Experimental Investigation for Behavior of Reinforced Hybrid Concrete Corbel-Column System Subjected to Un-Symmetrical Vertical Loading

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Abstract

In this paper, shear and flexural behavior of reinforced hybrid concrete corbel-column system was experimentally investigated. Fourteen hybrid and homogenous concrete corbel-column systemssubjected to un-symmetrical loading were constructed and tested within two test groups (A, B). The experimental program included several variables such as: type of hybrid concrete;high strength concrete(HSC) or steel fiber reinforced concrete(SFRC), shear span to depth ratio (a/d), area of hybridization in corbel - column system.Experimental results showed significant effects of concrete hybridization on structural shear and flexural behavior including: ultimate strength, cracking loads, cracking patterns, failure modes, and ductility. Hybridization process ingroup (A) included casting the corbel with HSC or SFRC instated of normal strength concrete (NSC). In shear behavior corbels (a/d= 0.37), this process led to increase the shear capacity of corbel by (26%, 38%) and shear cracking loads by (20%, 120%) respectively. Furthermore, in flexural behavior corbels (a/d= 0.74) shear capacity increased by (19%, 42%), flexural cracking loads increased by (29%, 143%) for HSC and SFRC corbels respectively. In group (B) hybridization process included increasing the hybrid area of corbel-column system in group (A) to represent a distributed region (D-region) or decreasing it to represent hybrid corbel. In both cases shear capacity of corbel increased with a range of (10 to 41) % for specimens hybridized monolithically with HSC, while it increased with a range of (19 to 44) % for specimens hybridized monolithically with SFRC; compared with homogenous NSC specimens having same (a/d) ratio.

Keywords: Hybrid Concrete, Corbel, Shear Behavior, Flexural Behavior, HSC, SFRC.

الخلاصة

تقدم هذه الدراسة تقصيا عمليا لسلوك القص و الانحناء لنموذج الكتف الخرساني المرتبط بعمود والمكون من الخرسانة الهجينة في منطقة الاتصال بين العمود والكتف. تضمنت الدراسة انشاء وفحص اربعة عشر نموذج من نماذج الكتف الخرساني المرتبط بعمود الهجينة والمتجانسة تحت تأثير احمال غير متماثلة ضمن مجموعتين(A,B).تضمنت المتغيرات العمليةنوع الخرسانةالهجينة;خرسانة عالية المقاومة(HSC)، الخرسانة الحاوية على الالياف الفولاذية(SFRC)، نسبة فضاء القص الى العمق الفعال(a/d)، مساحة التهجين في نموذج الكتف الخرساني المرتبط بعمود. بينت نتائج الدراسة العملية وجود تأثيرات مهمة لتهجين الخرسانة على تصرف القص والانحناء من حيث: المقاومة القصوى ،احمال التشقق، نمط التشقق شكل الفشل والمطاوعة. عملية التهجين في المجموعة(A) تضمنت صب الكتف بخرسانة عالية المقاومة او حاوية على الياف فولاذية بدلا من الخرسانة ذات التحمل الاعتيادي (NSC).تؤدي هذه العمليةالى زيادة مقاومة القص للكتف بحوالي (26%, 38%) واحمال تشققات القص بحوالي (20%, 120%) على التواليفي الاكتاف التي يكون تصرفها هو القص (a/d = 0.37).اضافة الى ذلك في الاكتاف التي تتصرف تصرف الانحناء(a/d=0.74) تزداد المقاومة القصوى للكتف بحوالي (19%-42%) اما احمال تشقق الانحناء تزداد بحوالي(29%, 143%) للأكتاف ذات الخرسانة عالية المقاومة او الخرسانة الحاوية على الالياف الفولاذية على التوالي.عملية التهجين في المجموعة(B)تضمنت زيادة مساحة التهجين لنماذج الكتف الخرساني المرتبط بعمود في المجموعة (A) لتمثل منطقة منتشرة(D-region) او تقليلها لتمثل كتف هجين. في الحالتين فان مقاومة الكتف تزداد بحوالي (10%-41%) للنماذج المهجنة باستخدام (HSC) والتي تم صبها في نفس الوقت بينما تزداد مقاومة الكتف بمدى يتراوح بين (19% - 44%) للنماذج المهجنة باستخدام (SFRC) التي تم صبها في نفس الوقت مقارنة بنماذج الخرسانة ذات التحمل الاعتيادي(NSC) والتي لها نفس نسبة فضاء القص الى العمق الفعال.

الكلمات المفتاحية :الخرسانة الهجينة ،الكتف، سلوك القص، سلوك الانحناء، الخرسانة عالية المقاومة ،الخرسانة الحاوية على الالياف الفولاذية.

1. Introduction

Corbels are structural members which are widely used in reinforced concrete construction particularly in precast structures, bridges and factory buildings. They are used to transfer loads from beams or slabs to columns or walls. **ACI-code 318R-14**defines corbels and bracketsascantilevers having shear span-to effective depth ratios not more than 1.0, which tend to perform as deep beams or simple trusses; therefore, it was widely assumed that they are principally regarded as shear transfer members.

