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Structural Behavior of Reinforced Concrete Corbels With Transverse Opening

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Abstract

In this paper, the shear and flexural behavior of reinforced concrete columns corbels having transverse openings is experimentally investigated. Nine standard concrete corbels were subjected to vertical loads in two groups (A and B). Multiple variables were tested in the experimental program, such as the size, shape, location of the openings, and shear span (a/d), as well as the presence or absence of horizontal reinforcement. According to experimental findings, transvers openings have a considerable impact on corbel structural behavior, including characteristics such as ultimate strength, deflection, and failure mechanisms. The technique decreased the ultimate load by 37.9%, the cracking load by (43.75%), the crack width by 100%, and the deflection by 351.6%.

Keywords: horizontal reinforcement, shear span ,ultimate strength, cracking loads, , deflection, failure modes, concrete corbels.

1. Introduction and back ground

For monolithic structures with columns (or walls) to carry enormous concentrated loads, such as precast beams, steel girders, and bridges, corbels (or brackets) are crucial structural components [1]. In Figure (1), the utilisation of precast reinforces concrete parts in the building and bridge industries has grown, so does the prevalence of reinforced concrete corbels. [2].

The design of corbels has grown in significance as precast concrete has become more widely used. To avoid confusion, the name "corbel" is typically reserved for cantilevers with shear span-depth ratios lower than 1. Because of this low ratio, shear is usually responsible for limiting corbels' strength. As shown in Figure (2), corbels are typically constructed to withstand the vertical reaction Vu at the end of the supported beam, but they may also be required to withstand a horizontal force (Nuc) communicated from the supported beam as a result of restricted shrinkage, creep, or temperature change [3]. Primary tension steel, horizontal hoops, and framing bars are typical types of corbel reinforcement [4]. It had been believed that reinforced concrete corbels served mainly as shear transfer members due to the fact that brackets and corbels operate more like simple trusses or deep beams than flexural members [5].

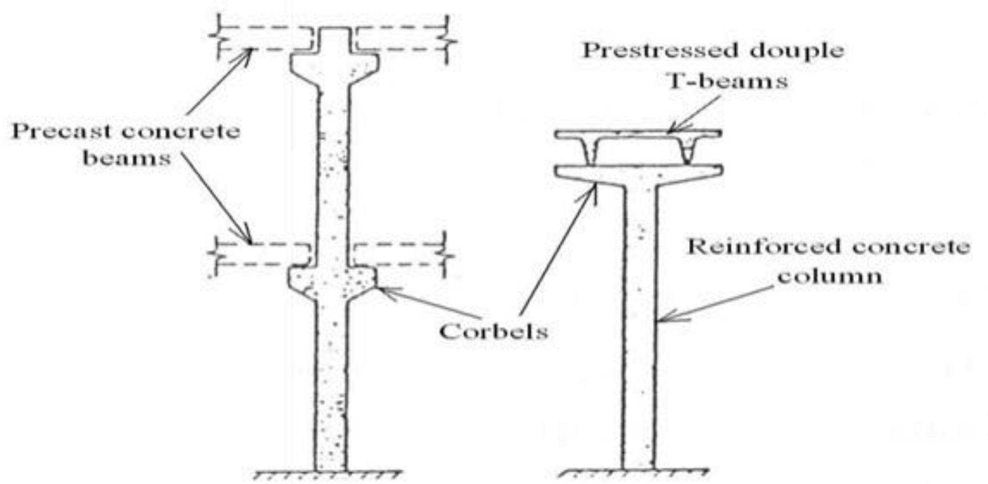

Fig .(1) Precast concrete column and corbels. [2]

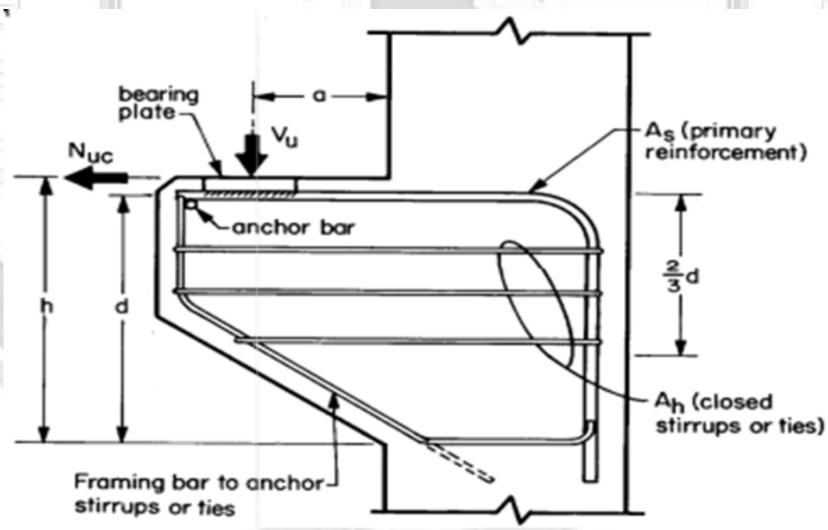

Fig .(2) Typical reinforced concrete corbel. [3]

