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Structural Behavior of Reinforced Concrete Corbels with Vertical Openings

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ABSTRACT

In this article, shear and flexural performance of reinforced concrete symmetrical corbel-column with vertical opening is investigated experimentally. The reinforced concrete corbels were cast using a normal concrete mixture using horizontal iron molds. To make openings for the specimen during casting, shapes made of wood for circular opening and cork for square opening were inserted into the mold. Two test groups (A, B) were used to construct and evaluate eight normal concrete corbel-columns subjected to vertically applied loads. Several variables were considered in the experimental program such as shape of opening, size of opening, location of opening, shear span (a/d), the presence or absence of horizontal reinforcement. Empirical findings revealed significant effects of openings on the structural behavior of specimens, such as ultimate strength, cracking loads, cracking patterns, deflection, and failure modes. The most influential variable on the behavior of the corbels was the large circular openings, where led to decrease the ultimate load by (39.6%), cracking loads by (50%), increase crack width by (90%) and increase deflection by (535%). Also, square opening more effect than circular openings, decrease ultimate load by (13%, 2.7%), decrease cracking load (31.25%, 25%), square and circular respectively. In addition to effect of openings at distance (a/2) more than tangential openings. Also, decrease (a/d) lead to decrease the effect of openings on the behavior of corbel. As for group B, corbels without ties, the presence of circular openings decrease ultimate load by 16% corbel C_{13} more than models with horizontal ties 2.3% corbel C_2.

1. INTRODUCTION

In constructions that are monolithic including columns or walls that support substantial, corbels or brackets are crucial structural components for concentrated loads like precast beams, steel girders, and bridges [1]. Example (1). The predominance of reinforced concrete corbels has increased along with the use of precast reinforced concrete components in the bridge and construction industries [2, 3].

The design of corbels has gained importance with the increased utilization of precast concrete, as illustrated in Figure 1. The expression "corbel" is often applied to cantilevers that have shear span-depth ratios smaller than one to prevent ambiguity. Due to this low ratio, shear often governs the strength of corbels (i.e., shear is more effective). Figure 2 shows the typical use of corbels is to support a vertical load Vu at their free end; yet, they may also be required to counteract a horizontal lod (Nuc) transmitted from the supporting beam due to creep, temperature variations, and limited shrinkage, which induces an outward horizontal pulling force. Typical methods of corbel reinforcement include framing bars, horizontal hoops and primary tension steel [3-5].

Reinforced concrete corbels were primarily regarded as shear transfer members because brackets and corbels function more effectively like flexural elements, such as simple trusses or deep beams according to Eq. (4) (ACI-Code 318-14) [5].

The 28 reinforced concrete corbels were tested by Mattock et al. [6] in a variety of conditions, including vertical and horizontal loads. Factors such as concrete strength, amount of steel reinforcing, aggregate type, ratio of shear span to effective depth, and ratio of vertical to horizontal loads were among numerous others. Experiment testing on 28 corbels proved that transferable shear remains constant when both sides of the fracture are simultaneously subjected to a moment equal to the cracked portion's flexural ultimate strength. Thus, the shear-friction design method is superfluous for a/d values below 0.5. Horizontal stirrup reinforcement was visible on 26 specimens. The most important results were:

• The maximum allowable shear stress dropped as a/d increased.

• The reinforcement of the primary tension and the stirrups both yield before the concrete fails at a higher ratio of a/d due to shear compression.

According to the design equations of (ACI-Code 318-14), the design calculations are induced, as follows:

Design for shear-friction

$$Avf=\frac{Vu}{fy\,\mu} \tag{1}$$

Design for flexural

$$Af = \frac{Mu}{fy\ 0.9\ d} \qquad (2)$$

Design for horizontal force

$$An = \frac{Nuc}{fy} \qquad (3)$$

where,

Avf=Shear-friction reinforcement provide to resist shear force *Vu*, mm^2;

Af=Flexural reinforcement to resist factored moment *Mu*, mm^2;

$$Mu = Vu.a + Nuc(h - d) \qquad (4)$$

An=Reinforcement area to resist factor tensile force *Nuc*, mm^2;

Nuc>0.2*Vu*

d=Effective depth (the separation between the centroid of the longitudinal tension reinforcement and the severe compression face), mm;

a=Shear span (The distance between the face of support and the concentrated load), mm;

Vu=Factored applied shear force, *N*;

Mu=The factored instant occurs simultaneously with Vu and N.mm;

Nuc=Due to creep deformation and long-term shrinkage, the supporting beam transmits horizontal force.

fy=Strength of reinforcement yield, MPa;

μ=Friction coefficient,

μ=1.4λ (concrete placed monolithically).

λ=Factor of concrete type,

λ=1 (regular concrete),

λ=0.85 (Sanded concrete that is lightweight) λ=0.75 (All-lightweight concrete).

Through an arrangement of apertures that let utilities' networks and lines travel through conduits and pipelines, essential services like electricity, sewage, water, computer networks, air conditioning and RC beams can pass through.

Apertures because of its adaptability, reinforced concrete is increasingly being used during the construction of buildings. However, because of the appretures' importance, more attention to detail in the design and construction of these components (such as corbels). Consequently, the main goal of the study is to determine the effect of variously sized, shaped, and positioned vertical apertures regarding the comprehensive structural response, integrity, and fracture morphology.