Until the mid-1960s of previous century, little of researcheswere available on the strength and behavior of corbels. Some designers have customarily designed them as short cantilevers, using the flexural and shear design equations derived for beams of more normal propositions. It is not surprising that corbels designed by these equations can have varying safety factors. After that, many researchers have studied the behavior and strength of reinforced concrete corbels.**Kriz and Raths, 1965** studiedthe behavior of corbels under effect of several parameters such as additional column loads, the arrangement and amount of reinforcement in the columns, and detailing of the corbel reinforcement.**Mattock,1976** presentedsimple design proposals for normal weight and lightweight reinforced concrete corbels based on previously reported experimental studies.**Abdul-Wahab, 1989**studied the influence of using steel fibers in reinforced concrete corbels. He concluded that the ultimate strength of reinforced concrete corbels with fibers can be best predicted by adding the fibers contribution to strength using the shear friction equation of the ACI Code 318-83 provisions.**Fattuhi,1990**investigated the column-load effect on reinforced concrete corbelswith main reinforcing bars and steel fibers used as a secondary (shear reinforcement). He found that the usage of steel fibers improved both ductility and strength of the corbels. Also, he proved that neither unequal corbel loads nor the column load have any significant effect on the strengths of several different corbels.**Elgwady *et.al.*, 1999** studied the effect of CFRP pattern in the increasing of the maximum load carrying capacity of corbels. They concluded that using diagonal CFRP strips increased the ultimate load carrying capacity of the corbel by (70%) in comparison with the control specimens.

Hybrid strength concrete refers to a new concept of casting two or more different types of concrete in the same section. Experimental and numerical studies for the behavior of reinforced hybrid concrete construction are summarized. **Hussain and Aziz, 2006** introduced experimental and theoretical investigation to study the shear behavior of hybrid reinforced concrete I-beams cast monolithically. A new manner by replacing (or strengthening) a certain part(s) or layer(s) of I-shaped reinforced concrete beams by steel fiber reinforced concrete (SFRC) or high strength concrete (HSC) has been introduced .**Hadi, 2009** explored the effects of adding steel fibers to high strength reinforced concrete columns in particular to the cover of the columns to make a hybrid concrete construction. He found that the hybrid concrete columns containing both FHSC (fibrous high strength concrete) in the outer concrete and HSC in the core exhibited higher levels of ductility than the columns containing FHSC throughout the entire cross-section. **Malik, 2015** presented an experimental and theoretical investigations in which he studied the effects of the hybridization of T-shaped beam by HSC and/or SFRC, the presence of construction joint for flexural and shear behaviorof simply supported reinforced concrete T-shaped beams. The results obtained from hisstudy showed significant effects of hybridization techniques on overall behavior of such beams.**Mahdi,2015** carried out experimental and theoretical investigations to study the behavior and ultimate strength of double-symmetrical concrete corbels with hybrid reinforcement (steel and CFRP) bars subjected to vertical distributed applied load. He concluded thata significantimprovement can occur in the behavior and carrying capacity of the corbels of hybrid reinforcement in main tension or in horizontal reinforcement (stirrups).

Sufficient research studies considered the behavior of corbels made of homogenous section namely, fabricated from one type of concrete were available, but no available work had been found on behavior and performance of RC. corbels made of hybrid concrete.

2. Experimental program

2.1 Design of Test Specimens

The test program comprises of fourteen corbel-column systems.Two of them are control systems (homogenous); others are hybrid concrete systems (i.e., placement of normal and high strength or steel fiber reinforced concrete in the same section). Some corbels were designed to fail in shear prior to flexure and others were designed to fail in flexure prior to shear according to the design provisions of (ACI-Code 318-14) by adopting two shear span to depth ratios (a/d) ; 0.37 for shear failure and 0.74 for flexural failure.The dimensions and reinforcement details of test specimens are as shown in Fig.1.

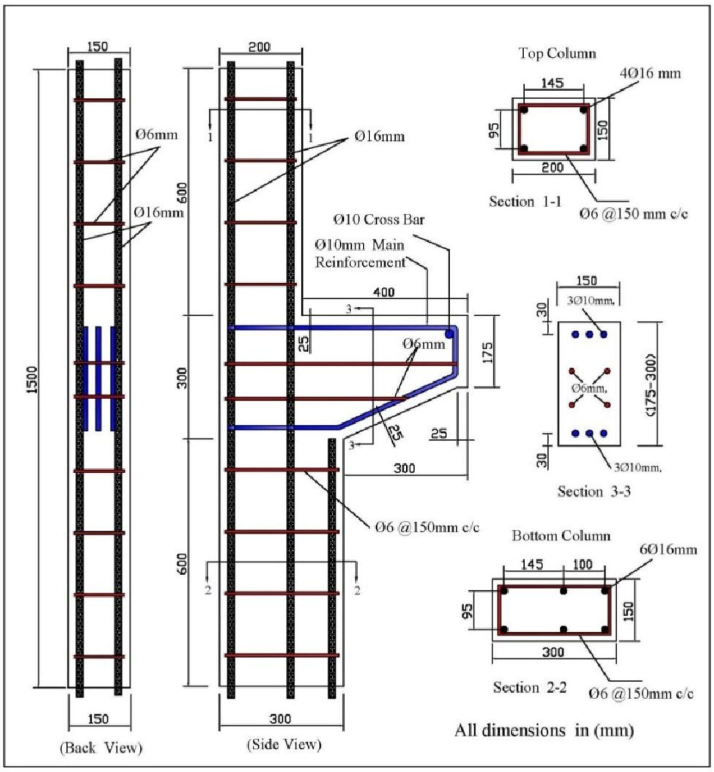

Fig.1Reinforcement Details and Dimensions of TestSpecimens

All Corbels had cantilever projection length of 300 mm, width of 150 mm, with total depth of 300 mm at the face of column and 175 mm at the free end. The reinforcement of corbels was kept the same in all samples, which consisted of main bars of 10 mm diameter employed as primary reinforcement and framing bars placed with 25mm effective cover from corbel edges.Cross bar of 10mm diameter was used near the end of each corbel to provide additional anchorage for the primary reinforcement. Also, the corbel has two stirrups of 6mm diameter placed within a distance of two thirds of the effective depth (d).

The columnhad a total height of 1500 mmsupporting cantilever corbel on one side and consisting of two segments. The top segment of column of cross section (200 ×150) mm and the bottom one of cross section (300 ×150) mm. The longitudinal reinforcement of columns included six deformed bars of 16mm diameter four of them extending along the whole height of column, and all bars extending along the bottom segment only. Column reinforcement having also closed ties of 6mm diameter deformed barsspaced at 150 mm center to center as shown in Fig.1.