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1. Failure modes of corbel

Modes of Corbel Failure The failure modes can be categorized into the following groups, per a thorough test programmer carried out by Kriz and Raths (1965): [6]

a- Failure of flexural tension due to the tension reinforcement's excessive yielding during a flexural tension failure, the concrete at the corbel's bottom face is crushed. As seen in Figure 3-a,, this type of failure is characterized by extremely wide flexural cracks.

b. Concrete is crushed at the corbel's slope face, causing failure to occur before significant main reinforcement yields, failure of flexural compression, as depicted in Figure 3-b.

c- Diagonal-splitting cracks appear along the diagonal compression strut after the emergence of flexural fractures. The failure finally results from shear compression, as seen in Figure 3-c.

d- At the corbel-column contact, vertical, narrow diagonal cracks form as a result of shear-friction failure. When the corbel separates from the column face, these cracks combine and cause sliding shear collapse, as depicted in Figure 3-d.

e- As demonstrated in Figure 3-e, the failure of the bearing is brought on by the crushing of the concrete beneath the loading plate as a result of an excessively flexible or subpar bearing plate.

f- Constricted precast concrete beams attached to the corbel may experience horizontal force as a result of creep, shrinkage, temperature change, or dynamic influence on crane girders. When a negative horizontal force is introduced and the corbel's face on the outer side is too shallow, this form of failure may also happen. These failure modes are depicted in Figure 3-f.

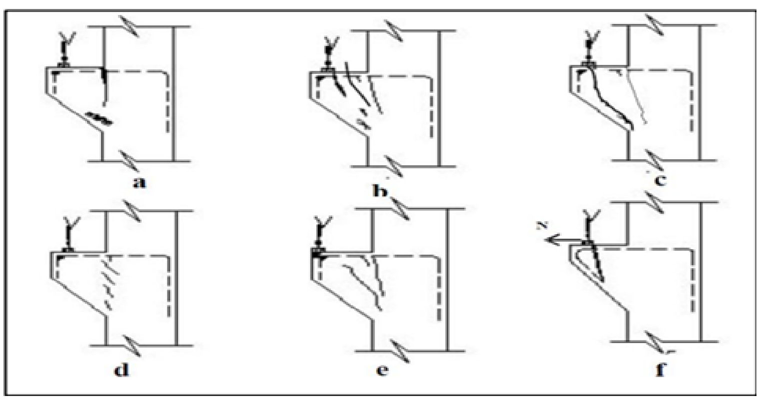

Figure (3) Failure mechanisms of corbel (kriz and raths, 1965). [6]
a) Flexural tension. b)Flexural compression. c) Diagonal splitting.
d) Shear friction failure. e) Crushing due to bearing. f) Horizontal tension.

3- Horizontal opening

The services are inserted horizontally into the same level of the structures via transverse openings, which allows the designers to reduce the necessary story height by making use of the space above the beam's soffit, resulting in a compact design as seen in Figure 4 [7].

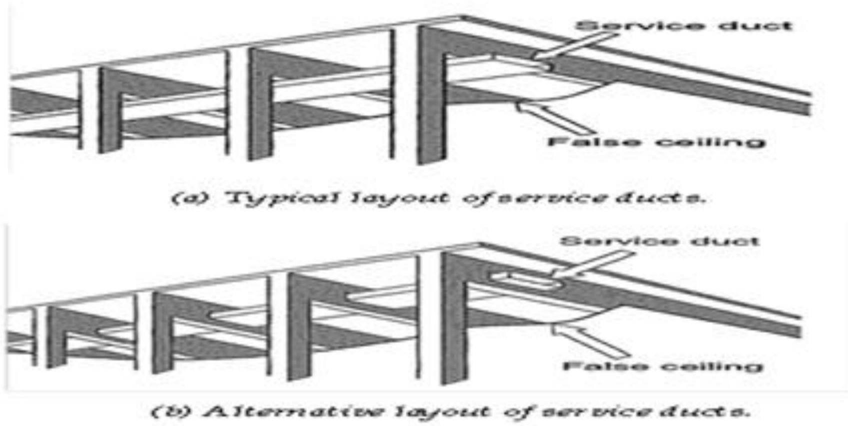

Figure 4: Typical and alternative layouts of service ducts for a high-rise building[7].