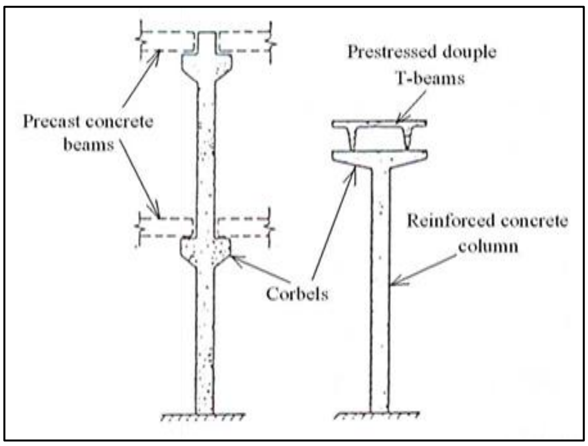


Figure 1. Corbels and columns made of precast concrete [2]

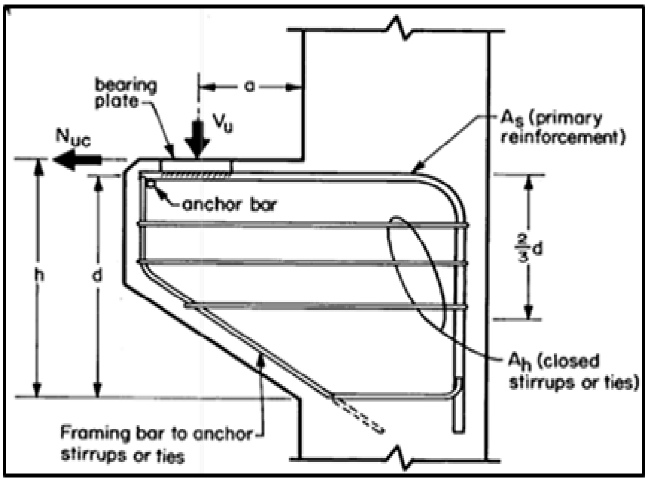


Figure 2. Typical corbel made with reinforced concrete [5]

2. FAILURE MODE OF CORBEL

Corbel Failure Modes Based on a detailed test program done by Kriz and Raths [7]. the failure modes could be divided into the next categories:

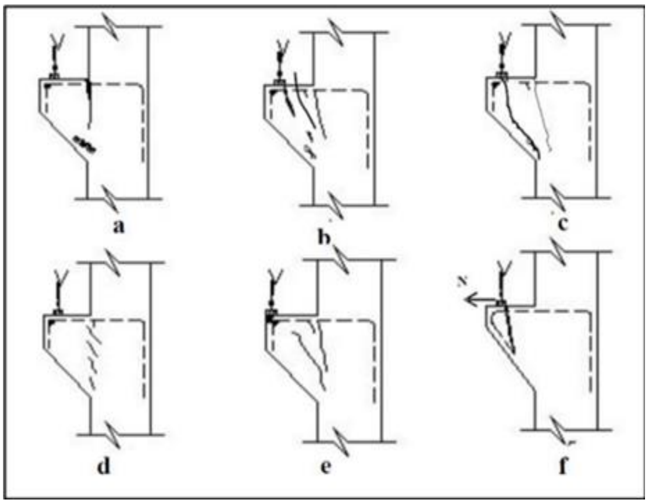


Figure 3. Corbel failure mechanisms [7]: (a) Flexural tension; (b) Flexural compression; (c) Diagonal splitting; (d) Shear friction failure; (e) Crushing due to bearing; (f) Horizontal tension

a) Failure of flexural tension: Concrete at the corbel's bottom face is crushed because of excessive yielding of the tension reinforcement in a flexural tension failure. This form of failure is characterized by flexural cracks that are unusually broad, as depicted in Figure 3(a).
b) Failure occurs prior to considerable main reinforcement yielding by crushing concrete at the corbel's sloping face. Flexural compression failure. Flexural cracks that have developed but not widened significantly as shown in Figure 3(b).
c) Following the development of flexural fractures, diagonal splitting cracks develop along the diagonal compression strut. Shear-compression eventually causes the failure, as depicted in Figure 3(c).
d) Failure of shear-friction is characterized by the development of vertical, narrow cracks that run diagonally at the corbel-column contact. As seen in Figure 3(d), these

fissures unite and cause collapse as a result of sliding shear when the corbel separates from the column face.

e) Failure of the bearing is caused by the crushing of the concrete beneath the loading plate due to an extremely flexible or inadequate plate of bearing, as depicted in Figure 3(e).
f) The creep, shrinkage, temperature change, or dynamic influence on crane girders may cause horizontal force on constrained precast concrete beams attached to the corbel. This type of failure may also occur when an unfavorable horizontal load is added and the corbel's face on the outer side is too shallow. These failure mechanisms are shown in Figure 3(f).

3. VERTICAL OPENING

In lieu of small slab penetrations, vertical openings in RC beams are utilized, particularly for low-rise structures of limited size and height. Due to the structure's capability to redistribute stresses, the impact of the opening size on the structural behavior of RC slabs is frequently overlooked [8]. However, it will consume valuable location and highlight the available services, so it possibly would not be aesthetically practical and would require a ceiling, suspended, or otherwise adornment to be aesthetically acceptable, as depicted in Figure 4.

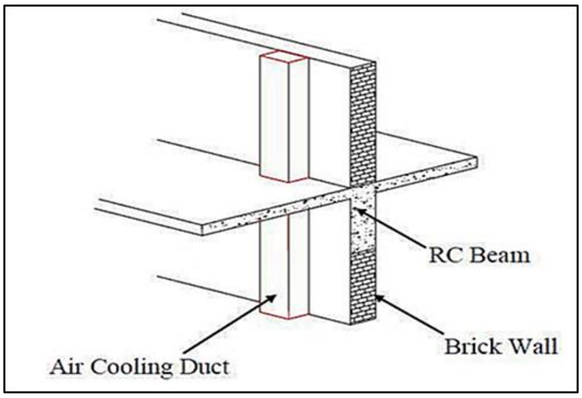


Figure 4. Air cooling duct through a slab (Flange of T-beam) [9]

Figure 5. Vertical services pipes hidden through wall finishes (Commercial building/Babil-Iraq)

Furthermore, the majority of ducts and pipelines passing through openings of vertical in RC beams will be concealed by partitions until they reach the desired location, as depicted in Figure 5. As a result, vertical openings in RC beams have gained widespread use.

In contrast to the horizontal opening, which can be properly location without severing beam compression region and has no effect on the ultimate moment capacity [10], the vertical opening will always cause damage outside of it, thereby reducing the area of concrete necessary to create a complete block of compressive stress. During design, the area of concrete reduced must be considered because it will reduce the shear strengths and ultimate flexural of the beam. In addition, creation of a vertical opening has the potential to cut or obstruct the flexural and shear reinforcement bars; therefore, the impact of vertical openings on the behavior and strength of RC beams must be evaluated, and special design considerations must be considered and approved by a licensed design professional [11].