2.2 Description of Test Groups

The experimental program consisted of examining the use of two test groups. Group (A) comprised of (6 corbels) to study theeffect of corbel concrete type; three types of concrete were used NSC, HSC and SFRC. Group (B) comprised of (8 corbels) to study the area of hybridization in corbel-column connection region. In this region, the hybridization processes are either increase or decrease the hybrid area in group (A) to improve the structural behavior of corbels. In the first process, the influence of geometric and/or stress discontinuities was studied by increasing the hybrid area through the addition of concrete layers at a distance approximately equal to the overall width of the column (h) away from the discontinuity.

Table 1- Designation and Details of Tested Corbels

Test Group	Corbel Designation	Corbel Concrete Type	Shear Span to depth ratio (a/d)
Group(A) Corbel Concrete Type	C1.N.(0.37,20,30)	NSC	0.37
	C2.H.(0.37,20,30)	HCS	0.37
	C3.SF.(0.37,20,30)	SFRC	0.37
	C4.N.(0.74,20,30)	NSC	0.74
	C5.H.(0.74,20,30)	HCS	0.74
	C6.SF.(0.74,20,30)	SFRC	0.74
Group(B) Area of Hybridization	C9.H.+2h.(0.37,20,30)	HSC+2h	0.37
	C10.SF.+2h.(0.37,20,30)	SFRC+2h	0.37
	C11.H.-h.(0.37,20,30)	NSC+HSC*	0.37
	C12.SF.-h.(0.37,20,30)	NSC+SFRC*	0.37
	C13.H.+2h.(0.74,20,30)	HSC+2h	0.74
	C14.SF.+2h.(0.74,20,30)	SFC+2h	0.74
	C15.H.-h.(0.74,20,30)	NSC+HSC*	0.74
	C16.SF.-h(0.74,20,30)	NSC+SFRC*	0.74

* Two types of concrete (hybrid section) cast monolithically.

In the second process, the full HSC or SFRC corbels were hybridized monolithically i.e. decrease the area of hybridization by replacing the column region by NSC layers (hybrid corbels). The two (a/d) ratios evaluated were (0.37), and (0.74) used in each one of the test groups (A and B).