A large number of researchers have carried out numerous experimental and numerical studies on RC beams with transverse openings. In a study on a collection of longitudinally reinforced T-beams, Hanson (1969) [8], Somes, and Corley (1974) [9] demonstrated a typical joist floor with square and circular tiny gaps in the web. Their observation that the strength was unaffected by a small gap close to the support is shown in Figure 5. The strength gradually decreases when the aperture is pulled away from the support until it reaches a fixed value. They discovered that the size of the opening had an almost linear effect on strength, whereas the vertical position of the hole had no discernible effect.
However, for square holes and circular openings, respectively, the size of the opening below which there was no decrease in shear strength was roughly 20% of the beam depth. They also suggested that by adding stirrups on either side of the opening, the strength of such a beam might be fully restored

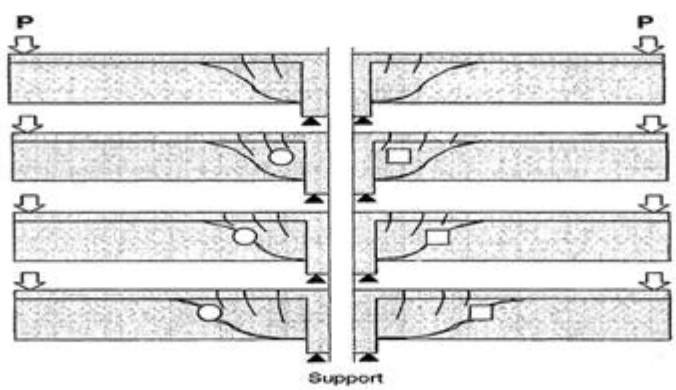

Figure 5: Typical shear failure of a beam with small openings containing no shear reinforcement[8,9].

A lot of research has studied the effect of horizontal opening in shallow beams and deep

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beams. However, no research is found so far studying the behavior of concrete corbels with horizontal opening, which is the main goal of the research.

1. Experimental program

1.1 Details of Specimen Geometry and Reinforcement

The test programme includes nine symmetrical concrete corbel systems. Seven of them have horizontal holes, whereas two are control specimens without them. Corbels were constructed using shear span to depth ratios (a/d) of 0.72 and 0.48 in accordance with ACI-CODE 318-14. [10] Fig. 6 displays the test specimens' dimensions and reinforcing information in detail. All corbels had symmetrical cantilever projections that measured 250mm long, 160mm wide, 240mm deep at the column face, and 80mm deep at the free end. Six examples each had identical corbel reinforcement, which was made up of frame bars set 25 mm effectively away from the corbel margins and main bars of 10 mm diameter used as primary reinforcement. Near the ends of each corbel, cross bars with a 10mm diameter were employed to add additional anchorage for the primary reinforcement. The corbel also features two 6-mm-diameter stirrups that are positioned within a distance of 2/3 of the effective depth (d). They differ from the other types, as do the final three, in that they do not have horizontal reinforcement. The column was 540mm tall overall, supporting two cantilever corbels, each of which was 250 x 160mm. Eight distorted 12 mm-diameter bars, each extending the whole height of the column, were used as longitudinal reinforcement for columns. In addition to closed ties of 6 mm-diameter deformed bars spaced at 100 mm center to center, see Figure 6 for column reinforcement.

1.2 Description of Test Group

Two test groups were used as part of the experimental programmer. Studying the impact of horizontal opening on the structural behavior of reinforced concrete corbels involved group (A) with ties made up of six specimens) the (a/d) for five and one specimen respectively equals (0.72) and (0.48).

According to the truss analogy, Group B three specimens were used to investigate the impact of horizontal openings on the structural behavior of reinforced concrete corbels lacking horizontal reinforcement. For this group, the evaluated (a/d) ratio was 0.72. The following corbel-column connection specimen designations and features are given and shown in Fig. 6, and each symbol for specimen is illustrated in Figure 7.

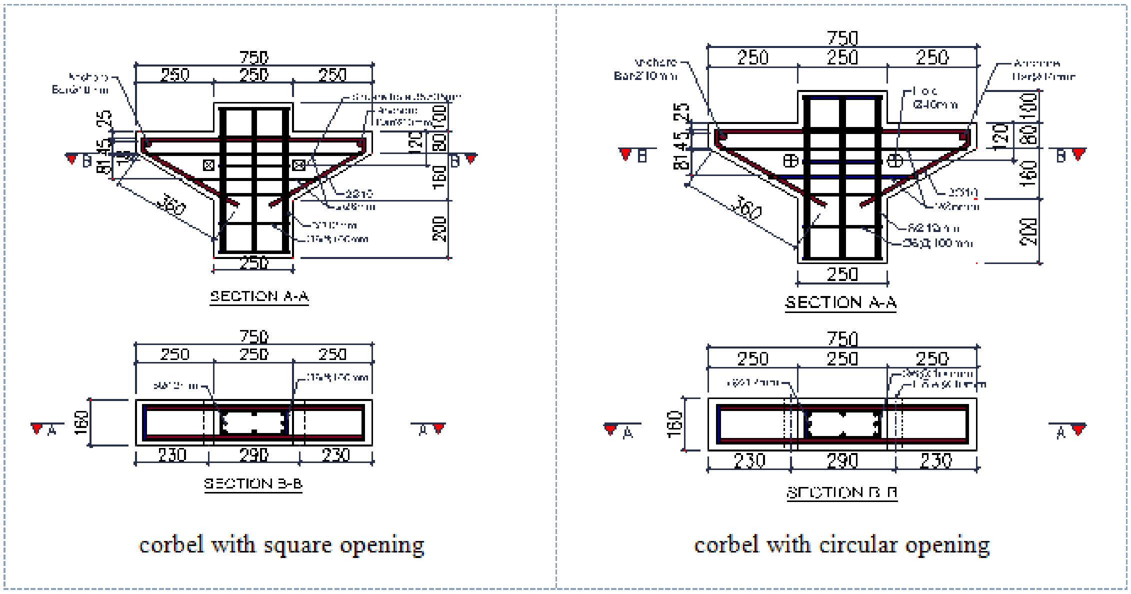

Figure 6: Dimension and reinforcement of test specimen.