There is currently no research examining the behavior of concrete corbels with vertical apertures, despite the fact that numerous studies have looked at the effects of vertical openings in shallow and deep beams. In essence, this is the primary objective of the study.

4. EXPERIMENTAL PROGRAM

4.1 Details of specimen geometry and reinforcement

Eight symmetrical concrete corbel systems make up the test program. Seven of them have vertical openings, whereas two are control specimens (no opening). We followed ACI-CODE 318-14 in the design of the corbel [12], utilizing 0.72 shear span to depth ratios (a/d) and 0.48. Figure 6 displays the test specimens' size and reinforcing specifics. The symmetrical cantilever projections on each corbel were 80 mm at the free end, 240 mm at the column face, 160 mm at the breadth, and 250 mm at the length. The corbel reinforcement in all six examples was identical, with 10mm diameter primary reinforcement bars and framing bars that are positioned 20 mm from the side margins and 25 mm effective from the corbel borders. A 10 mm-diameter crossbar was used at the end of each corbel to improve the anchoring of the main reinforcement. Additionally, there are two 6 mm-diameter stirrups on the corbel that are situated within two-thirds of the effective depth (d). The absence of horizontal reinforcement sets the remaining three versions apart from one another. The column was 540 mm high and was made up of a single 250 × 160 mm segment with cantilever corbels on both sides. Eight distorted bars with a 12 mm diameter each made up the longitudinal reinforcement of the columns, which extended the entire height of the column. The column reinforcement, which is made up of distorted rods measuring 6 mm in diameter and 100 mm center to center, is described in Figures 6 and 7. Figures 6 and 7 display all of the corbel model diagrams utilized in this investigation.

4.2 Test group description

The experimental program included examining the use of two groups of the test. Group (A) with ties comprised of (six specimens) to examine the vertical opening impact on how concrete reinforced corbels behave structurally. The (a/d) equal to (0.72), (0.48) for five and one specimen respectively.

Group (B) comprised of (two specimens) to examine Vertical opening's effect on reinforced concrete corbels' structural behavior without horizontal reinforcement according to truss analogy. The (a/d) ratio evaluated was 0.72 for this group. Designations and details of symbol corbel-column connection specimens are reported and presented in Figure 8 as follows. In group (A) the shear arm to the effective depth (a/d) was changed to study the effect of the shear arm on the behavior of the corbel in the presence of openings. Table 1 displays the specimen order in the test groups.

The symbols used in the specimen designation serve as references.

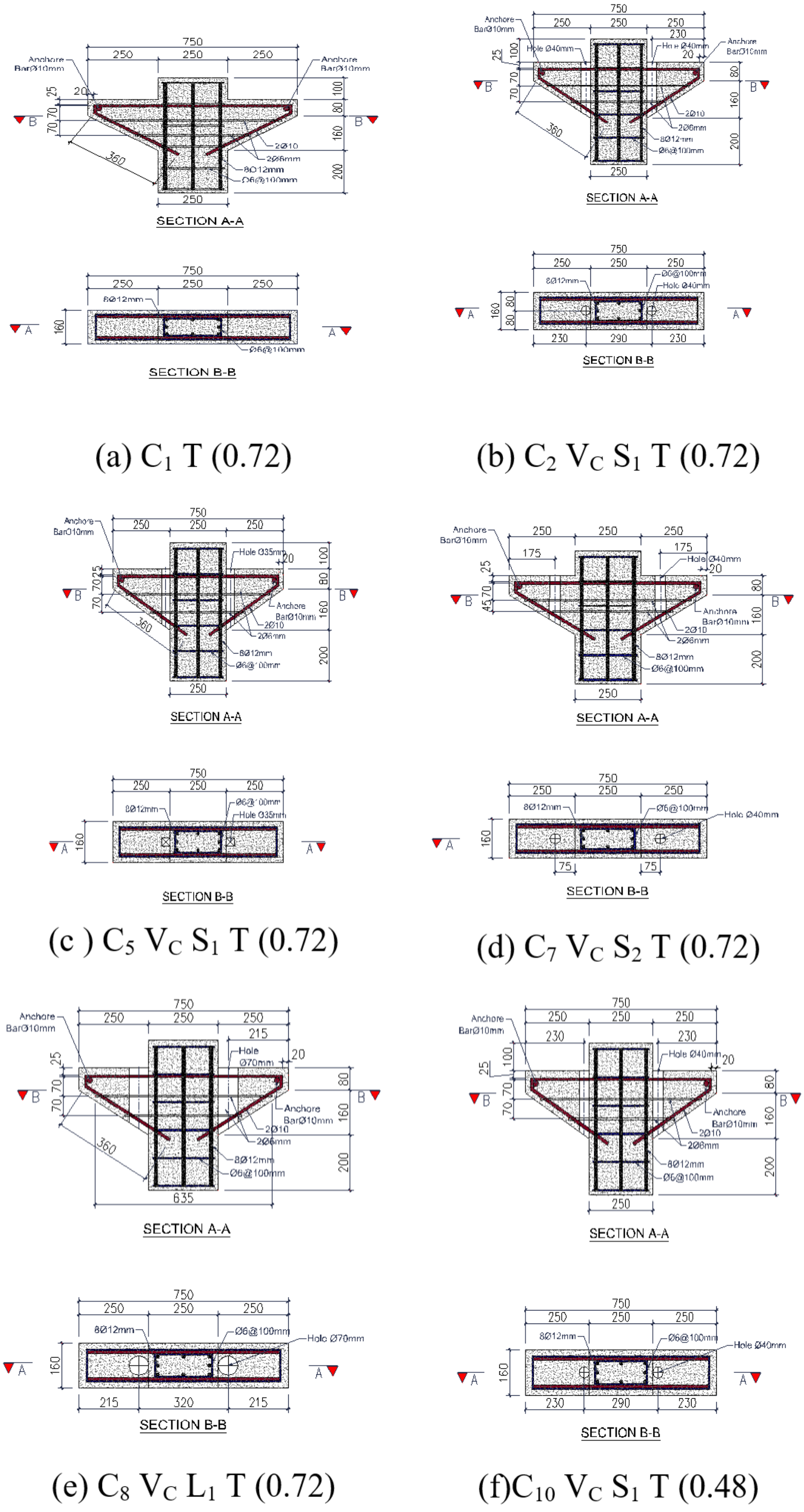
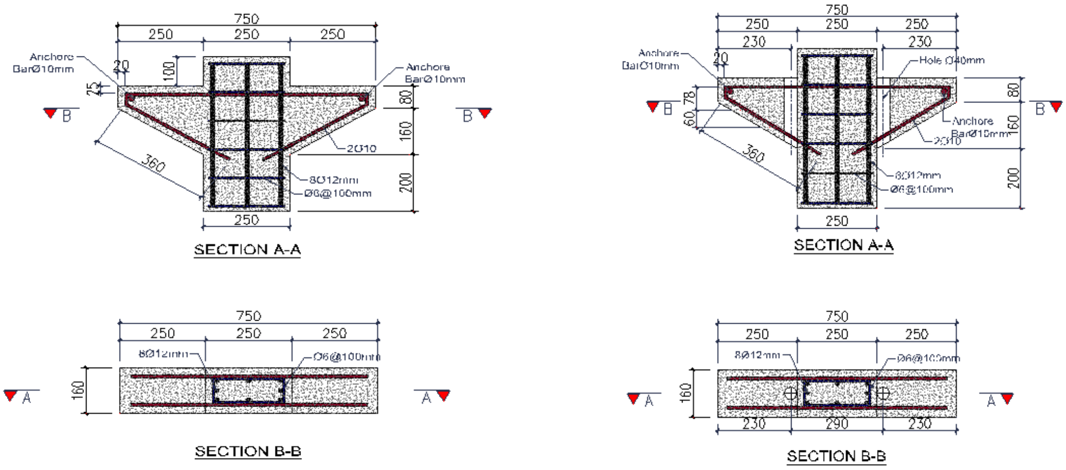


