# Behavior of Reinforced Hybrid Concrete Corbel-Column Connection with Vertical Construction Joint

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## Abstract

In this paper, shear behavior of reinforced hybrid concrete connection of corbel-column is experimentally investigated. Nine homogenous and hybrid concrete corbel-column connections subjected to vertical applied loads were constructed and tested within two test groups (A, B). The experimental program included the effect of several variables such as type of hybrid concrete;high strength concrete (HSC) or steel fiber reinforced concrete (SFRC), monolithic casting of hybrid concrete connection, and presence of construction joint at the interface of corbel-column. Experimental results showed significant effects of concrete hybridization on the structural behavior of connection specimens such as: ultimate strength, cracking loads, cracking patterns, and failure modes. Hybridization process in group (A) included hybrid connection of corbel-column with HSC or SFRC corbel instated of NSC. This process led to increase the capacity of connection by (26%, 38%) and shear cracking loads by (20%, 120%) respectively. Moreover, connections of hybrid concrete corbels cast monolithically improved the shear capacity of corbels by (19%, 42%) for HSC or SFRC respectively. In group (B), presence of construction joint at connection region reduced the shear capacity of connectionsby (10% to 22%) and cracking loads by (23%-62%) compared with connections cast monolithically.

**KeyWords:** Hybrid Concrete, Corbel, Connection, Construction Joint, Monolithic, HSC, SFRC.

## الخلاصة

تقدم هذه الدراسة تقصيا عمليا لسلوكمنطقة الاتصال بين العمود والكتف والمكونة من الخرسانة الهجينة. تضمنت الدراسة انشاء وفحص تسعة من نماذج الكتف الخرساني المرتبط بعمود الهجينة والمتجانسة تحت تأثير احمال عمودية ضمن مجموعتين(A,B).تضمن البرنامج العملي تأثير عدة متغيرات مثل نوع الخرسانة الهجينة;خرسانة عالية المقاومة(HSC) او الخرسانة الحاوية على الالياف الفولاذية (SFRC)،الصب الموحد لمنطقة الاتصال الهجينة ،وجود مفصل انشائي في منطقة التداخل بين العمود والكتف. بينت نتائج الدراسة العملية وجود تأثيرات مهمة لتهجين الخرسانة على التصرف الانشائي لنماذج الاتصال من حيث: المقاومة القصوى ،احمال التشقق، نمط التشقق، شكل الفشل. عملية التهجين في المجموعة(A) تضمنت انشاء منطقة اتصال هجينة بين الكتف والعمود عن طريق صب الكتف بخرسانة عالية المقاومة او حاوية على الياف فولاذية بدلا من الخرسانة ذات التحمل الاعتيادي(NSC).تؤدي هذه العمليةالى زيادة مقاومة منطقة الاتصال بحوالي(26%, 38%) واحمال تشققات القص بحوالي 20%, (120%) على التوالي.اضافة الى ذلك ، تزداد مقاومة القص في مناطق الاتصال ذات الاكتاف الخرسانية الهجينة التي تم صبها في وقت واحد بحوالي (19%-42%) للأكتاف المهجنة بالخرسانة عالية المقاومة او الخرسانة الحاوية على الالياف الفولاذية على التوالي. في المجموعة (B)،وجود مفصل انشائي في منطقة الاتصال يقلل من مقاومتها للقص بحوالي(10%-41%) واحمال التشقق بحوالي(23%- 62%) مقارنة بمناطق الاتصال التي تم صبها في وقت واحد.

**الكلمات المفتاحية:** الخرسانة الهجينة ،الكتف، منطقة اتصال، مفصل انشائي، الصب الموحد، الخرسانة عالية المقاومة، الخرسانة الحاوية على الالياف الفولاذية.

## 1.Introduction and Background

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-Code318R-14**defines corbels and brackets as cantilevers 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.

Corbel is regarded a common simple precast concrete connection. The connections between precast concrete components play an important role in determining the successful of precast concrete framed structures.**Abd.Rahman** *et al*.**,2006** studied the structural behavior of simple (pinned) beam to column connection comprised of precast beams, corbels and columns connected together by steel connecters such as angles, plates and bolts. A total of four specimens of beam to column connections were designed and formed to study the behavior of load-displacement relationships, moment-rotation relationships and type of failure in connection under static incremental load.

Construction joints, commonly called "Cold Joints" are stopping places in the process of placing concrete and they are provided to simplify construction of a structure, or even to make the construction possible. Construction joints may be horizontal as in certain structures and columns, or vertical as in slabs and corbels or both as in walls or retaining walls. In the connection of corbel-column, vertical construction joint may form at the interface of corbel-column. This case may be important during the conservation of concrete structures, where layers of new concrete are often applied to an old concrete of the structure in order to rehabilitate the structural element.

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. **Husain and Aziz,2006**introduced experimental and theoretical investigations 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 studied the effects of hybridization of T-shaped beam by HSC and/or SFRC, the presence of construction joint, using epoxy resin layer and shear connectors for flexural and shear behavior of simply supported reinforced concrete T-shaped beams . The results obtained from his adopted technique showed significant effects of SFRC and/or HSC on overall shear and flexural 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 that a significant improvement could occur in the behavior and carrying capacity in corbels of hybrid reinforcement in main tension or in horizontal reinforcement (stirrups).

Information about the response of reinforced hybrid concrete corbel-column connection cast monolithically was not available. Furthermore, the presence of vertical construction joint in RC. Corbels with homogenous or hybrid concrete was not considered in previous studies.

# 2. Experimental Program

## 2.1 Detailsof Specimen GeometryandReinforcement

The test program comprises of nine systems of corbel-column connection specimens.One of them is control specimen (homogenous); others are hybrid concrete specimens castmonolithically or with vertical construction joint at the interface of corbel-column.Corbels were designed to fail in shear according to the design provisions of (ACI-Code 318-14) by adopting shear span to depth ratio (a/d) equal to 0.37.The dimensions and reinforcement details of test specimens are shown inFig.1. 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 specimens, 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. In addition, the corbel has two stirrups of 6mm diameter placed within a distance of two thirds of the effective depth (d).