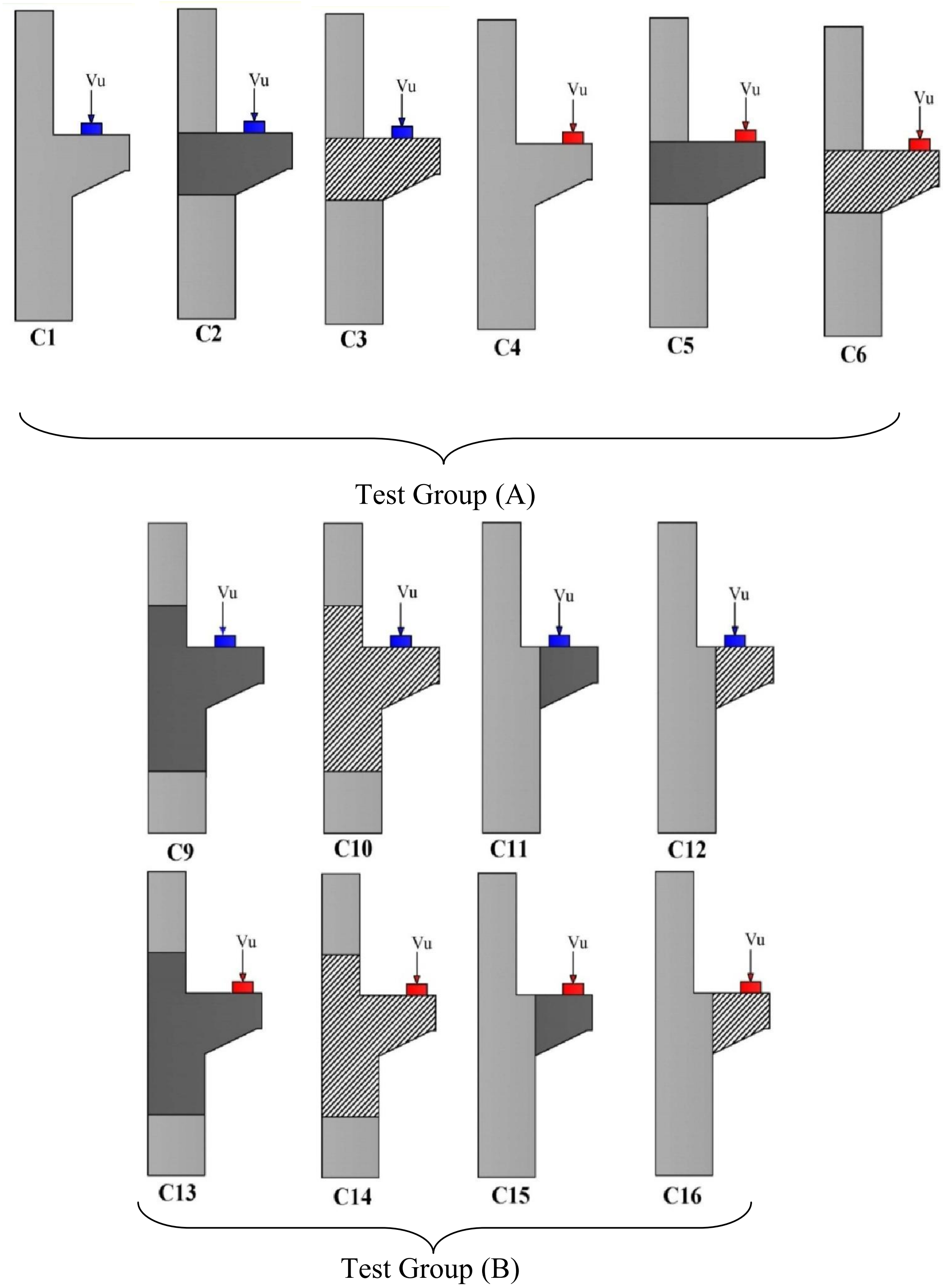

Fig.2Designation of Test Groups

Designations and details of hybridization processes of tested specimens are presented and reported in Fig.2 and Table1, each symbol in this table refers to: C1 to C16 sequence of corbels in the test groups, N: Normal strength concrete, H: High strength concrete, SF: Steel fiber reinforced concrete, (-h): replaced concrete region from corbel along the width of bottom column, (+2h): addition concrete regions to the corbel with heights equal to the widths of top and bottom columns, 20, 30: width of top or bottom segments of column (cm).

2.3Material

In the experimental program,tensile test of steel reinforcing bars was carried out on (ϕ 16mm, ϕ 10mm, and ϕ 6mm) deformed steel reinforcing bars with average yield strengths (f_y) of 516, 464, and 520MPa, and average ultimate strengths of 673, 681, and 749MPa respectively which conform to the American specification ASTM A615/A615M-15a **(ASTM ,2015)**.Three types of concrete mixes (NSC, HSC, and SFRC) with proportions shown in Table 2 were used after several trial mixes for making the specimens. The concrete was prepared with Portland cement from Iraqi plant named TASLUJA, crushed gravel from Al-Nibbaey region in Iraq of maximum size 19mm, natural sand from AL-NAJAF city in Iraq of nominal maximum size 4.75 mm (fineness modulus =2.76),and fresh drinking water. Hooked steel fibers (0.75×60mm) with volume fraction (V_f =1.0%) and aspect ratio (L_f/D_f) =80 were used in steel fiber reinforced concrete. The steel fibers come in water-soluble glued bundles, to ensure their good dispersion in the concrete mixing and to make the process of handling more easily. Superplasticizer admixture commercially named Sika Viscocrete®4100 was used when preparing all concrete mixes; however, its use was primarily intended to improve the workability of high strength and fibrous concrete mixes. The compressive strength test of concrete cubes was carried out on NSC, HSC and SFRC in accordance with BS1881-116 (**BS, 1983**) at test time of each specimen within averagevalues as shown in Table 2 for each type of concrete mix.

Table 2- Proportions and Compressive Strength of Concrete Mixes

Parameter	Concrete Type		
	Normal strength concrete	High strength concrete	Steel fiber reinforced concrete
Water/cement ratio	0.47	0.3	0.47
Cement (kg/m3)	400	525	400
Fine Aggregate(kg/m3)	825	656	825
Coarse Aggregate(kg/m3)	1050	1050	1050
Steel Fiber Volume (%)	--	--	1
Superplasticizer (L/ m3)	1	3.15	2.5
Comp.Strength (MPa)	45	82	58

2.4 Supporting and Test Setup

The corbel-column systems were tested using servo-hydraulic actuator of 2000kN capacityavailable in the structural laboratory of civil engineering department, Faculty of Engineering, University of Kufa. The machine has been modified from testing beams to the test of corbel -column systemswithin the locally available possibilities as shown in Fig.3.The supporting method was such as to prevent the ends of the column from rotating by providing fixed steel supports welded within the rigid frame of testing machine to support top and bottom ends of the column. The supports were made from W-shape section and stiffeners of C-shape welded within the supports to increase their stiffness. They were perforated with a design manner, achieved the cases of shear span (a) used in the experimental program. The column reinforcing bars having threaded ends;were fixed with the supports by properly tightened nuts.See Fig.3.

2.5 Test Procedure

All specimens were tested in an inverted position and subjected to vertical load at the upper edge of corbel as shown in Fig.3.At first, corbel was loaded by 5 kN to seat the supports and the loading system, then unloading to zero.After that,the load was applied gradually.At each load step, the deflection corresponding to the applied load was measured by a dial gauge installed at the end span of the corbel.Cracks formation and propagation were examined at each load step, as well as recording the first and ultimate cracking loadsas shown in Fig.4.All measurements were recorded up to the failure load of corbel.

Fig.3 Testing Machine

Fig.4 TestProcedure

3. Test Results and Discussion

The main objective of the present work is to examine and study the effect of concrete hybridization technique on the structural behaviorand ultimate shear strength of reinforced concrete corbels. The overall structural behavior of fourteen reinforced hybrid or homogenous systems of corbel-columnare investigated and discussed. During the experimental program, load versus deflection, cracking and ultimate loads cracking patterns, modes of failure,deflection at service and ultimate loads as well as ductility index (k) were recorded for each specimen. Table 3 shows a summary of the experimental results.

Table 3- Summary of the Experimental Results

Group	Corbel Symbol	Cracking Loads (kN)		Ultimate Load (kN)		Deflection (mm)		Ductility ratio $k=\frac{\Delta_u}{\Delta_s}$	+ Mode of Failure
		Vcr(s)* (kN)	Vcr(f) ** (kN)	V_u	$\frac{V_{u\,(i)}}{V_{u(c)}}$	*** Δ_u	*** Δ_s		
A	C1	100	130	370	---	11.6	6.75	1.72	D.S.
	C2	120	180	465	1.26	15.97	8.4	1.9	D.S.
	C3	220	240	510	1.38	19.39	8.6	2.25	D.S.
	C4	70	70	270	---	14.76	8.2	1.8	F.C.
	C5	90	90	320	1.19	18.87	9.8	1.93	D.S.
	C6	110	170	383	1.42	28.19	9.6	2.94	F.T.
B	C9	200	220	520	1.41	16.71	9.3	1.8	D.S.
	C10	200	260	530	1.43	19.99	9.7	2.06	D.S.
	C11	140	210	432	1.17	15.61	8.0	1.95	F.C.
	C12	260	150	440	1.19	14.2	8.2	1.73	F.C.
	C13	140	80	334	1.24	20.49	9.2	2.44	F.T.
	C14	120	140	388	1.44	27.05	12.0	2.25	F.T.
	C15	90	50	298	1.10	16.24	7.4	2.19	D.S.
	C16	130	80	350	1.30	20.81	8.8	2.36	F.T.