Figure 6. Dimension and reinforcement of test specimen group A [9]



(a) C_{12} (0.72) (b) C_{13} V_C S_1 (0.72)

Figure 7. Dimension and reinforcement of test specimen group B [9]

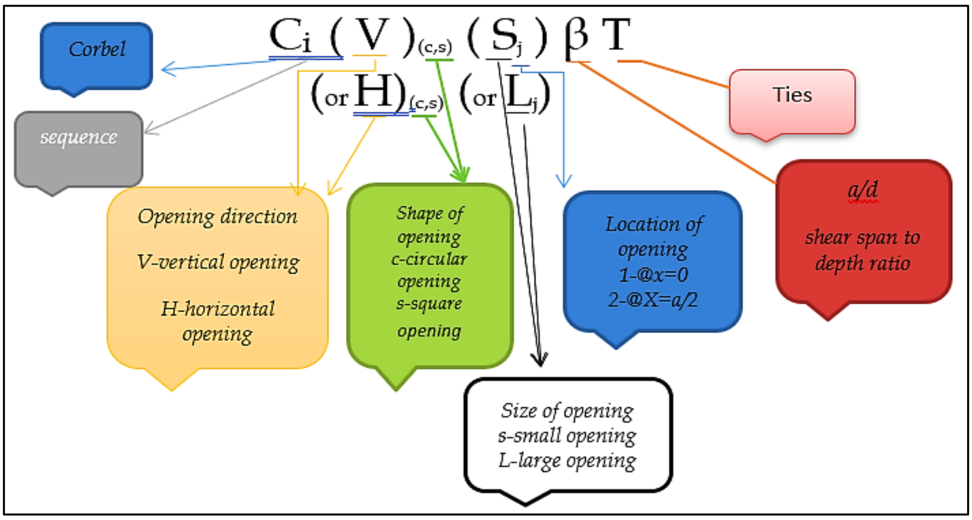


Figure 8. Designation for symbols of tested corbel [9]

Table 1. Details of the tested concrete corbel specimens

Group No.	Specimen Designation	Shape of Opening	Location of Opening (x)	Size of Opening (D or bXb)	a/d Shear Span to Depth Ratio	Horizontal Ties
A	C_1T (0.72)	…	…	…	0.72	With
	C_2 Vc S1 T (0.72)	Circular	Tangent X=0	Φ40mm	0.72	With
	C_5 Vs S1 T (0.72)	Square	Tangent X=0	35×35	0.72	With
	C_7 Vc S2 T (0.72)	Circular	Far from column X=a/2	Φ40mm	0.72	With
	C_8 Vc L1 T (0.72)	Circular	Tangent X=0	Φ70mm	0.72	With
	C_{10} Vc L1 T (0.48)	Circular	Tangent X=0	Φ40mm	0.48	With
B	C_{12} (0.72)	…	…	…	0.72	Without
	C13 VC S1 (0.72)	Circular	Tangent X=0	Φ40mm	0.72	Without

4.3 Materials

Program for experimentation involved tensile strength testing of deformed bars of steel reinforcement measuring Φ 12mm, Φ 10mm, and Φ 6mm, exhibiting mean yield strengths (fy) of 475, 520, and 485 MPa, and average final strengths about 590, 640, and 565 MPa, respectively, in accordance with the American specification ASTM/A615M-15a [13]. One type of concrete mix, normal strength concrete (NSC), was utilized after conducting multiple trial mixes to create the specimens. The mix quantities of NSC were 1:1.8:2.3 (water-to-cement ratio=0.53, cement content=408 kg/m³). Using the prescribed material proportions, a conventional concrete mix with a 28-day compressive strength of 30 MPa was produced. Similarly, alternative materials were selected due to their compliance with the design specifications for concrete corbels, as well as their market availability and acceptable pricing.