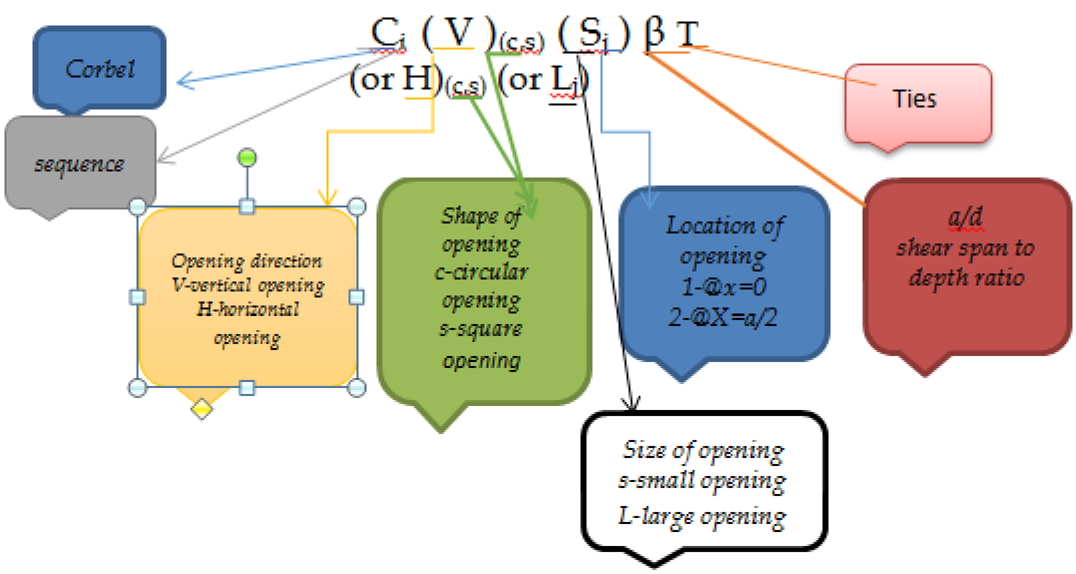

Figure 7 Designation for symbol of tested corbels.

Symbols used in specimens designation refer to sequence of specimens in the test groups according table 1.

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Table 1: Details of the tested concrete corbel specimens.

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Group	Specimen designation	Location	Shape	Size	a/d

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No.		opening	Opening	opening	

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A	C1 T (0.72)	……….	………	……..	0.72

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	C3 Hc S1 T (0.72)	Tangent with	Circular	Small opening	0.72

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		column		Φ40mm	

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	C4 Hs S1 T (0.72)	Tangent with	Square	Small opening	0.72

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		column		35X35mm	

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	C6 Hc S2 T (0.72)	Distance from	Circular	Small opening	0.72

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		column at 75mm		Φ40mm	

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	C9 Hc L1 T (0.72)	Tangent with	Circular	Large opening	0.72

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		column		Φ70mm	

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	C11 Hc S1 T (0.48)	Tangent with	Circular	Small opening	0.48

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		column		Φ40mm	

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B	C12 (0.72)	……….	………	………	0.72

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	C14 Hc S1 (0.72)	Tangent with	Circular	Small opening	0.72

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		column		Φ40mm	

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	C15 Hc S2 (0.72)	Distance from	Circular	Small opening	0.72

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		column at 75mm		Φ40mm	

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1.1 Materials

In the experimental programme, steel reinforcing bars with average yield strengths (fy) of 475, 520, and 485 MPa and average ultimate strengths of 590, 640, and 565 MPa, respectively, that adhere to the American specification ASTM/A615M-15a were subjected to tensile tests. (ASTM, 2015) [11]

One type of concrete mix (NSC) was employed to create the specimens. The concrete was made with Portland cement from the Iraqi plant name Al-Mass, crushed gravel from the Al-Nibbaey region with a maximum size of 14 mm, natural sand from Al-Ukhaidir, Al-Qattara Factory with a nominal maximum size of 10 mm (fineness modulus =2.3), and fresh drinking water. The mix proportions of NSC were 1:1.8:2.3 (w/c =0.53; cement content = 408kg/m3).

1.1 Testing

Servo-hydraulic actuators with a 2000 kN capacity that were available in the structural laboratory of the College of Engineering at Karbala University were used to test the corbel-column systems. Each specimen underwent incremental vertical load application at the upper edge of the corbel while being tested inverted as shown in Figure 8. Deflections in accordance with the applied stress, the emergence and spread of cracks.

