhead most of these cracks will move outside the shearhead.
٣. The test results show that the change of stiffeners from single cross to double cross increase the punching perimeter for zero eccentricity loading from (٣٢,٢ to ٣٧,١ %).
٤. Increase in eccentricity loading decrease the critical section of punching perimeter in all slabs with or without shearheads and make the punching shape crack as an incomplete punching crack due to the increase unbalance moment applied by the eccentricity loading.

Table (٣) Critical Section Perimeter of Punching

Group	Specimen	Calculated perimeter (mm) ACI ٣١٨-٠٨	Critical Section Perimeter at X/٢ (mm)	% Increase in Critical Section Perimeter Relative to G١	% Decrease Critical Section Perimeter Relative to zero eccentricity specimen
G١	S٠	٧٢٨	١٢٣٦	---	---
	S٦٠	٧٢٨	١١٧٤	---	٥
	S١٢٠	٧٢٨	١٠٦٣	---	١٤
G٢	SHS٠	٧٥٤	١٦٣٥	٣٢,٢	---
	SHS٦٠	٧٥٤	١٥٢٠	٢٩,٥	٧
	SHS١٢٠	٧٥٤	١٥١٧	٤٢,٧	٧,٢
G٣	SHD٠	٨٨٠	١٦٩٥	٣٧,١	---
	SHD٦٠	٨٨٠	١٦٨٨	٤٣,٨	٠,٤
	SHD١٢٠	٨٨٠	١٤٥٥	٣٦,٨	١٤,١

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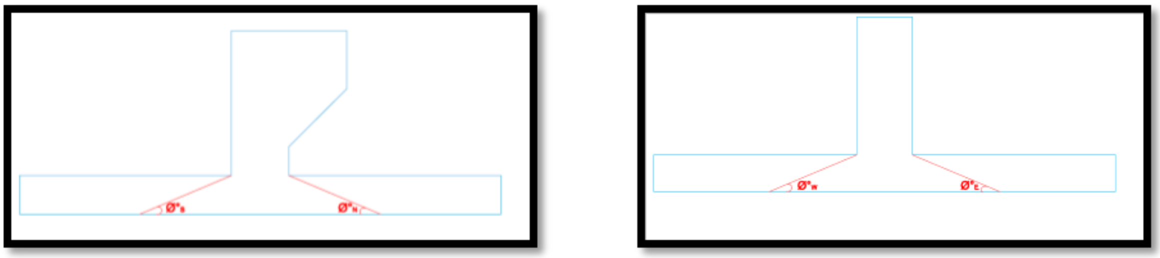
٦,٥. Failure Angle

Figure (١١) shows the location of failure angles of the punching pyramid, the angles are measured by indicating the dimensions of crushed zone at the center line passing through the loaded area. Table (٤) shows the failure angle, where Y represents the distance between the failure perimeter to the column face and the subscript (N, S, E & W) define the direction.

- The results show that a shearhead decreases the failure angle in comparison to the slabs without shearhead.
- Increasing the stiffeners of shearhead increase the failure angle in north direction for slab with or without eccentricity.
- Eccentric loading decrease the failure angle in slabs with shearheads reinforcement and.
- The increasing of eccentricity gives no failure angle in the opposite side of eccentricity, and cause a collapse at only one side (at north direction).

Table (٤) Failure Angle

Group	Specimen	YN (mm)	YS (mm)	YW (mm)	YE (mm)	Ø N	Ø S	Ø W	Ø E
G١	S٠	٢٦٠,٠٢	٢٨٥,٤	٢٢٠,٩٢	٢٩٠,١٨	١٧,١٠	١٥,٧٠	١٩,٩٠	١٥,٤٠
	S٦٠	٢١٧,٠٥	٢٢٨,٧٤	١٩٣,٤٣	٢٩٢,٦٣	٢٠,٢٠	١٩,٣٠	٢٢,٥٠	١٥,٣٠
	S١٢٠	٢٠١,٠٩	٠	٢٧٩,١	٢٣٠,٣٠	٢١,٧٠	---	١٥,٩٩	١٩,٢٠
G٢	SHS٠	٣٣٥,٧٥	٢٧١,٦٤	٢٨٦	٢٧٠,٤	١٣,٤٠	١٦,٤١	١٥,٦٠	١٦,٥٠
	SHS٦٠	٣٦٠,٥٧	٠	٣٨٣,٢	٣٦٠,١	١٢,٥٠	---	١١,٧٩	١٢,٥٣
	SHS١٢٠	٣٠٢,٦٥	٠	٤٣٦,٦	٣٥٨,٤	١٤,٨٠	---	١٠,٣٨	١٢,٥٨
G٣	SHD٠	٢٥١,١	٢٧٩,٠٥	٣٥٢,٧	٣٥٠,٠٦	١٧,٦٧	١٦,٠٠	١٢,٧٨	١٢,٨٧
	SHD٦٠	٢٧١,٥٢	٣٠٣,٤	٣٤٤,٩	٣٢١	١٦,٤٢	١٤,٧٧	١٣,٠٦	١٣,٩٩
	SHD١٢٠	٣٠٥,٤٣	٠	٣٤٦,٦	٣٢١,٦	١٤,٦٨	---	١٣,٠٠	١٣,٩٧



a. N-S direction **b. E-W direction**

Figure (١١) Location of failure angles

٧. Conclusions

According to the test program carried out in the present study, the following conclusions can be drawn:-

١. The punching shear failure in slabs with eccentricity loading is gradual and incomplete in most of slabs, while it is a sudden punching shear failure in slabs with no eccentricity loading.
٢. The eccentricity loading decreases the ultimate load.
٣. Slabs fail in punching shear have no visible cracks on the compression surface and the punching line occurred directly at the vicinity of the column faces.
٤. The presence of shearhead reinforcement in a reinforced concrete slab increases the punching shear strength of the slab.

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