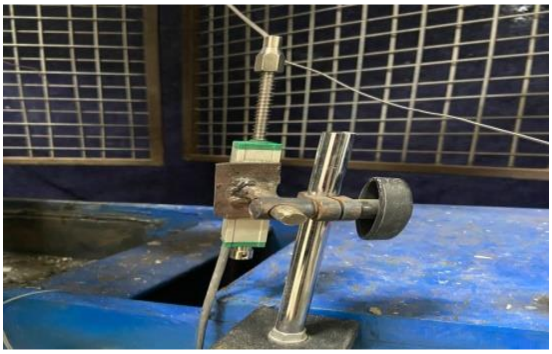


Figure 9. LVDT to measure deflection

Figure 10. Crack meter to measure crack width

4.4 Testing

The corbel-column systems were tested using servo-hydraulic actuator of 2000kN capacity exist in Karbala University's College of Engineering's structural laboratory. All samples were examined and evaluated by applied load vertically at the corbel's upper line subjected gradually and sitting inverted position, deflections corresponding to the applied load, cracks formation and propagation. Throughout each test, instruments were used to measure how connections behave structurally at different loading stages. (linear variable differential transformer-LVDT was utilized to measure the mid-form vertical deflection (i.e., mid-column), the concrete crack width was measure by (AEM40X, MICROSCOPE) crack meter. The load -deflection data was collected by computer system programmed by (LABVIEW) software. All device using as shown in Figures 9-11.

Figure 11. Test setup

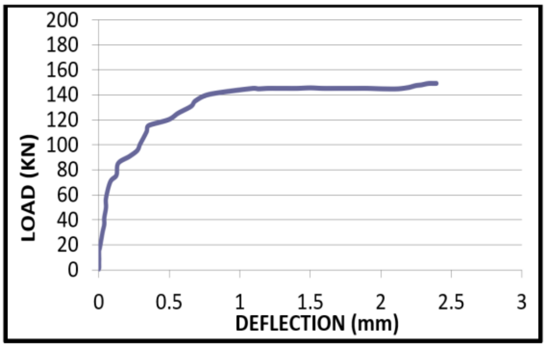
5. TEST RESULTS AND DISCUSSIONS

This research is to investigate and analyze the effect of vertical opening on reinforced concrete corbel-column's maximum strength and structural behavior. The eight corbels made of reinforced concrete was investigated and discussed from where Pu, Pcr, Δs, mode failure, mode failure of opening, all testing results as shown in Table 2.

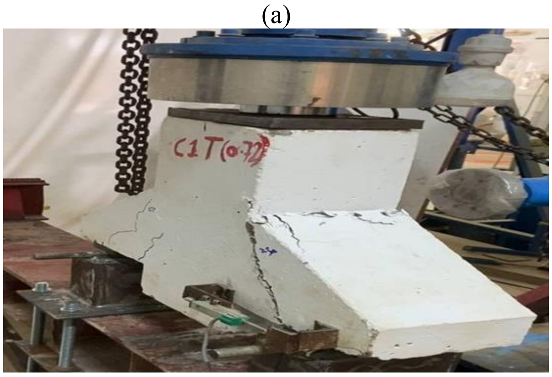
Table 2. Results of test specimens

Specimen	Pcr Cracking Load (kN)	Pu Ultimate Load (kN)	Deference in Ultimate Load to Reference Corbel %	Δs Service Deflection (+) (mm)	Deference in Service Deflection %	Failure Mode of Corbel	Failure Mode of Opening
C_1T (0.72)	40$^{(*)}$	149	-	0.274	-	Diagonal splitting failure	-
C_2 V_C S_1 T (0.72)	30$^{(*)}$	145.5	-2.3	1.09	+297	Flexural compression and diagonal splitting failure	Frame type
C_5 V_S S_1 T (0.72)	27.5$^{(*)}$	130	-13	0.7	+155.5	Diagonal splitting and flexural compression failure	Frame type
C_7 V_C S_2 T (0.72)	27.5$^{(*)}$	140	-7	0.26	-5	Diagonal splitting failure	Beam type
C_8 V_C L_1 T (0.72)	20$^{(**)}$	90	-39.6	1.74	+535	Diagonal splitting +shear failure	Beam type
C_{10} V_C S_1 T (0.48)	30$^{(**)}$	160.5	+7.7	0.84	206.5	Diagonal splitting failure	Beam type
C_{12}(0.72)	30$^{(**)}$	125	-	1.33	-	Shear failure	-
C_{13} V_C S_1 (0.72)	22.5$^{(**)}$	105	-16	1.728	299	Diagonal splitting failure	Frame type

*Flexural crack.
**Diagonal shear crack.
+deflection @service load of reference corbel (0.65Pu) [14]

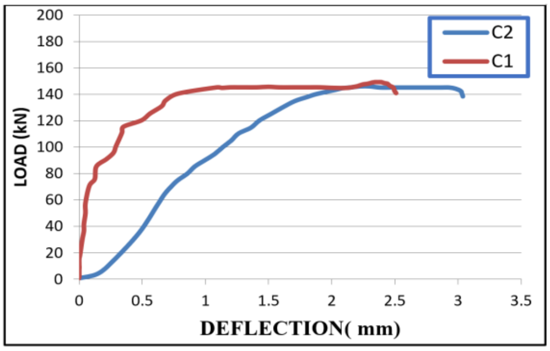


(a)

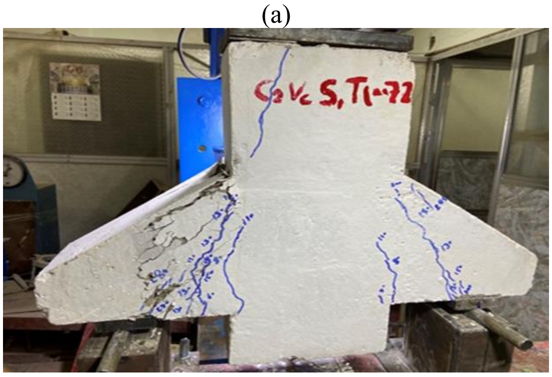


(b)

Figure 12. (a) Load-deflection of specimen C1; (b) Failure mode of specimen C_1 [9]



(a)