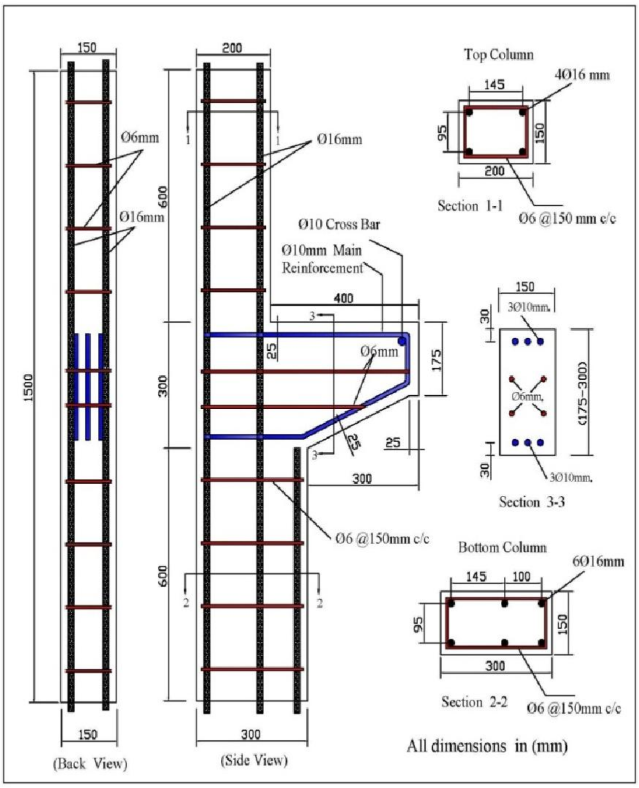



**Fig. 1-Dimensions and Reinforcement Details of TestSpecimens**

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, seeFig.1.

## 2.2 Description of Test Groups

The experimental program consisted of examining the use of two test groups. Group (A) comprised of (five specimens) to study the monolithic concrete hybridization teqniques of corbel-column connection. Group (B) comprised of (four specimens) to study the effect of construction joint at the interface of corbel-column between same or different types of concrete. The (a/d) ratio evaluated was 0.37for the two test groups. Designations and details of corbel-column connection specimens are reported and presented in Fig. 2 as follows:

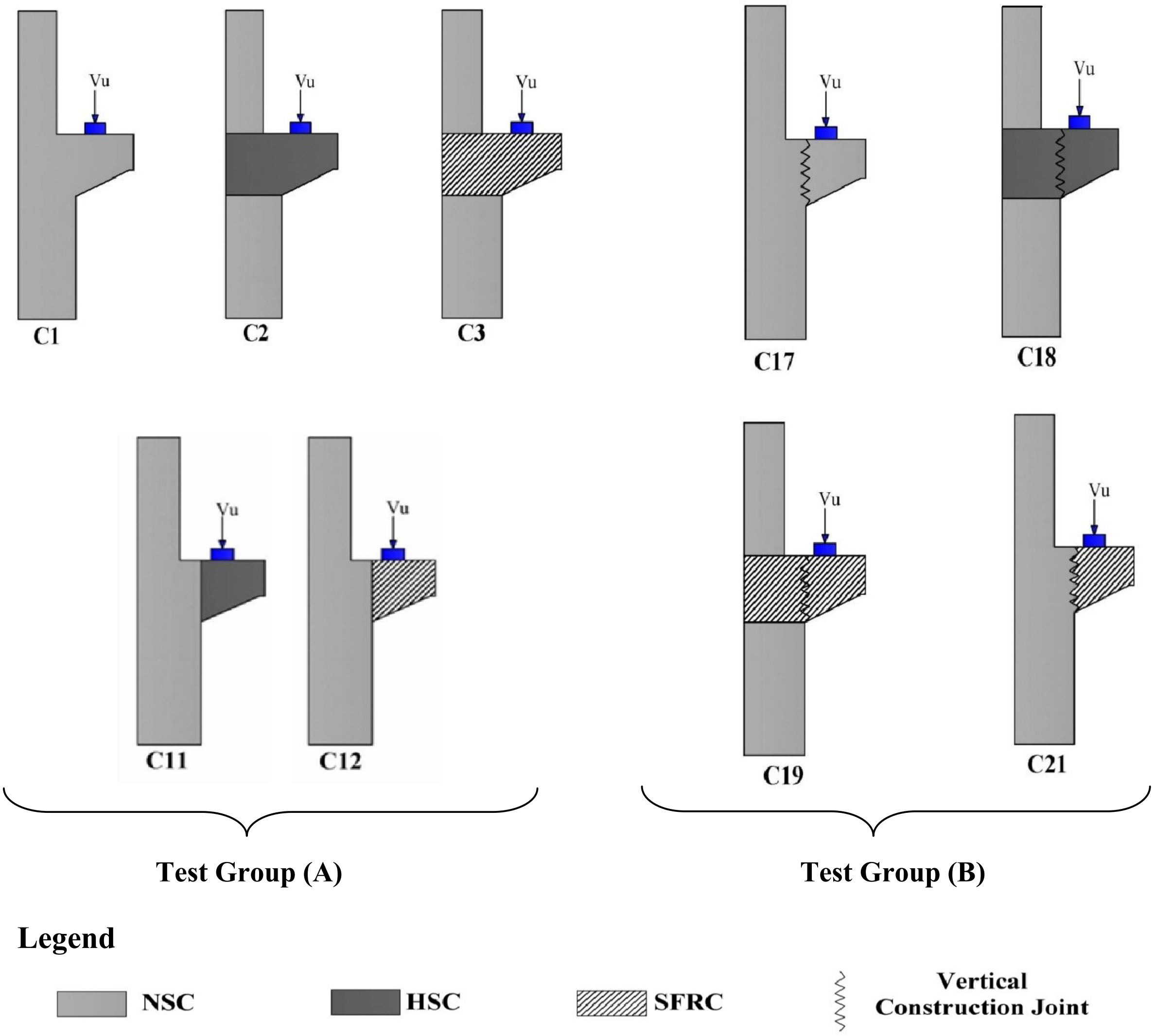



**Fig.2-Designation of Test Groups**

Symbols used in specimens designation refer to: C1 to C21 sequence of specimens 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, J: vertical construction joint at the interface of corbel-column, 20, 30: width of top or bottom segments of column (cm).