. Refers to load at initiation of first shear crack.
***… Δ_uRefers to deflection at ultimate load.
.+….. **F.T.** Refers to flexural tension failure.
+….. **D.S.** Refers to diagonal splitting failure.

** …. Refers to load at initiation of first flexural crack.
***…. Δ_s Refers to deflection at service load (0.65Vu).
+ …. **F.C.** Refers to flexural compression failure.
i …. Refers to considered specimen
c….. Refers to control specimen.

3.1 Load- Deflection Response

There are three stages of load-deflection response; these are elastic-uncracked, elastic-cracked and ultimate stages, where the first stage terminated when the cracks developed. In elastic-uncracked stage, deflection increased linearly in all corbels with loading since the materials in compression and tension zones were in elastic manner. In elastic-cracked stage there was also linear relationship between load and deflection but with reduction in slope of load – deflection response up to approximately 65% of ultimate load. After this stage, the slope decreased largely and aggravated increments in deflection can occur with small increase in loading level up to failure. Figs. (5,6) show the load-deflection response of groups (A and B).

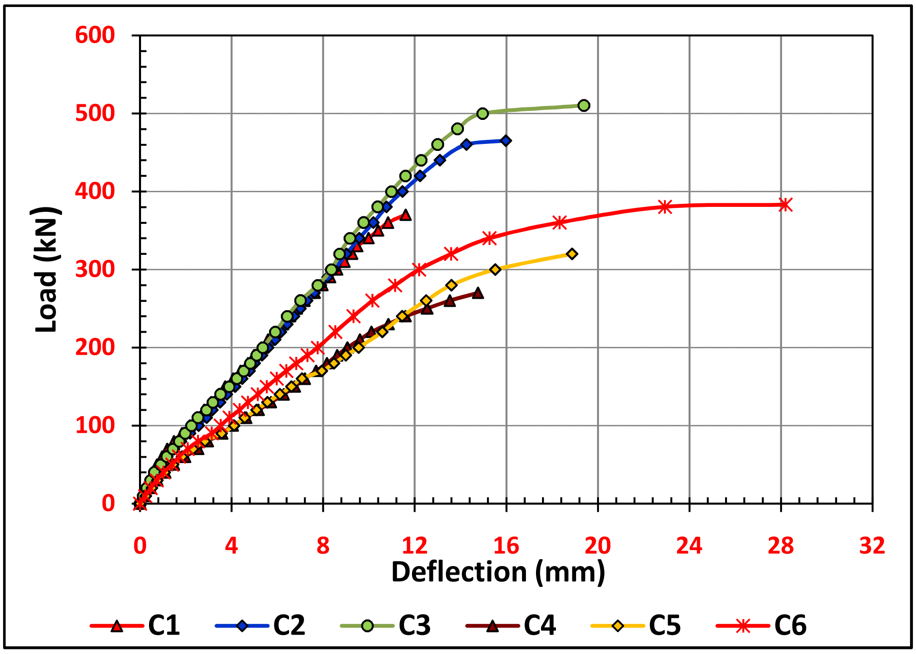

Fig.5 Load –Deflection Curves of Test Group (A)

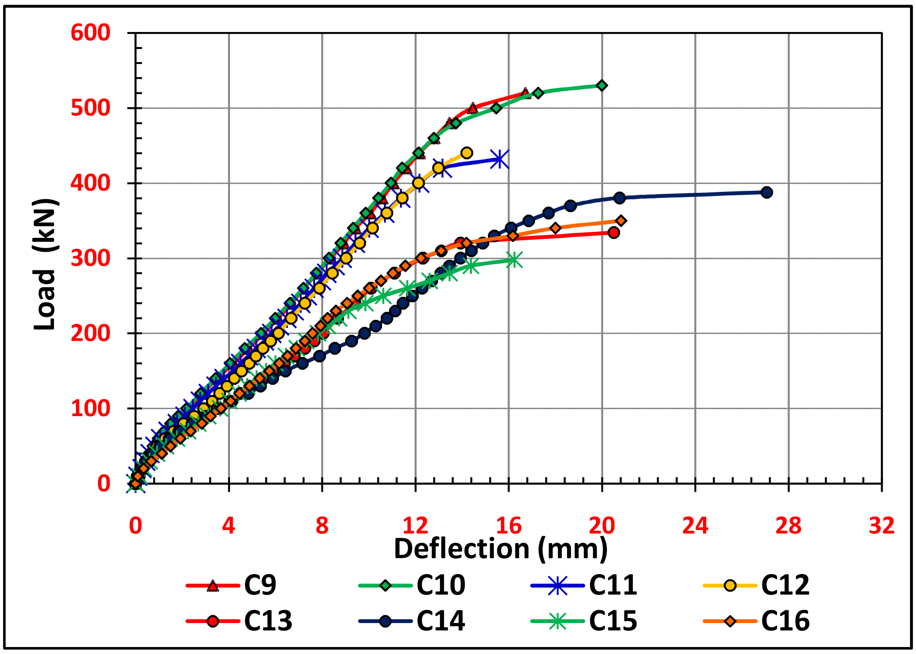

Fig.6 Load – Deflection Curves of Test Group (B)

3.2 Cracking Loads, Ultimate Strength and Modes of Failure

At early stages of loading, all tested corbels were free from cracks and behaved in an elastic manner at low load levels. The deflections were proportional to the applied loads. Consequently, the stresses were small and the full cross section was active in carrying the applied loads. With increasing load increments, more cracks were developed. In general there are three types of developed cracks, flexural cracks, flexure-shear cracks and inclined (diagonal)shear cracks.Flexural failure occurred by wide opening of the flexural cracks, while the diagonal cracks remained fine. In case of shear failure, the flexural cracks remained fine and failure was characterized by widening of one or more shear cracks associated with concrete crushing near the intersection of the sloping edge of corbel and the column face. Failure was defined as the load level at which the load could no longer be increased.Figs.7 to 20 show the cracking patterns and failure modes of tested specimens.