(b)

Figure 13. (a) Load-deflection of specimen C_2 and C_1; (b) Failure mode of specimen C_2 [9]

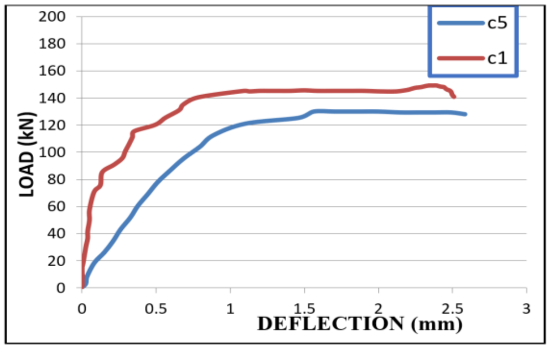
5.1 Corbel with ties

» SPECIMEN C_1 T (0.72)

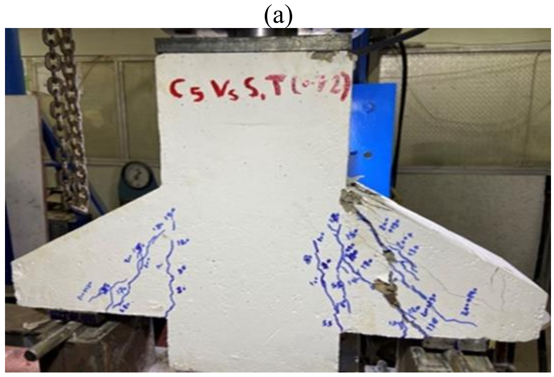
This specimen features a corbel constructed without an opening, which is considered a reference for subsequent forms. Figure 12(a) illustrates the reinforced concrete corbel's load-deflection response at a final load of 149 kN. At a load of 40 kN, or 27% of the ultimate load, the initial crack in the corbel developed at the junction line of the column. The crack was determined to be flexural, with a maximum width of 1 mm. As shown in Figure 12(b), the fracture pattern identified the model's failure type, diagonal splitting failure, which is categorized as ductile failure. For this specimen, the number of cracks is small and the post-cracking rigidity is high.

» SPECIMEN C_2 V_c S_1 T (0.72)

The corbel boasts a vertical circular, tiny tangential opening with a diameter of 40 mm, situated at the midpoint of its breadth. Figure 13(a) illustrates the diagram of load-deflection relationship for this specimen, indicating a maximum load that can be applied 145.5 kN. The corbel's first fracture showed up at a load of 30 kN, which is about 20.6% of the total load. It was characterized as a flexural crack with ultimate dimension of 1.5 mm, indicating an increase of approximately 50% in contrast to the reference corbel C_1. The fissures began parallel to the vertical aperture parallel to the compression strut to the opening, and Figure 13(b) illustrates the corbel's failure mode (diagonal splitting and compression failure), ductile failure, and the collapse mechanism of the opening (frame type). When the hole was there, there were more cracks than in model C1 (the reference model). The maximum load went down by 2.35 percent, the deflection at service load went up by 297.7 percent, and post-cracking rigidity went down compared to main specimen C_1, as shown in Figure 13(a).



(a)



(b)

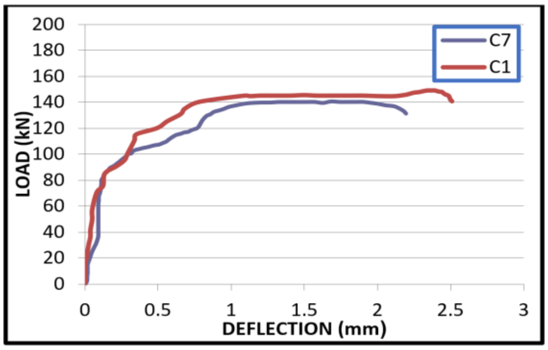
Figure 14. (a) Load-deflection of specimen C_5 and C_1; (b) Failure mode of specimen C_5 [9]

» SPECIMEN C_5 V_s S_1 T (0.72)

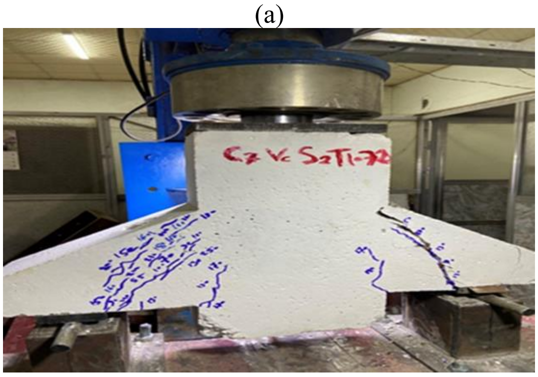
The corbel features a vertical square tangential opening, centrally located along the Z-axis, with dimensions of 35 mm by 35 mm. The curve of load deflection for this corbel is shown in Figure 14(a). It shows that the highest load applied was 130 kN at the column face. The initial crack in the form appeared at a load of 27.5 kN, which is about 21.2% of the maximum load. This initial type of break, classified as a flexural fracture, exhibited a maximum dimension of 1.25 mm, representing an increase of approximately 25% compared to the main corbel C_1. The corbel's failure commenced with the expansion of fractures on the compression strut near the corbel's aperture, culminating in failure load about 130 kN, as illustrated in Figure 14(b). Failure Mode in the specimen includes compression failure and diagonal splitting, as well as ductile failure characterized by an opening mode (frame type). A 12.7% decrease in maximum load capacity was accompanied by a 155.5% rise service deflection and a decline in post-cracking stiffness relative to the control specimen C_1.