- **SPECIMEN C1.N.(0.37, 20, 30):**

Homogenous connection region of corbel and column made of NSC.

- **SPECIMEN C2.H.(0.37, 20, 30):**

Hybrid connection region having HSC corbel.

- **SPECIMEN C3.SF.(0.37, 20, 30):**

Hybrid connection region having SFRC corbel.

- **SPECIMEN.C11.H.-h.(0.37,20,30):**

Connection of hybrid corbel having two types of concrete (NSC, HSC) castmonolithically.

- **SPECIMEN.C12.SF.-h.(0.37,20,30):**
  Connection of hybrid corbel having two types of concrete (NSC, SFRC) castmonolithically.
- **SPECIMEN C17.N.J.(0.37,20,30):**
  Connection of NSC corbel cast with construction joint.
- **SPECIMEN C18.H.J.(0.37,20,30):**
  Connection of HSC corbel cast with construction joint.
- **SPECIMEN C19.SF.J.(0.37,20,30):**
  Connection of SFRC corbel cast with construction joint.
- **SPECIMEN.C21.SF.-h.J.(0.37,20,30):**
  Connection of hybrid corbel having two types of concrete (NSC, SFRC) castwith vertical construction joint.

## 2.3 Materials

In the experimental program, tensile test of steel reinforcing bars was carried out on ($\phi$ 16mm, $\phi$ 10mm, and $\phi$ 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/A615M-15a **(ASTM , 2015)**

Three types of concrete mixes (NSC, HSC, and SFRC) were used after several trial mixes for making the specimens.Mix proportions of NSC and SFRC were 1:2.0625:2.625 (w/c =0.47,cement content = 400kg/m$^3$),while for HSC, they were 1:1.25:2 (w/c =0.3,cement content = 525kg/m$^3$).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 with quantities of (1, 3.15, 2.5) L/m$^3$when preparing all concrete mixes for (NSC, HSC, and SFRC) respectively; however, its use was intended to improve the workability of high strength and fibrous concrete mixes.

## 2.4 Testing

The corbel-column systems were tested using servo-hydraulic actuator of 2000kN capacity available in the structural laboratory of College of Engineering in Kufa University.The machine has been modified from testing beams to the test of corbel -column systems within the locally available possibilities as shown in Fig.3. The column was prevented from rotating by providing steel supports welded within the rigid frame of testing machine to fix the top and bottom ends of the column. The column reinforcing bars having threaded ends; were fixed with the supports by properly tightened nuts,see Fig.3. All specimens were tested in an inverted position and subjected gradually to vertical load

**Fig.3 - Test Setup**

applied at the upper edge of corbel**.** Deflections corresponding to the applied load, cracks formation and propagation, as well as connection rotation were recorded at each load step up to the failure load of corbel. Duringeach test, instruments were used to detect the structural behavior of connections at loading stages. Dial gauge of accuracy 0.01mm was used to measure the vertical deflection at the free end of the corbel. Two horizontal dial gauges of accuracy 0.01mm were used to estimate the rotation of corbel-column connection, while the concrete crack width was measured by crack meter (Elcometer900, X50magnification). The compressive strength test of concrete cubes (150×150×150) mm was carried out on NSC, HSC and SFRC in accordance with BS1881-116(**BS, 1983**) at test time of each specimen with average values (46,79,56) MPa for each type of concrete mix respectively.

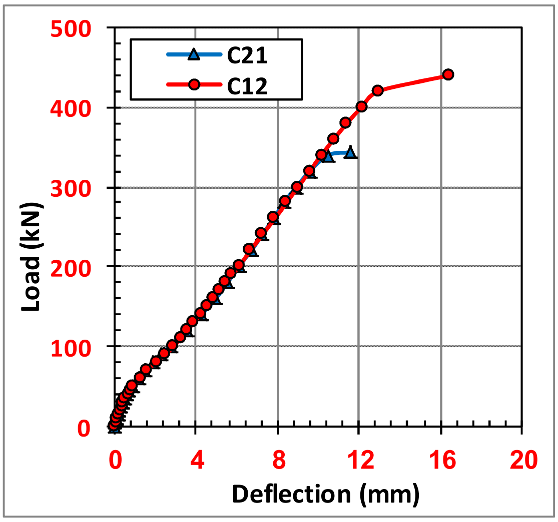
## 3. Test Results and Discussion

The main objective of the present work is to examine and study the effect of concrete hybridization technique on the structural behavior and ultimate shear strength of reinforced hybrid concrete corbel-column connection cast monolithically or with construction joint. The overall structural behavior of nine reinforced hybrid or homogenous systems of corbel-column connection were investigated and discussed.

### 3.1 Homogenous Concrete Connection

**» SPECIMEN C1.N. (0.37, 20, 30)**

Fig.4 (a) shows the load deflection response of the reinforced homogenous concrete connection of NSC. The maximum applied load was 370kN .The first shear crack in corbel appeared at 100 kN (*i.e.* 27% from the ultimate load) at the location of loading towards the corbel-column junction line with maximum width of 0.04mm.