Figure:8 – Test setup with corbel specimen

1. Test Results and Discussion

Examining and analyzing the effect of opening on the structural behavior and ultimate shear strength of reinforced concrete corbel-columns is the main goal of the current work. Nine reinforced concrete corbels' general structural behavior was examined and commented, as shown in table 2.

Table 2: Experimental results of test specimen

Specimens	P_{cr}	p_u	Δ_s	failure Mode of corbel	failure Mode of opening
C1 T (0.72)	40 KN	149 KN	0.274mm	Diagonal splitting failure	-------------
$C_3 H_c S_1$ T (0.72)	40 KN	147 KN	1.2 mm	Flexural compression	Frame type

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1.1 CORBELS WITH TIES

» SPECIMEN C_1 T (0.72)

In this specimen, the corbel was made without opening and is a source for other model Fig.9-b depicts the effect of the load on the deflection of reinforced concrete corbel. A maximum load of 149 kN was recorded . At load 40 kN (about 26.8% from the ultimate load), a flexural crack in the corbel appeared at the face of column junction line with maximum crack width of 1 mm.

Due of the huge vertical force, the corbels' initial vertical crack might be predicted. The crack pattern reflected the diagonal splitting specimen failure as illustrated in Figure 9-a. Post cracking stiffness is high as shown in Fig 9-b and number of crack is minimum for this specimen.

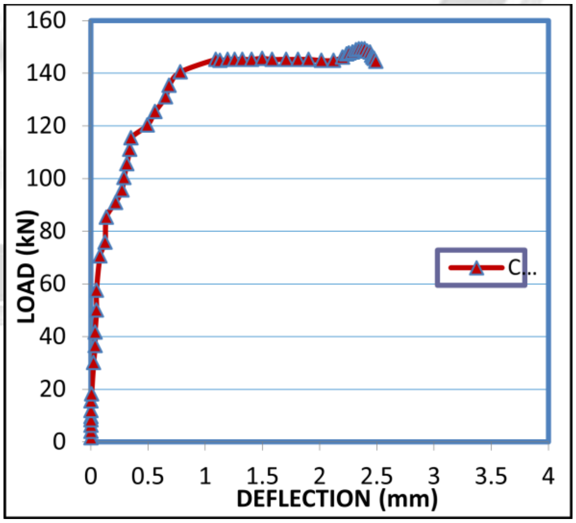

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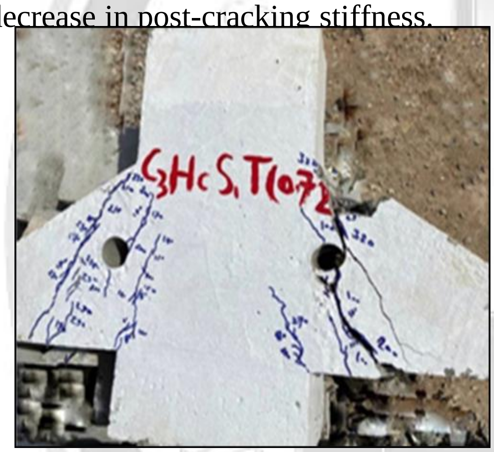
Figure:(9-a) Mode failure of specimen C_1 Figure:(9-b) Load-deflection of specimen C_1

» SPECIMEN C_3 H_c S_1 T (0.72)

The opening in this particular corbel is 40 mm in diameter and is located on the horizontal plane and tangential to face of column at mid depth. At load 40 kN (about 27.2% of the ultimate load) and the maximum width of the crack of 1.75 mm, an increase of nearly 75% from the reference corbel C_1, a major crack in the corbel (diagonal crack) from the place of support. At load 147 kN, the corbel failed due to the crack under the opening along the compression strut adjacent to the hole in the corbel enlarging. The crack pattern indicated that a diagonal splitting+ flexural compression failure, as shown in Figure 10-a, and (ductile failure) had occurred, which was consistent with the failure of the control specimen and the modal failure of the opening (frame type). As can be seen in Fig.10-b, the ultimate load capacity was reduced at a value of about 1.34%, followed by an increase in service deflection about 338% and decrease in post-cracking stiffness.