» SPECIMEN C_7 V_c S_2 T (0.72)

The corbel in this specimen features a vertical circular opening with a diameter of 40 mm, positioned 75 mm from the column and at the midpoint of the corbel's breadth. As illustrated in Figure 15(a) The final load is 140 kN. The initial significant fracture in the corbel manifested parallel to the aperture at a load of 27.5 kN (about 19.6% of the maximum load). This was the initial type of fracture (flexural fracture), with a maximum dimension of 1.5 mm, representing an increase of roughly 50% compared to the main corbel C_1. The failure transpired at the support's periphery as the crack traversed from the upper to the lower section of the opening close to strut of compression next to the hole, culminating in load failure at 140 kN, as illustrated in Figure 15(b). The type failure resulting from the pattern of cracks was diagonal splitting and shear failure, ductile failure, with the failure method of opening classified as beam type. A reduction in the ultimate load capacity might be attained at around 6%. Furthermore, there is no addition in deflection under load service and the cracking stiffness is inferior compared to control specimen C1, as shown in Figure 15(b) (i.e., the number of cracks exceeds that of the control specimen, and the stiffness of the specimen is lower than that of control specimen C1).



(a)

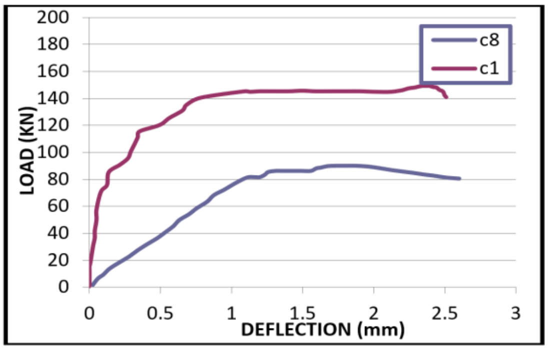


(b)

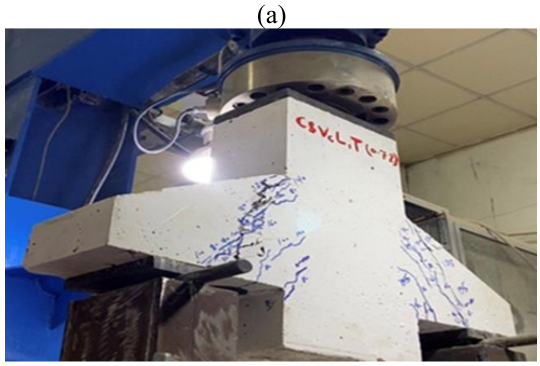
Figure 15. (a) Load-deflection of specimen C_7 and C_1; (b) Failure mode of specimen C_7

» SPECIMEN C_8 V_c L_1 T (0.72)

The corbel in this specimen features a vertical circular opening with a diameter of 40 mm, positioned 75 mm from the column and at the midpoint of the corbel's breadth. As illustrated in Figure 16(a). The maximum load was 140 kN. The initial significant fracture in the form emerged parallel to the aperture at a load of 27.5 kN, which is roughly 19.6% of the maximum load. This was the initial type of fracture (flexural fracture), with a maximum dimension of 1.5 mm, representing an increase of about 50% compared to the main corbel C_1. The failure transpired at the support's periphery as the crack traversed from the upper to the lower section of the aperture near the compression strut adjacent to the aperture, culminating in failure at a load of 140 kN, as illustrated in Figure 16(a). The fracture pattern resulted in a failure type known as diagonal splitting and shear failure, also known as ductile failure. The failure method of the opening was classified as beam type. A reduction in the ultimate load capacity might be attained at around 6%. Figure 16(b) shows that the cracking stiffness is lower than that of control specimen C1, and there is no increase in deflection under service load. This means that there are more cracks than in control specimen C1, and the stiffness of the specimen is lower than that of control specimen C1.

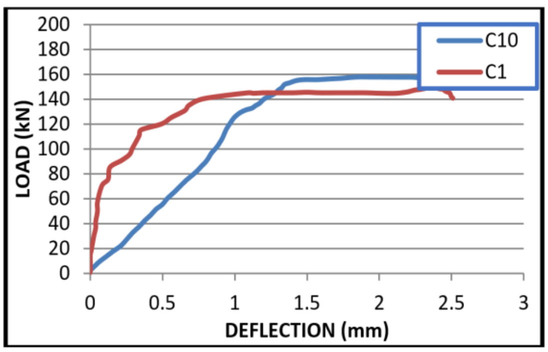


(a)



(b)

Figure 16. (a) Load-deflection of specimen C8 and C1; (b) Failure mode of specimen C_8



(a)

(b)

Figure 17. (a) Load-deflection of specimen C_{10} and C_1; (b) Failure mode of specimen C_{10} and C_1

» SPECIMEN C_{10} V_c S_1 T (0.48)

The corbel in this specimen features a vertical circular opening with a diameter of 40 mm, positioned 75 mm from the column and at the midpoint of the corbel's breadth. As illustrated in Figure 15(a), The ultimate applied load is 140 kN. The initial significant fracture in the corbel emerged parallel to the aperture at a load of 27.5 kN (about 19.6% of the ultimate load). This first type of crack is a flexural crack, with a maximum width of 1.5 mm, representing an increase of roughly 50% compared to the main corbel C_1. The failure transpired at the support's periphery as the crack traversed from the upper to the lower section of the opening beside the hole on the compression strut, culminating in failure at a load of 140 kN, as illustrated in Figure 17(a). The crack pattern resulted in diagonal splitting and shear failure, also known as ductile failure, and the failure method of the opening was classified as beam type. The final load capacity could be reduced by approximately 6%. Figure 17(b) shows that the cracking stiffness is lower than that of control specimen C_1, and there is no increase in deflection under service load. This means that there are more cracks than in control specimen C_1, and the stiffness of the specimen is lower than that of control specimen C_1.