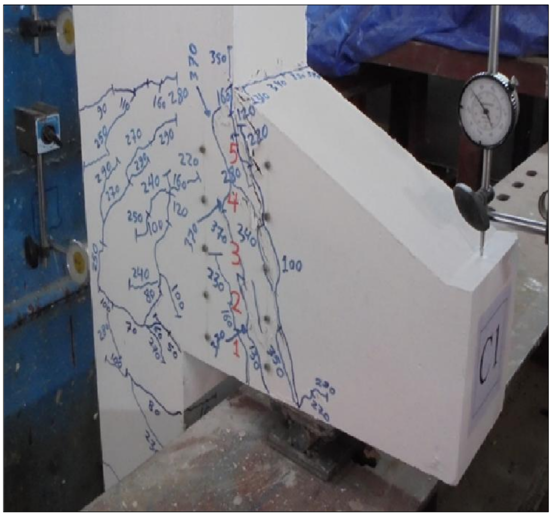




**Fig.4 (a)Load-Deflection of Specimen C1** **Fig.4 (b)Failure Mode of Specimen C1**

The location of the first shear crack was predictable in the corbels due to high shear force.Also, a vertical crack (flexural crack) appeared at 130 kN at the junction of the corbel–column connection. The crack pattern reflected the shear failure of specimen as shown in Fig.4 (b).

### 3.2 Monolithic Connectionsof Hybrid Concrete

In these specimens, an attempt to enhance the ultimate capacity of corbel-column connection was done by fabricating hybrid connection systems comprises of NSC and/or HSC, SFRC cast monolithically. Hybrid connection systems were compared with homogenous one *(i.e.* the control specimen C1) to study the effect of concrete hybridization teqniques in monolithically casted corbel-column connection.

**»SPECIMEN C2.H. (0.37, 20, 30)**

In this specimen, the corbel was made with high strength concrete.The first major diagonal crack in corbel (shear crack) appeared at the point of loading at 120 kN (approximately 26% of the ultimate load) and width of 0.02mm,with an increase about 20% from the reference corbel C1 of same location cracking load, while flexural crack appeared at 180 kN at the face of corbel.Failure in the corbel was initiated by widening of the major crack along the compression strut in the corbel up to failure at load 465 kN, see Fig.5 (b). A failure type resulted from the crack pattern was shear failure, which was similar to the failure of control specimen. Significance increase in the ultimate load capacity could be achieved at about 26% followed by an increase in deflection at service load by 24% and increase in post cracking stiffness compared with control specimen C1 as shown in Fig.5(a).

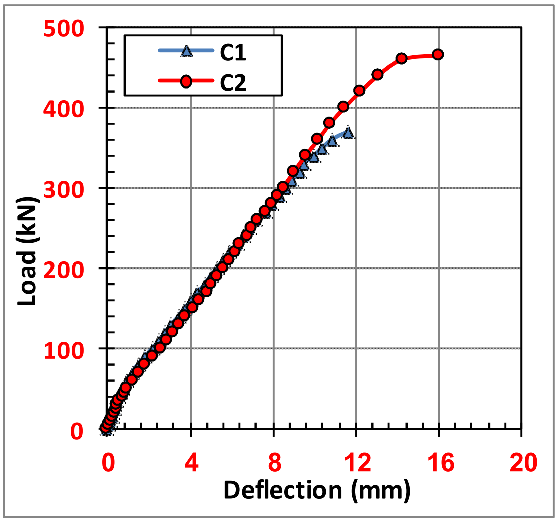
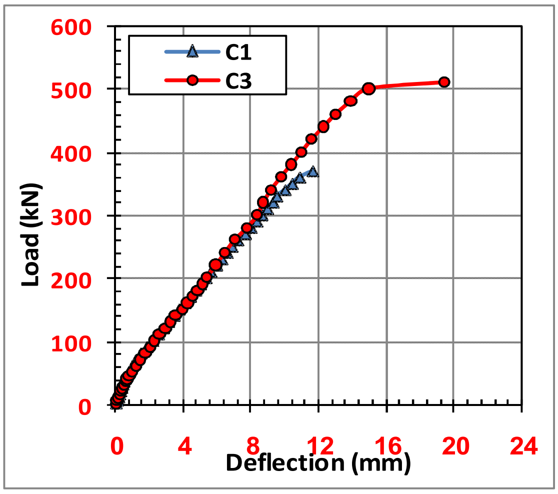



**Fig.5 (a) Load - Deflection Curves of Specimens C1 and C2**

**Fig.5 (b)Failure Mode of Specimen C2**

**» SPECIMEN C3.SF. (0.37, 20, 30)**

In this specimen corbel was made from steel fiber reinforced concrete.The first major shear crack in corbel was observed at the point of loading at 220 kN and width of 0.02mm,with an increase about 120% from the reference corbel C1 of same location cracking load. The formation of first shear crack represented approximately 43% of the ultimate load (*i.e.* there was a high level of ductility).With increasing the applied load, a flexural crack appeared at load 240 kN at loading area near the bearing plate. Further increase in the applied load led to failure at 510 kN.Fig.6 (a) and Fig.6 (b) show the load-deflection response and crack pattern at failure. Crack pattern idealized the shear failure that was similar to the reference corbel C1. It can be observed that deflection at service load increased by 27%, significance increase in the ultimate load capacity can be achieved at about 38% and an increase in post cracking stiffness compared to the control specimen C1. The increase in strength was due to the presence of steel fibers, fibers spanning the micro cracks, controlling the crack's propagation and rate of widening, which ultimately led to a higher load carrying capacity.