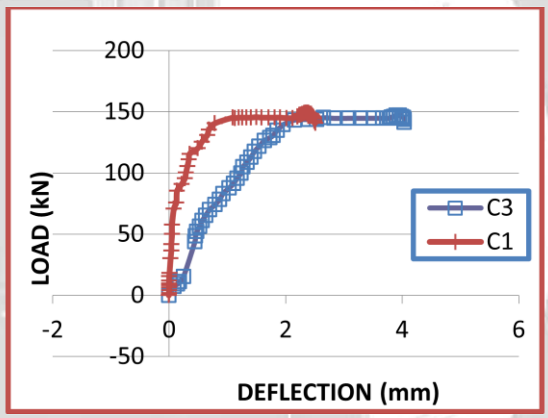


Figure :(10-a) Mode failure of specimen C_3 Figure :(10-b) Load-deflection of specimen C_3 and C_1

» SPECIMEN C_4 H_s S_1 T (0.72)

In this specimen, the corbel was made with a horizontal, square (35X35mm), small tangential to face of column at mid depth. The first major crack in corbel (flexural crack) appeared at face of column at 25 kN (approximately 18.38% of the ultimate load) and a maximum width of 1.1 mm, with an increase about 10% compared with reference model C_1. The crack under the opening along the compression strut close to the hole in the corbel widened to the point of failure at a load of 136 kN, as shown in Figure 11-b. The crack pattern indicated that a diagonal splitting failure as shown in Figure 11-a (ductile failure) had occurred, which was consistent with the failure of the control specimen and the modal failure of the opening (frame type). service Deflection increased by 139% and post-cracking stiffness decreased when compared to the control specimen C_1, and reduction in ultimate load capacity at roughly 8.72%.

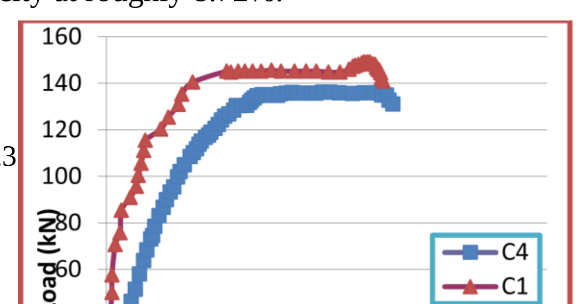


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Figure:(11-a) Mode failure of Specimen C_4 Figure:(11-b): Load-deflection of specimen C_4 and C_1

» SPECIMEN C_6 H_c S_2 T (0.72)

In this specimen, the corbel was made with a horizontal circular small opening; the distance from the column to the center of the opening was 75 mm, and the location from the top face of the corbel was 70 mm, and the diameter of the opening was 40 mm. The first crack in the corbel (diagonal crack) appeared above and under the opening at a load of 30 kN (approximately 20.6% of the ultimate load) and the maximum width of the crack was 2 mm, with an increase of about 100% from the reference corbel C_1. Failure in the corbel happened suddenly when the crack crossed from the top to the bottom of the opening through the opening and along the compression strut until failure at 145 kN Fig. 12-b. Different from the failure of the control specimen and the mode failure of opening (beam type), the failure type that emerged from the crack pattern was a diagonal splitting + shear failure as can be seen in Fig. 12-a ,the presence of the hole in the concrete corbels at a distance from the column alters the behavior of failure to brittle failure, resulting a decrease in the ultimate load capacity at about 2.7%. Additionally, there is increase in service deflection about 38.7% and decrease in the post cracking stiffness compared with the control specimen C_1.

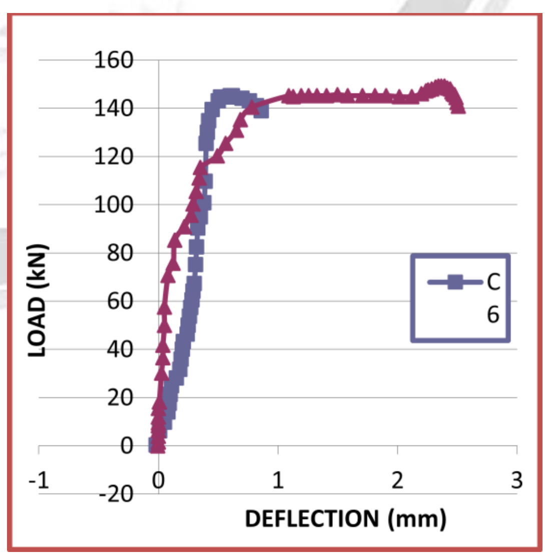

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Figure :(12-a) Mode failure of specimen C_6 Figure :(12-b) Load-deflection of specimen C_6 and C_1

» SPECIMEN C_9 H_c L_1 T (0.72)

This specimen has a large opening; its diameter is 70 mm, tangential to face of column at mid depth. At a load of 22.5 kN (about 24.3% of the ultimate load) and a maximum crack width of 2 mm, this was an increase of almost 100% from the cracking load of the reference corbel C_1. a significant crack in the corbel (diagonal crack) occurred above and under the opening; corbel failure began at load 92.5 kN, as shown in Fig.13-b, when the crack under the opening along the compression strut close to the hole in the corbel widened. Diagonal splitting+ shear failure as shown in Fig. 13-a (ductile failure) was the failure type that emerged from the crack pattern, and the mode failure of opening (beam type). Compared to the control specimen C_1, the ultimate load capacity of the test specimen may be reduced by roughly 37.9%, followed by an increase in deflection at service load of 830% and decrease in post cracking stiffness.