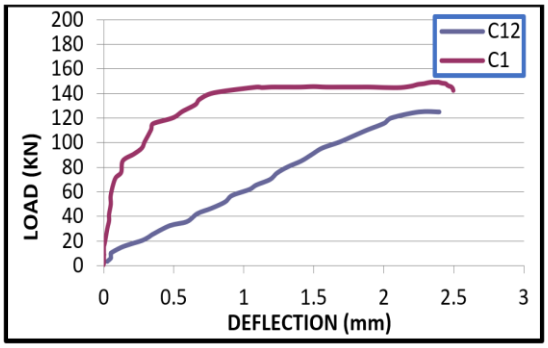
5.2 Corbel without ties

» SPECIMEN C_{12} (0.72)

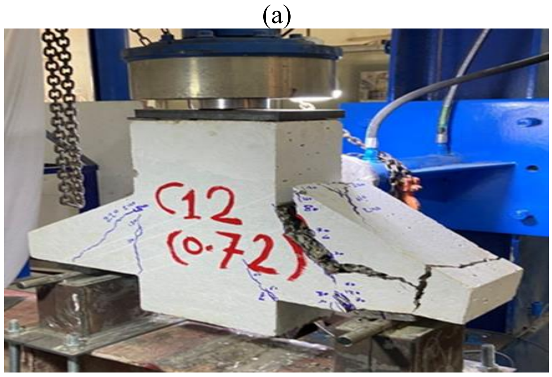
This specimen lacks horizontal links and openings, serving as a reference for the subsequent model. At a maximum force of 125 kN, Figure 18(a) shows that the initial diagonal fracture in the corbel showed up at the column face when the load reached 30 kN, which is about 24% of the maximum load. It was a diagonal shear crack with a maximum fracture width of 1.25 mm. The corbel's failure was triggered by the advancement of a crack via the compression strut from a point load at a weight of 125 kN. Figure 18(b) illustrates that the fracture pattern causes shear failure, which is a brittle failure.

» SPECIMEN C_{13} V_c S_1 (0.72)

The example features a corbel with a vertical, circular tangential aperture of 40 mm in diameter, positioned at the midpoint of the corbel's breadth and lacking horizontal connections. Figure 19(a) illustrates that the maximum applied load of 105 kN resulted in the first significant crack on the corbel at a load of 22.5 kN (approximately 21% of the maximum load). This initial crack, classified as diagonal shear, exhibited a maximum width of 1.5 mm, reflecting an increase of approximately 20% compared to the cracking width of the reference corbel C12. The corbel's failure commenced with fracture propagation from the edge support along the compression strut at the corbel's aperture, culminating in failure at 105 kN. As seen in Figure 19(b). The diagonal splitting failure type was caused by the crack pattern, brittle failure, and opening failure mode (frame type). The maximum load capacity may decrease by roughly 16%, accompanied by a 299% increase in deflection at service loads relative to the reference model C12.

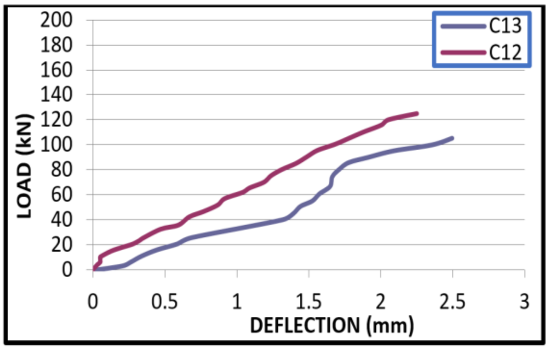


(a)

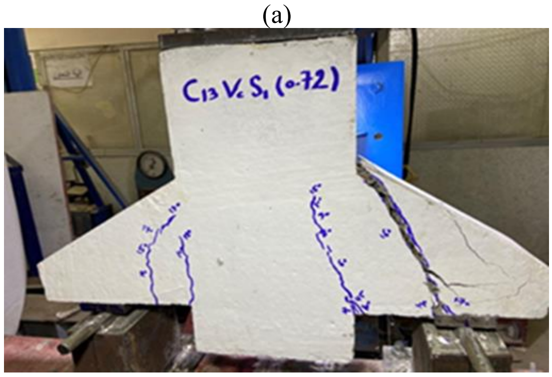


(b)

Figure 18. (a) Load-deflection of specimen C_{12} and C_1; (b) Failure mode of specimen C_{12} [9]



(a)



(b)

Figure 19. (a) Load-deflection of specimen C_{13} and C_{12}; (b) Failure mode of specimen C_1 [9]

6. CONCLUSION

In general, the presence of holes reduces the strength of the corbels.

The greatest impact of openings was in the presence of large openings with diameter 70mm in terms of maximum load, initial cracking, crack width, and service deflection. the ultimate strength decreases by (39.6%), decrease cracking loads by (50%), increase crack width by 90% and increase service deflection by (535%) as compared to reference model C_1.

The effect of the square hole with a dimension (35*35) mm is greater than the circular in terms of ultimate strength, cracking load, crack width and service deflection (12.7%, 31.25%, 25%, 155.5%) respectively. Because of the concentration of stresses at the corners of the opening, which makes its effect greater than circular openings.

As for the small circular hole, it has less effect on the behavior of corbel specimen, as follows decrease in ultimate strength 2.3%, cracking load 25%, increase crack width 50%, increase deflection at service load by 297.8%. Therefore, small circular tangential holes are considered the appropriate choice for passing service pipes.

The effect of small circular at a distance from column more than small circular tangential opening in terms of ultimate strength, decrease cracking load and increase crack width (6%, 31.25%, 50%), respectively. Because it is located at the compression strut transfer zone.

Reducing the shear arm leads to an increase in the maximum load of the model with the hole, so that it reaches higher than the original model that does not contain the hole, increase ultimate strength by 7.7%, increase crack width 50%, increase deflection 206.5%, the type of failure is similar to the original model, The reason for the increase in corbel resistance is due to the decrease in bending moment.

The presence of the hole in the models that not contain horizontal reinforcement decrease strength of corbel and ductility more than corbel with ties and the presence of the hole.

Mode type of opening (beam type). The type of failure in specimen that opening near from support.

Mode type of opening (frame type). The type of failure in specimen that opening tangential with column.

The large hole is considered to have the most influence on the corbel's bearing, then the circular hole when there are no horizontal ties, then the square hole, and the penultimate one is the small circular hole at a distance, and finally the tangent circular hole, as shown in Table 2.

Reinforced concrete corbels that have big holes vertically can be strengthened and rehabilitated using various FRP products, this consider as recommendation for future work.

Small circular holes are considered the ideal choice for passing water drainage pipes when using corbels in bridges and various buildings.

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