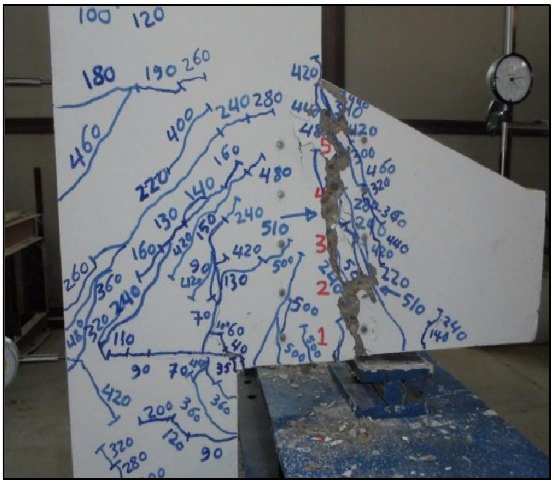



**Fig.6 (a) Load - Deflection Curves of Specimens C1 and C3**

**Fig.6(b) Failure Mode of Specimen C3**

**» SPECIMEN C11. H.-h. (0.37, 20, 30)**

This test specimen represented connection of hybrid corbel made from normal and high strength concrete cast monolithically to study the significance and advantages of corbel hybridization technique on the behavior and strength capacity of corbel-column connection.

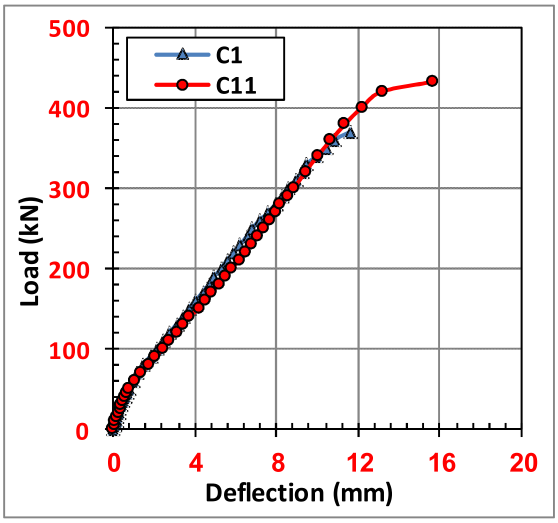




**Fig.7 (a) Load - Deflection Curves of Specimens C1 and C11**

**Fig.7 (b) Failure Mode of Specimen C11**

The first shear crack formed at the face of corbel started at 140 kN from the point of loading towards the critical section. Flexural crack observed at 210kN. Fig.7 (b) describes that failure is terminating by crushing at the point of intersection of column-corbel sloping end at 432 kN. However, the appearance of the crack pattern reflected the flexural compression failure mode of hybrid corbel, which was dislike the shear failure of the full normal or high strength concrete corbels. Fig.7 (a) shows the load deflection curves of specimens C1, C11.

It can be noticed that the shear strength of hybrid corbel increased by17%, shear and flexural cracking loads increased by 40%, 62% respectively, post cracking stiffness was increased at the proceeding stages of loadingwith respect to the homogenous connection of full normal strength concrete.

**» SPECIMEN C12. SF.-h. (0.37, 20, 30)**

This specimen represented connection of hybrid corbel made from two types of concrete, NSC and SFRC. Formation of flexural crack was at 150kN at the inner edge of bearing plate. Further increasing in the applied load to 260 kN led to formation of shear crack. The formation of the flexural and shear cracks was at loads represent approximately 34% and 59% of peak load, respectively, which larger than the flexure and shear cracking loads of specimen C1 by 15.4% and 160% respectively. Finally, crushing at the point of intersection of the column and the corbel sloping end led to flexural compression failure in the corbel at 440 kN as shown in Fig.8 (b).

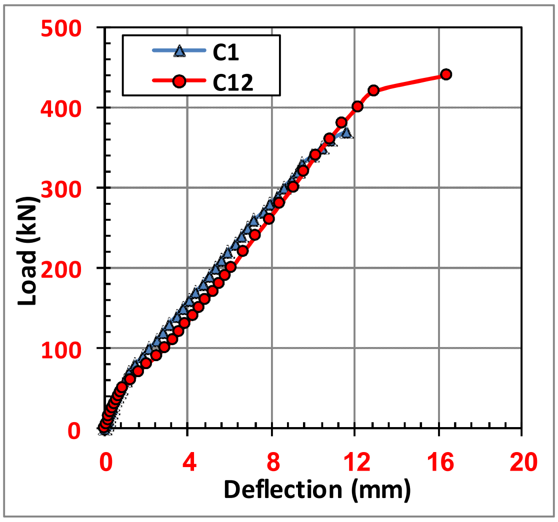



**Fig.8 (a) Load - Deflection Curves of Specimens C1 and C12**

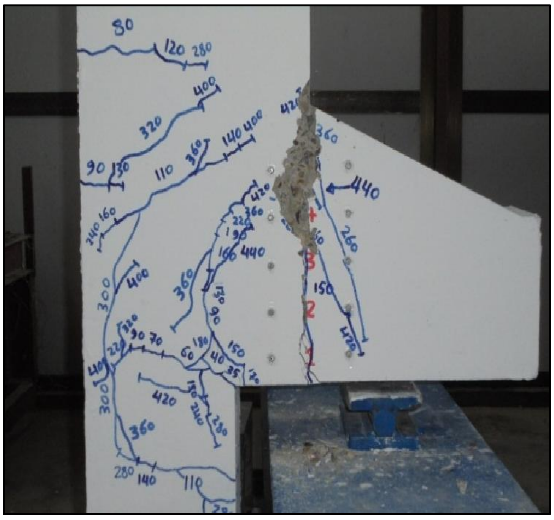


**Fig.8 (b) Failure Mode of Specimen C12**

It can be noticed that the specimen C12 has larger deflection at service load about 22%, larger shear capacity by 19% and larger stiffness of post-cracking response when compared with the control specimen C1 as shown in Fig.8 (a). The presence of SFRC layer led to an increase in the ultimate capacity and deflection due to its ability in energy absorption.

### 3.3 Connections Cast with Vertical Construction Joint

In group (B), the use of vertical construction joint at the interface of corbel-column has been studied .Four specimens were cast at two stages at different times. The type of concrete in the second stage was the same or different and cast after 28 days from the concrete of the first stage. However, this represents the strengthening of concrete corbels, where the layers of new casting concrete applied to a precast concretestructure in order to repair the damaged corbels.