For normal strength corbel-column system hybridized with HSC or SFRC corbels, in shear behavior corbels (a/d=0.37) the ultimate strength increasedby(26%, 38%), shear cracking load increased by (20%, 120%) for HSC and SFRC respectively. Consequently, in flexural behavior corbels (a/d =0.74) the ultimate strength increased by (18.5%, 42%), flexural cracking load increased by (29%, 143%) for HSC and SFRC respectively.

Increasing the area of hybridization of corbel-column connection region(as a D-region) for HSC or SFRC corbels with shear span to depth ratio (a/d)equal to 0.37 increased the ultimate load about (40% and 43%) respectively compared with control corbel C1. On the other hand, when (a/d=0.74), the ultimate load increased about (24% and 44%) respectively compared with control corbel C4.Decreasing the hybrid area in corbel-column connection regionto represent hybrid corbels improved the ultimate strength of corbels compared with control specimens of homogenous section. For hybrid corbels fabricated of (NSC plus HSC or SFRC) layers cast monolithically, the ultimate load capacity of shear behavior corbels improved by (17%,19%) respectively compared with homogenous control corbel of NSC.While in flexural behavoir corbels, the ultimate load improved at about (10%,30%) respectively.

The modes of failure in test groups were identified as follows**, (Kriz and Raths)**:

i- Diagonal tension (splitting) failuer mode, in which diagonal cracks that formed initially at point of loading and/or loading area near inner edge of the bearing plate which propagated towards the critical section.

ii- Flexural compression failure occured by crushing of concrete at the bottom face of the corbel before extensive yielding of tension reinforcement. The developed flexural cracks have not excessively opened.

iii- Failure of the flexural tension that happened when excessive yielding occured inthe flexural reinforcement caused concrete crushing at the sloping end of the corbel; the flexural cracks became extremely wide.