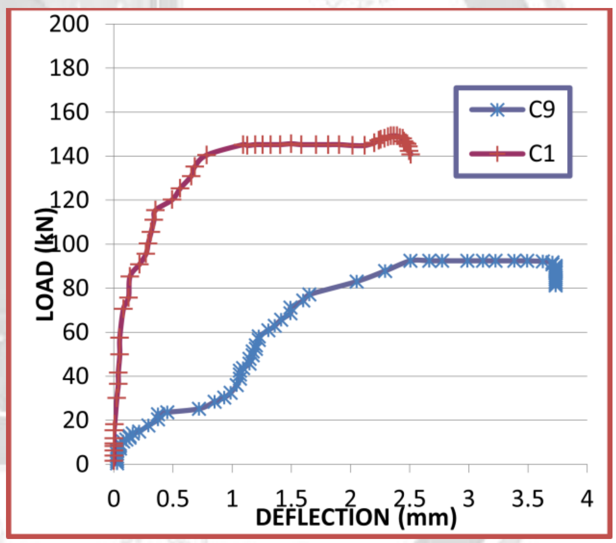

Figure :(13-a) : Mode failure of specimen C_9 Figure(13-b) : Load-deflection of Specimen C_9 and C_1

» SPECIMEN C_{11} H_c S_1 T (0.48)

This specimen is the same as model C_3. The corbel contains small circular of diameter 40 mm tangential to face of column at mid depth, but differs in shear span (a/d) = 0.48. The first major crack in corbel (diagonal crack) appeared at the face of column at 25 kN parallel opening (approximately 13% of the ultimate load) and a maximum width of crack of 0.75 mm, with a decrease of about 25% from the reference corbel C_1. As shown in Fig. 14- b, the corbel failed at a load of 190 kN because the crack under the opening along the compression strut next to the hole in the corbel widened. Diagonal splitting failure as shown in Figure14-a (ductile failure) was the failure type that emerged from the crack pattern, mirroring the failure of the control specimen and the mode failure of the opening (frame type). As can be seen in Fig. 14-b, the ultimate load

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capacity was significantly increased by about 27.5%, followed by a drop in service deflection about 91.6% and increase in post-cracking stiffness.

Figure :(14-a): Mode failure of specimen C_{11}

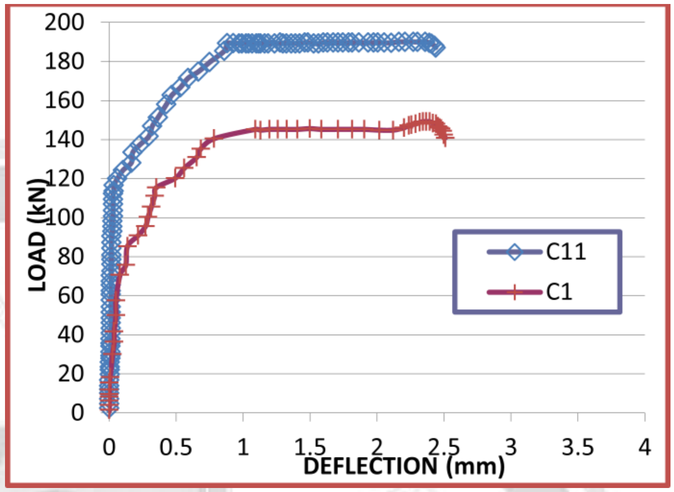

Figure :(14-b): Load-deflection of specimen C_{11} and C1

1.1 CORBELWITHOUT TIES

» SPECIMEN C12 (0.72)

This specimen does not contain horizontal ties ,nor an opening ; it is considered as reference for the following models. The first significant crack in corbel (diagonal crack) appeared at the face of column at 30 kN (approximately 24% of the ultimate load) and a maximum crack width of 1.25 mm. The failure of the corbel was initiated by the propagation of crack from a point load along the compression strut to 125 kN, as depicted in (Fig.15-b). shear failure is a failure variety that resulted from the crack pattern as shown in Figure 15-a.

Figure :(15-a) : Mode failure of specimen C_{12}

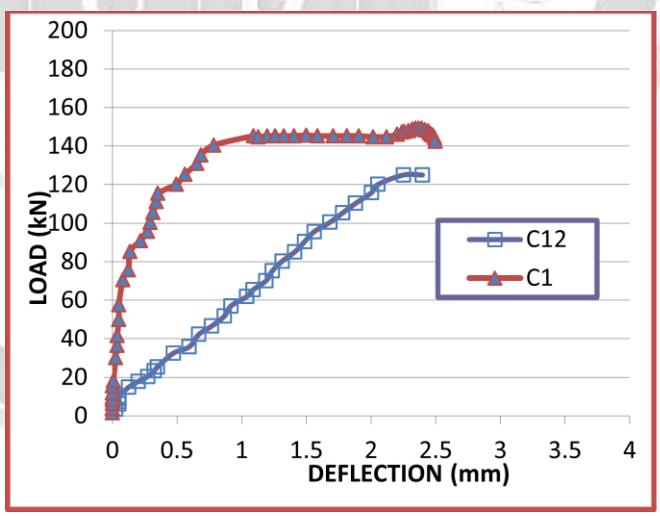

Figure :(15-b): Load-deflection of Specimen C_{12} and C_1

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» SPECIMEN C_{14} H_c S_1 (0.72)