**» SPECIMEN C17. N.J. (0.37, 20, 30)**

The specimen C17 was made from normal strength concrete for overall corbel and column. It wassimilar to the control specimen C1 in all details, but the difference was the existence of the construction joint. However, the corbel was cast at two stages with same NSC mix; time between the [illegible] stages was 28days. In general, a vertical crack (flexural crack) appeared at 5[illegible] kN at the interface of the corbel-column connection. This location of the first crack was predictable in this case due to the presence of construction joint at that location. The first shear crack in corbel face appeared at 110 kN at the point of loading. The flexural and shear cracks represented 15% and 33% respectively from the ultimate load. Flexural crack continued to develop and widen until reach the ultimate load of 332 kN that the flexural compression failure took place as shown in Fig.9 (b). It can be observed that the specimen C17 has lesser shear capacity by about 10%, lesser flexural cracking load by 62% and lesser post cracking stiffness when compared with the control specimen C1 due to the presence of the construction joint which reduced both the stiffness and the cracking load as shown in Fig.9 (a).

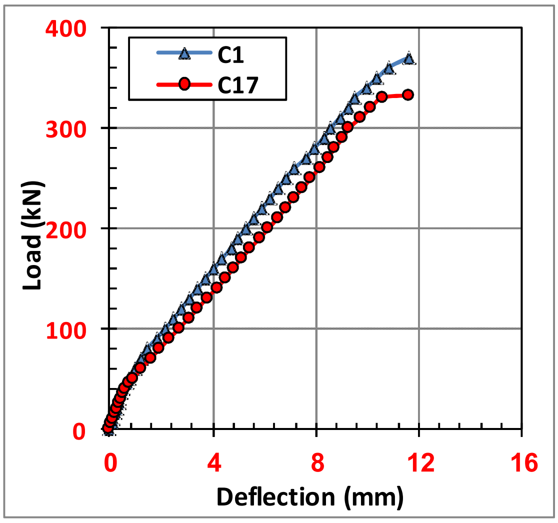



**Fig.9 (a) Load - Deflection Curves of Specimens C1 and C17**

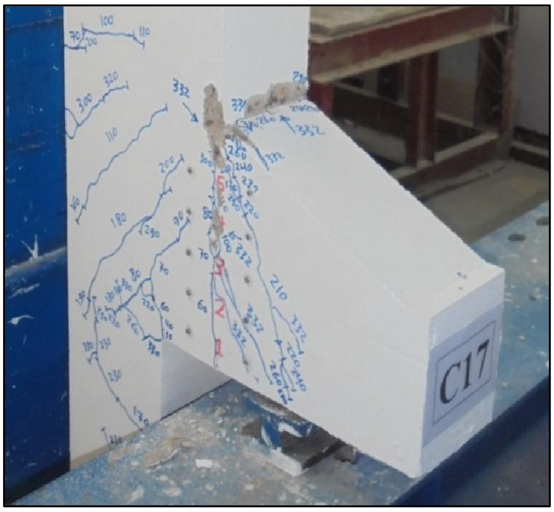



**Fig.9 (b) Failure Mode of Specimen C17**

**» SPECIMEN C18. H.J. (0.37, 20, 30)**

The specimen C18 represented connection of high strength concrete corbel cast with vertical construction joint. The Major vertical crack (flexural crack) appeared at 70 kN at the interface of the corbel–column connection while shear crack appeared at 130 kN. However,failure of flexural compression took place at 391 kN, as shown in Fig. 10 (b).It can be seen from Fig.10 (a) that the specimen C18 had lesser shear capacity by 16%, lesser flexural cracking load by about 61% when compared with the reference specimen C2 due to the presence of the construction joint which reduced both the stiffness and the cracking load.

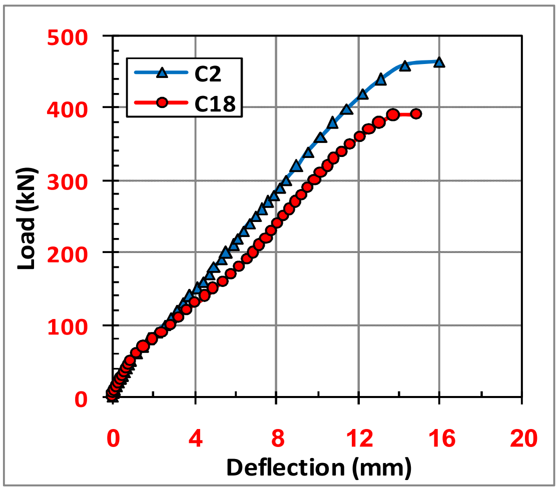



Fig.10 (a) Load - Deflection Curves of Specimens C2 and C18

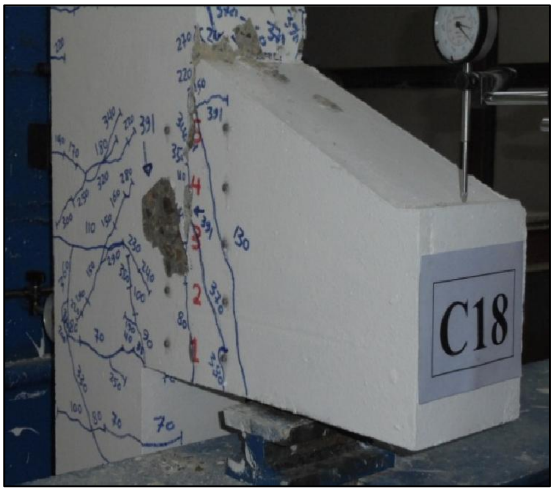



Fig. 10 (b) Failure Mode of Specimen C18

**SPECIMEN C19. SF.J. (0.37, 20, 30)**

The specimen C19 represented connection of a steel fiber reinforced concrete corbel cast with vertical construction joint. Flexural crack appeared at 80 kN at the location of construction joint. The first visible shear crack appeared at 220 kN .The flexural and shear cracks represented 18.4% and 50.6% respectively from the ultimate load. Further increase in the applied load, led to develop and widen the flexural crack until the flexural compression failure happened at 435 kN as shown in Fig.11 (b).