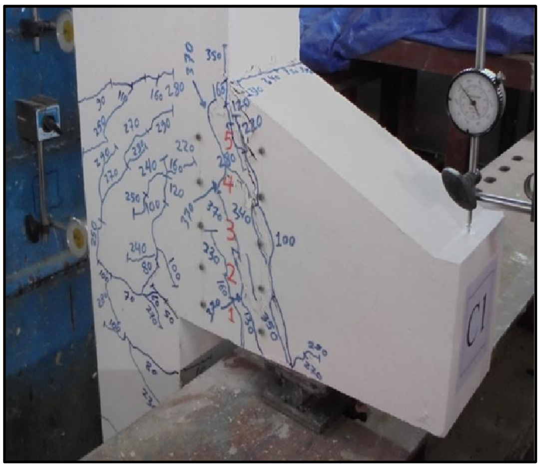

Fig.7-Failure Mode of Specimen C1

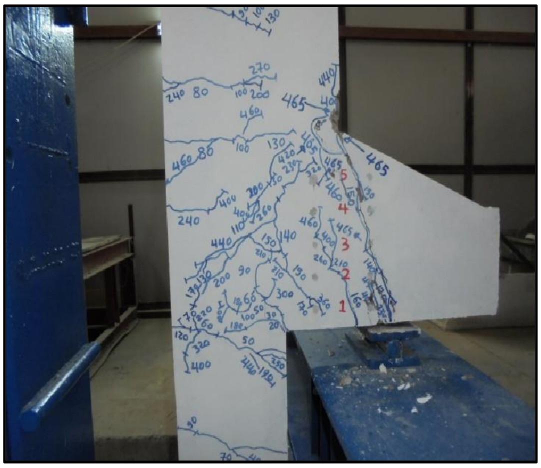

Fig.8-Failure Mode of Specimen C2

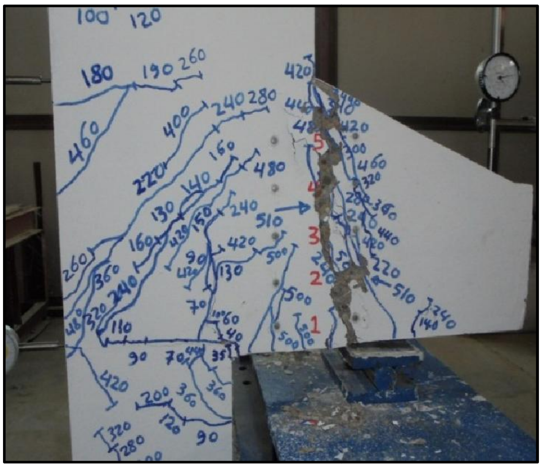

Fig.9-Failure Mode of Specimen C3

Fig.10-Failure Mode of Specimen C4

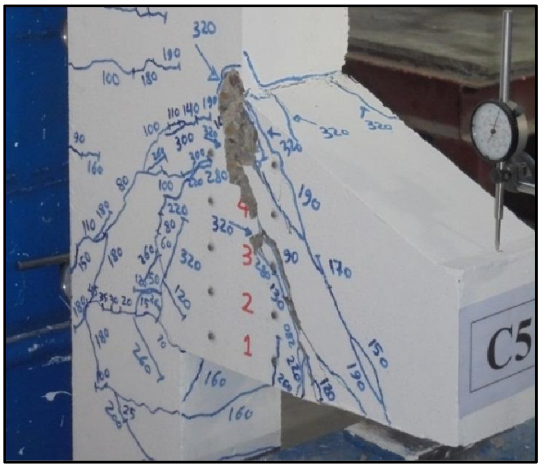

Fig.11-Failure Mode of SpecimenC5

Fig.12-Failure Mode of Specimen C6

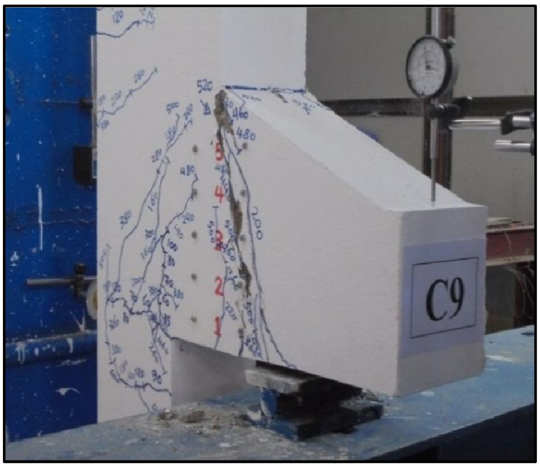

Fig.13-Failure Mode of Specimen C9

Fig.14-Failure Mode of Specimen C10

Fig.15-Failure Mode of Specimen C11

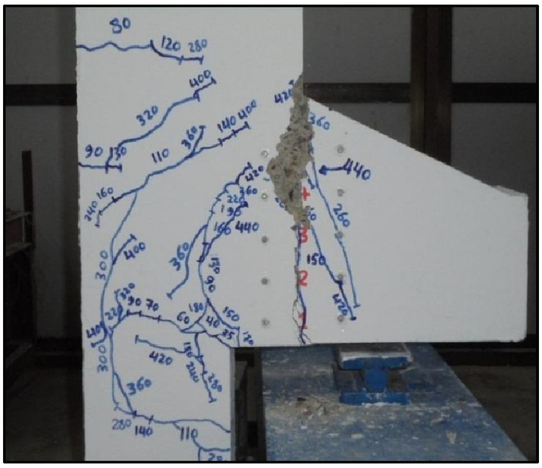

Fig.16-Failure Mode of Specimen C12

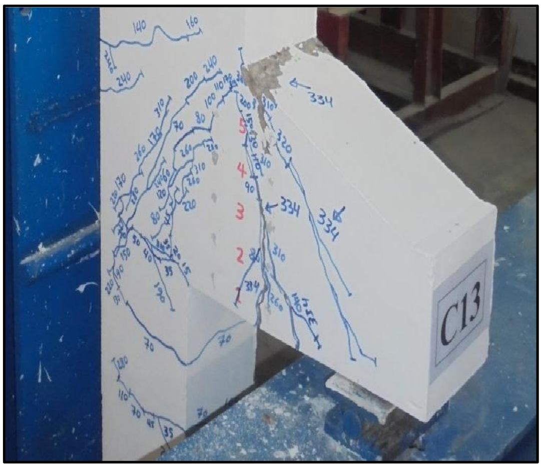

Fig.17-Failure Mode of Specimen C13

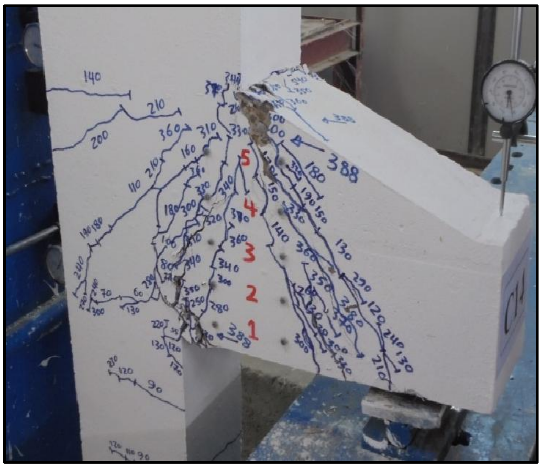

Fig.18-Failure Mode of Specimen C14

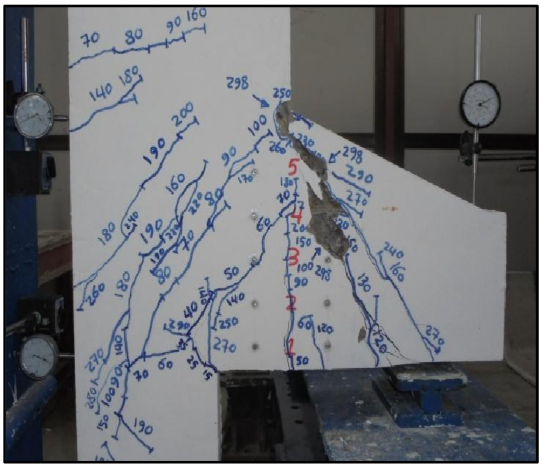

Fig.19-Failure Mode of Specimen C15

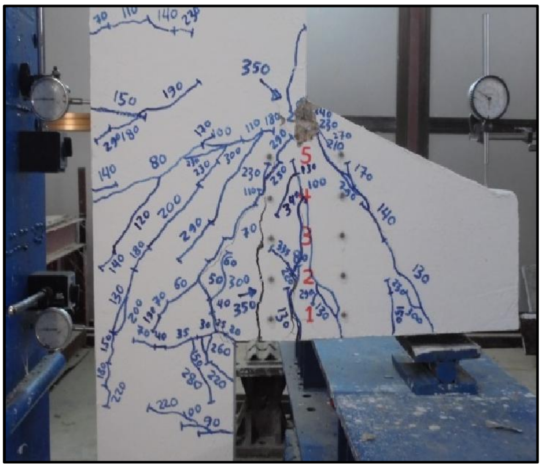

Fig.20-Failure Mode of Specimen C16

In general,tested of hybrid specimens with shear failure exhibited better cracking pattrens compared with hybrid specimens with flexural failure in which larger values of bending moment caused additional cracks moving towards the point of loading. However,increasing in shear span to depth ratio transformed the failure mode to more ductile and increased the number of the formed cracks.