This specimen without ties , The corbel contains small circular diameter 40 mm tangential to face of column at mid depth. The first major diagonal crack in corbel (flexural crack) around opening and at 25 kN (approximately 23.5% of the ultimate load) and a maximum width of crack of 2mm, with increase of about 33.3% from the reference corbel C_{12}. As shown in (Fig. 16- b), the corbel failed at a load of 106.5 kN because the crack around the opening along the compression strut next to the hole in the corbel widened. As shown in Figure 16-a diagonal splitting failure was the failure type that emerged from the crack pattern, and the mode failure of the opening (frame type). As can be seen in Figure 16-b, the ultimate load capacity was significantly decreased by about 14.8%, followed by increase in service deflection by 30.8% and a reduction in post-cracking stiffness.

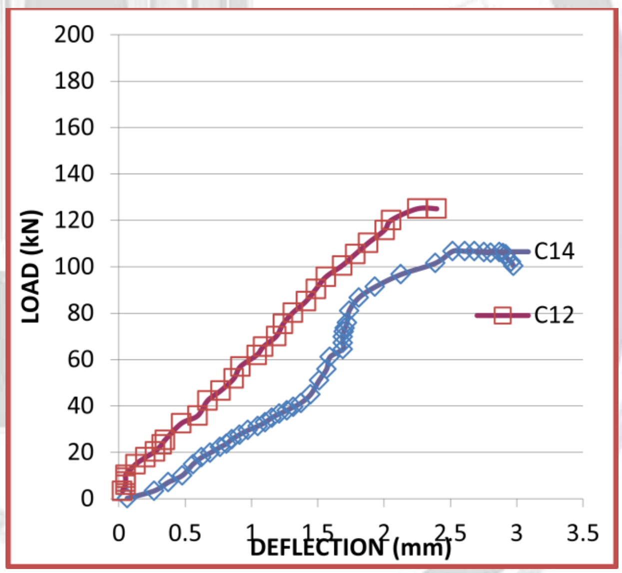

Figure :(17-a) Mode failure of Specimen C_{14} Figure :(17-b) Load-deflection of specimen C_{14} and C_{12}

2. Conclusion

1. The concrete column-corbels having a small horizontal tangential opening of 40 mm decrease the ultimate strength by 1.34%, increase crack width by 75%, and increase deflection by 338%. In the case of a large circular opening diameter of 70 mm, ultimate strength decreases by 37.9%, cracking loads by (43.75%), crack width increases by 100%, and deflection increases by 830%.

2. The effect of the square hole with a diameter of 35mm is greater than the hole at a distance from the column and the tangential small circular hole in terms of ultimate strength and crack load, respectively (8.7%, 2.68%, 1.34%), (37.5%, 25%, 0%). square hole, circular opening at a distance of 75mm, tangential circular opening,
3. Models that do not contain horizontal reinforcement have the type of failure brittle failure.
4. Mode type failure of the opening is (beam type), this type of failure occurs in the case of an opening location under the bearing plate.
5. Mode type failure of opening is (frame type) ,the type of failure in the case of the opening location at the tension face of the corbel

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مجلة جامعة بابل للعلوم الهندسية مجلة جامعة بابل للعلوم الهندسية مجلة جامعة بابل للعلوم الهندسية

التصرف الأنشائي للأكتاف الخرسانية المسلحة مع الفتحات المستعرضة

هديل صادق محمد حسن   عمار ياسر علي

الخلاصة:

يقدم هذا البحث تحقيقًا تجريبيًا لسلوك القص والانثناء لأعمدة واكتاف من الخرسانة المسلحة ذات الفتحات المستعرضة. في مجموعتين اختبار (أ ، ب) ، تسعة أعمدة واكتاف خرسانية منتظمة ذات أحمال رأسية. قام البرنامج التجريبي بفحص تأثيرات عدد من العوامل ، بما في ذلك حجم الفتحات وشكل الفتحات وموقع الفتحات وامتداد القص / a) (dللفتحات وكذلك وجود أو عدم وجود التسليح الأفقي. وفقًا للنتائج التجريبية ، فإن الفتحات المستعرضة لها تأثير كبير على السلوك الهيكلي للاكتاف ، وخصائص مثل التحمل الاقصى ، والانحراف ، وآليات الفشل. خفضت التقنية الحمل النهائي بنسبة ٣٧.٩٪ ، وحمل التكسير بنسبة (43.75٪) ، وزيادة عرض الشق بنسبة(100%) ، وزيادة الانحراف بنسبة 830٪

الكلمات الدالة: التسليح الأفقي، مدى القص، الحمل الاقصى، أحمال التكسير، الهطول، أوضاع الفشل، اكتاف خرسانية.