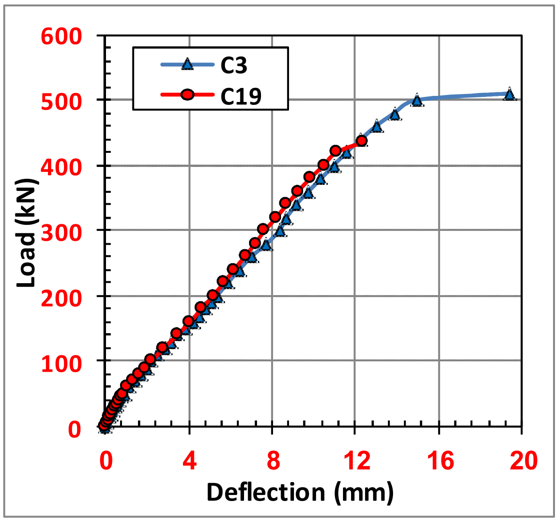



Fig. 11 (a) Load - Deflection Curves of Specimens C3 and C19


Fig.11 (b) Failure Mode of Specimen C19

It can be seen that due to the presence of the construction joint, specimen C19 had lesser shear capacity by approximately about 15%, lesser flexural cracking load by 67% and lesser deflection at service load by 15% when compared with the reference specimen C3 without construction joint, as shown in Fig.11 (a). In addition, it can be seen the identical formation of first shear crack at 220kN for both specimens (C3, C19).

**»SPECIMEN C21. SF.-h.J. (0.37, 20, 30)**

This specimen was cast at two stages. Firstly, the column was cast with NSC. After 28 days, subsequent SFRC layers were cast at the projected part of corbel (i.e. formation of vertical construction joint). This case is important in the maintenance of concrete structures. Flexural crack observed at 90 kN at the location of construction joint. The first visible shear crack appeared at the point of loading at 220 kN. The flexural and shear cracks represented 26% and 64% respectively from the ultimate load. Failure of flexural tension took place at 343 kN as shown in Fig. 12(b). It can be observed that the specimen C21 hada decreasein shear capacity by 17%, lesser shear and flexural cracking load by 15%, 40% respectively and lesser deflection at service load by 21%; see Fig.12(a), when compared with the reference specimen C12 which cast monolithically.

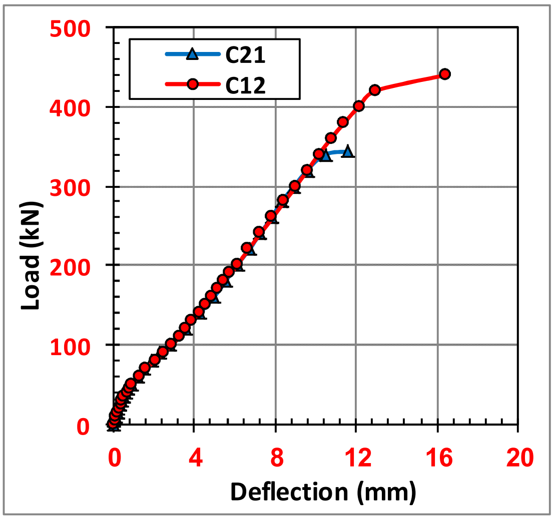



**Fig.12 (a) Load - Deflection Curves of Specimens C12and C21**


**Fig.12 (b) Failure Mode of Specimen C21**

## 4. Summary of theResults

During the experimental program, load versus deflection, connection rotation, cracking and ultimate loads,deflection at service and ultimate loads, cracking patterns, and modes of failure, were recorded for each specimen. Load-deflection and moment-rotation curves of connection specimens were plotted and compared with each other within the test groups (A, B) as shown in Figs. 13 to 16.

For connections of hybrid concrete cast monolithically, the ultimate deflection and connection rotation increased with ranges between (22%-67%) and (15%-35%) respectively compared with homogenous connection of NSC.However, more increase values was in hybrid connections employing SFRC. Besides, presence of the vertical construction joint in homogenous or hybrid concrete corbels decreased the ultimate deflection with a range (0-36%) and connection rotation with a range(7%-28%) with respect to the typical corbels cast monolithically. This is due to the reduction in ultimate load or moment capacities of these specimens in the presence of construction joint.

It can be found that in hybrid connections having HSC or SFRC corbels cast monolithically, the ultimate strength increased by (26%, 38%), shear cracking load increased by (20%, 120%) for HSC and SFRC respectively. Furthermore, connections of hybrid corbel having two types of concrete (NSC plus HSC or SFRC) cast monolithically improved the ultimate strength of corbels by (17%, 19%) respectively compared with control connection of homogenous NSC. The presence of construction joint in connections cast from homogenous or hybrid concrete produced reduction in ultimate strength by (10% -22%) and flexural cracking loads by (23%-62%) compared with typical connections cast monolithically.