3.3 Ductility

Ductility can be defined as the energy absorbed by the material until a complete failure occurs**(Hussain *et.al.,* 1995)**. In the present work, the experimental ductility ratios (k) are calculated according to the deflection at ultimate load divided by the deflection at service load (approximately 65% of ultimate load)**(Jeffrey , 2003).** Ductility ratios of the tested corbelsare listed in Table (3). Results showed that the corbel-column specimens hybridized with (HSC) exhibited an increase in ductility between (5%-23%) compared with homogenous specimens of NSC, while the specimenshybridized with (SFRC) exhibited larger increasing in ductility between (20%-63%).In both cases, ductility increasing can be attributed to the increase in ultimate load capacity, which produced higher ultimate deflection. Also, it is clear that the shear failure was lesser ductile than flexural mode and the ductility ratio increased when steel fibers were used.

4. Conclusions

1. For normal strength corbel-column system hybridized with HSC or SFRC corbels, in shear behavior corbels (a/d=0.37) the ultimate strength increasedby (26%, 38%), shear cracking load increased by (20%, 120%) for HSC and SFRC respectively.
2. For normal strength corbel-column system hybridized with HSC or SFRC corbels, in flexural behavior corbels (a/d =0.74) the ultimate strength increasedby (18.5%, 42%), flexural cracking load increased by (29%, 143%) for HSC and SFRC respectively.
3. Increasing the area of hybridization of corbel-column connection region (as a D-region) improvedthe ultimate strength of HSC or SFRC corbels. For shear span to depth ratio (a/d)equal to 0.37the ultimate load increasedby (40% and 43%) respectively compared with control corbel-column system of NSC.Furthermore, when (a/d=0.74), the ultimate load increasedby (24% and 44%) respectively compared with control corbel having same (a/d) ratio.
4. For hybrid corbels fabricated of (NSC plus HSC or SFRC) layers cast monolithically , the ultimate load capacity of shear behavior corbels improved by about (17%,19%) respectively compared with homogenous control corbel of NSC.In flexural behavoir corbels the ultimate load improved by about (10%,30%) respectively.
5. Tested of hybrid specimens of shear failure exhibited better cracking pattrens compared with hybrid specimens of flexural failure in which larger values of bending moment causes additional cracks moving towards the point of loading.
6. Different hybridization techniques for systems of shear or flexural behavoir increased the cracking loads of RC.corbels (i.e.increasedserviceability).This increase is found to vary within a range between (14-100)% in hybrid systems with HSC layers to the range of (14 -160)% in hybrid systems with SFRC layers.
7. Hybridization processes with (HSC) exhibited an increase in ductility between (5%-23%) ; while the hybridization processes with (SFRC) exhibited larger increase in ductility between (20%-63%) compared with homogenous specimens of NSC.

References

Abdul-Wahab, H.M., 1989"Strength of reinforced concrete corbels with fiber", ACI – Structural Journal /January –February.

ACI-Committee 318,"Building Code Requirements for Structural Concrete ACI-318M-14 and commentaryACI-318M-14, American Concrete Institute.

ASTM A615/A 615M–15a, 2015"Standard Specification for Deformed and Plain Carbon Steel Bars for Concrete Reinforcement", American Society for Testing and Materials.

Aziz, A.H. , 2006" Flexural and Shear Behavior of Hybrid I-Beams with High-Strength Concrete and Steel Fibers ", Ph.D.Theise Al-Mustansiriya University, College of Engineering, Iraq.

BS1881-116, 1983"Method for Determination of Compressive Strength of Concrete Cubes", British Standards Institute, London.

Elgwady, M.A., Rabie, M. and Mustafa, M. T., "Strengthening of Corbels Using CFRP an Experimental Program", Published paper in Cairo University, Giza, Egypt.

Fattuhi, I. N. 1990,"Column Load Effect on Reinforced Concrete Corbels", ASCE, Journal of Structural Engineering, Vol.116, No.1, Jan. pp.188-197.

Hadi, M.N.S. , 2009"Reinforced Concrete Columns with Steel Fibers" Asian Journal of Civil Engineering (Building and Housing) Vol.10 No.1, pp.79-95.

Hussain, M., Alfarabi, S, Basunbul A., Baluch M.H., Al-Sulaimani G.J. , 1995 "Flexural Behavior of Precracked Reinforced Concrete Beams Strengthened Externally by Steel Plates" ACI Structural Journal, Vol.92, Issue.1.

Jeffrey S. Russell,2003 "Prestrectives in Civil Engineering", Commemorating the 150^{th} Anniversary of the American Society of Civil Engineering,ASCE Publications,.p.p.375.

Kriz, L.B., and Raths, C.H. ., 1965 "Connections in Precast Concrete Structures-Strength of Corbels", PCI Journal, Vol. 10, No. 1, Feb, pp.16-61.

Mahdi, A.M., 2015. "Experimental and Theoretical Analysis for Behavior of Concrete Corbels with Hybrid Reinforcement", M.Sc. Thesis, Babylon University, Iraq,

Malik M.M. , 2015"Flexural and Shear Behavior of Reinforced Concrete T-section Beams Composed of Hybrid Concrete" M.Sc. Thesis, University of Babylon, Babylon, Iraq.

Mattock, A. H., 1976."Design Proposals of Reinforced Concrete Corbels", Prestress Concrete Institute (PCI) Journal, May-, pp. 18–42.