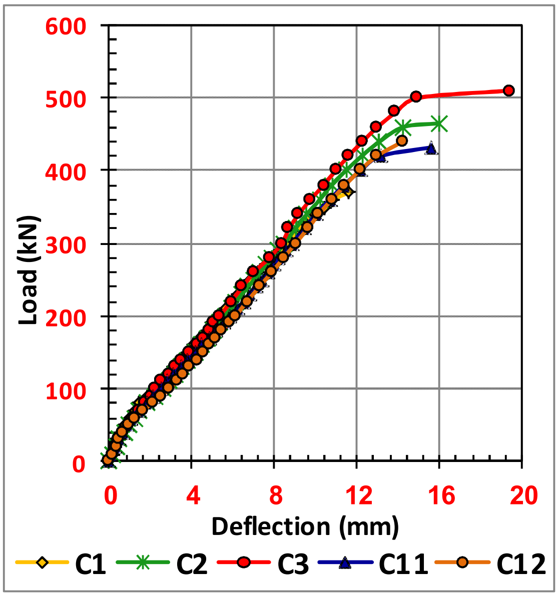



**Fig. 13 Load-Deflection Response of Group (A)**

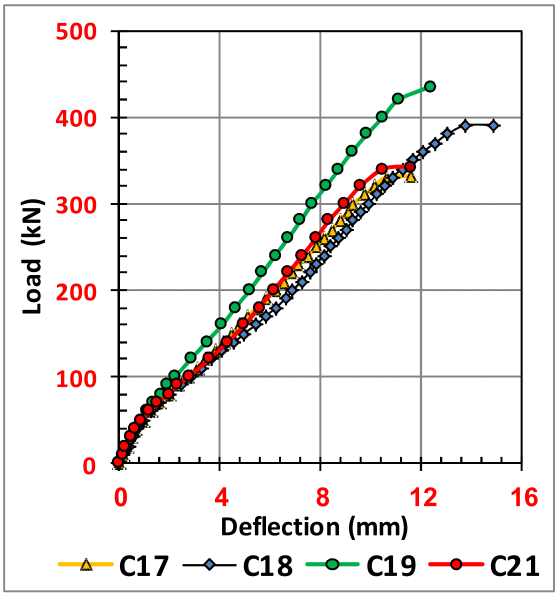



**Fig. 14 Load-Deflection Response of Group (B)**

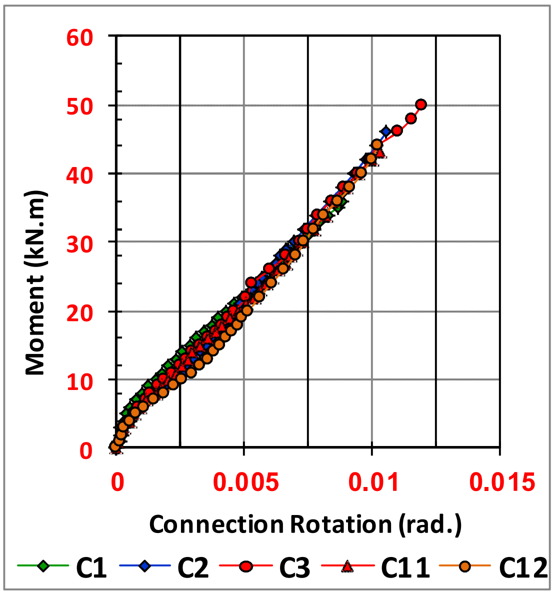



**Fig. 15Moment-Rotation Response of Group (A)**

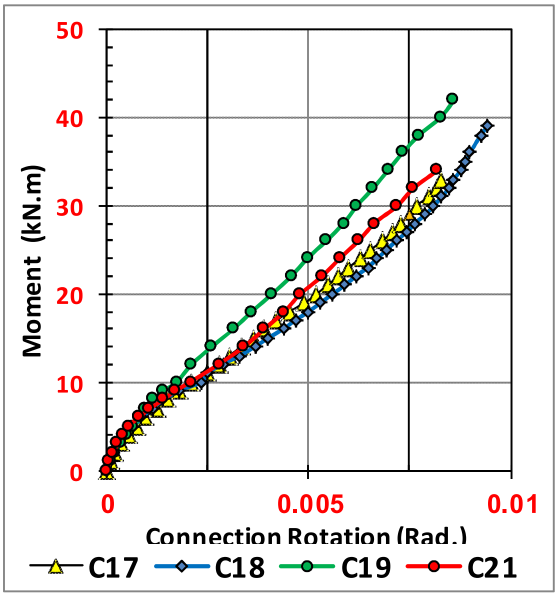



**Fig. 16 Moment-Rotation Response of Group (B)**

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

i- Diagonal tension (splitting) failure mode, in which diagonal cracks that formed initially at the point of loading and/or loading area near inner edge of the bearing plate which propagated towards the critical section.
ii- Flexural compression failure occurred 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 occurred in the flexural reinforcement caused concrete crushing at the sloping end of the corbel; the flexural cracks became extremely wide.

It can be seen that the presence of construction joint change the failure mode of monolithic hybrid corbels from flexural compression to flexural tension mode and homogenous corbelsfrom diagonal splitting to the flexural compression failure.

## 5.Conclusions

1. In hybrid connections of corbel-column having HSC or SFRC corbels cast monolithically, the ultimate strength increasedby (26%, 38%), shear cracking load increased by (20%, 120%) for HSC and SFRC corbels respectively.
2. Connections of hybrid corbel having two types of concrete (NSC plus HSC or SFRC) cast monolithically improved the ultimate strength of corbels by (17%,19%) respectively compared with control connection of homogenous NSC only.
3. The presence of construction joint at the interface of corbel-column connection produced reduction in ultimate strength of homogenous or hybrid concrete connections by (10%-22%) and cracking loads by (23%-62%) compared with typical connections cast monolithically.
4. It can be seen that the presence of construction joint change the failure mode of monolithic hybrid corbels from flexural compression to flexural tension mode and homogenous corbels from diagonal splitting to the flexural compression failure.
5. For connection of hybrid concrete cast monolithically,the ultimate deflection and connection rotation increased with ranges between (22%-67%) and (15%-35%) respectively compared with homogenous connection of NSC.
6. The presenceof vertical construction joint in connections of homogenous or hybrid concrete corbels decreased the ultimate deflection of corbel by (0-36%) and connection rotation by (7%-28%) with respect to the typical corbels cast monolithically.

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