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The Assessment of Using CFRP to Enhance the Behavior of High Strength Reinforced Concrete Corbels

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ABSTRACT

In this research, an experimental study is conducted to investigate the behavior and strength of high strength reinforced concrete corbels externally bonded with CFRP fabric sheets and Plates with different patterns taking into account the effect of adopted variables in enhancing the ultimate strength; the effect of shear span to effective depth (a/d), configuration, type and amount of bonding. Eleven high strength reinforced corbels were cast and tested under vertical loads. Test results showed there was an improvement in the behavior and load carrying capacity of all strengthened corbels. An increasing in the ultimate strength of strengthened corbel by inclined CFRP strips reached to (92.1%) while the increasing reached to (84.21%) for using one horizontal CFRP Plates compared to un-strengthened reference specimen. Also, it can be conducted that the increase of (a/d) ratio from (0.6 to 0.8) resulted in decreasing by 21.05% in ultimate load capacity of corbels and from (0.4 to 0.6) by 31.25% and 58.69% in cracking and ultimate loads respectively.

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تقييم استخدام الياف الكاربون البوليمربة لتحسين تصرف الكتائف الخرسانية المسلحة عالية المقاومة

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الخلاصه

يتضمن البحث اجراء دراسة عملية عن تصرف ومقاومة الكتائف الخرسانية المسلحة عالية المقاومة المقواة بشرائط و صفائح الياف الكاربون بمختلف انماط التقوية مع اخذ بنظر الاعتبارتاثير المتغيرات التالية في السلوك والمقاومة القصوى للكتائف; تأثير نسبة فضاء القص الى العمق الفعال (a/d), اتجاه ,نوع وعدد شرائط او صفائح الياف الكاربون البولميرية المستخدمة . تم فحص احد عشر نموذج من الكتائف الخرسانية تحت تاثير الاحمال العمودية فقط.أظهرت النتائج تحسن سلوك وسعة تحمل للكتائف المقواة وان زيادة المقاومة القصوى قد بلغت 92.1% للكتائف المقواة بشرائط الياف الكاربون باتجاه الربط المائل بينما بلغت الزيادة 84.21% للكتائف المقواة باستخدام صفائح الياف الكاربون بالأتجاه الأفقي بالمقارنة مع نموذج الكتف غير المقوى. لوحظ ان زيادة نسبة فضاء القص الى العمق الفعال a/d من (0,6 الى 0,8) سببت نقصان بمقدار 21,05% في مقاومة التحمل القصوى للكتائف بينما زيادة نسبة فضاء القص الى العمق الفعال من 0,4 الى 0,6 سببت نقصان بمقدار31,25% و58,69 % في حمل التشقق والحمل الاقصى .

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1. INTRODUCTION

Corbels are structural members which are commonly used in reinforced concrete structures and particularly in precast structures [1]. They are short cantilevers with shear span to effective depth ratio lower than one, generally built monolithically with columns or walls [2].

Corbels are mainly designed to resist the vertical loads applied by supporting members, but unless precautions are taken to avoid horizontal forces caused by creep, shrinkage or temperature change of the member supported by corbel [3].

The use of high strength concrete(HSC) has increased widely during the recent years in bridges, high buildings and other structures due to its benefits of higher strength and relatively lighter weight by reducing the size and weight of member (cross sectional area) [4].

ACI Committee 363, defined HSC in 2011 is a concrete having cylinder compressive strength for the design (55MPa) or more [5].

Structural strengthening is required for many reasons such as deteriorations arising from environmental exposure, upgrading the structure to resist higher load, inadequate design, poor quality construction and deterioration that has taken place over the years of use [6].

Fiber Reinforced Polymer (FRP) is a composite material consisting of discourteous fibers embedded in a polymeric matrix to form many types of products such as bars, structural sections, plates and sheets [7]. Using FRP strips or plates improves the ultimate load carrying capacity; retard crack formation and energy absorption capability. Externally bonded FPR reinforcement for structural strengthening has many advantages such as lower in specific weight, very low coefficient of thermal expansion, easy to handle and to apply[8][9][10]. CFRP carbon fiber reinforced polymer has been used excessively as strengthening in practical field and researches to improve flexural and shear capacity of RC members [11].

Zeller et al.,(1991) tested two double corbels with different a/d ratios (0.5 and 1). The amount of horizontal reinforcement or the using vertical stirrups are variables. When using high horizontal ratio ,the corbel exhibited higher load failure and ratio a/d =1.0 showed decrease in load failure and diagonal splitting that occurred suddenly [12] .

Attiya and Atif et al.,(2012) carried out tests on seventeen high strength concrete corbels . Volume fraction of steel fiber, (a/d) ratio ,compressive strength of concrete , the tension reinforced bars (Asm) and presence of horizontal stirrups are the parameters .It found that higher horizontal stirrups and concrete strength resulted in higher ultimate load while increase shear span-to-depth ratio resulted in decreasing ultimate load [13] .

Mohsen et al.,(2015) sixteen reinforced concrete corbels. Eleven of them strengthened with CFRP strips, and three were repaired to study the effect of CFRP as strengthening or repairing material for reinforced concrete corbels. The variables considered the strengthening scheme (location, orientation, and amount of strips. The test results show increase in ultimate and cracking loads for strengthened and repaired specimens with CFRP strips [14].

The investigation of Yassin ,L. et al.,(2017) tested 20 normal reinforced concrete corbels. Six of them under monotonic and fourteen under non-reversed repeated loads to study strengthening with CFRP strips. The parameters were the direction and width of CFRP strips and the load level of ultimate load of reference corbel. The results obtained that strengthening increasing the cracking and failure loads in addition to the ultimate deflection for the monotonically and the non-reversed repeated loaded [15].

2. EXPERIMENTAL PROGRAM

The experimental program included testing of eleven high strength reinforced concrete corbels subjected to vertical loads only .The work is divided into two parts; the first part consists of three un-strengthened specimens tested with varied a/d ratio (0.6,0.4, 0.8) ,while the second part includes strengthening of corbels with CFRP fabric sheets and plates . The main considered variables are the effect of strengthening pattern (direction , amount and type of bonding) for the same strengthening materials and the effect of shear span to effective depth ratio (a/d) on the behavior HSC reinforced corbels. Corbels geometry and the amount of steel reinforcement are maintained constant.

2.1. *Corbel Details*

All the tested specimens consist of double-corbels and a short column. The corbel dimensions, column dimensions, main and secondary reinforcements are kept constant throughout for all specimens . The dimensions and reinforcement details of the test specimen are shown inFig.1.

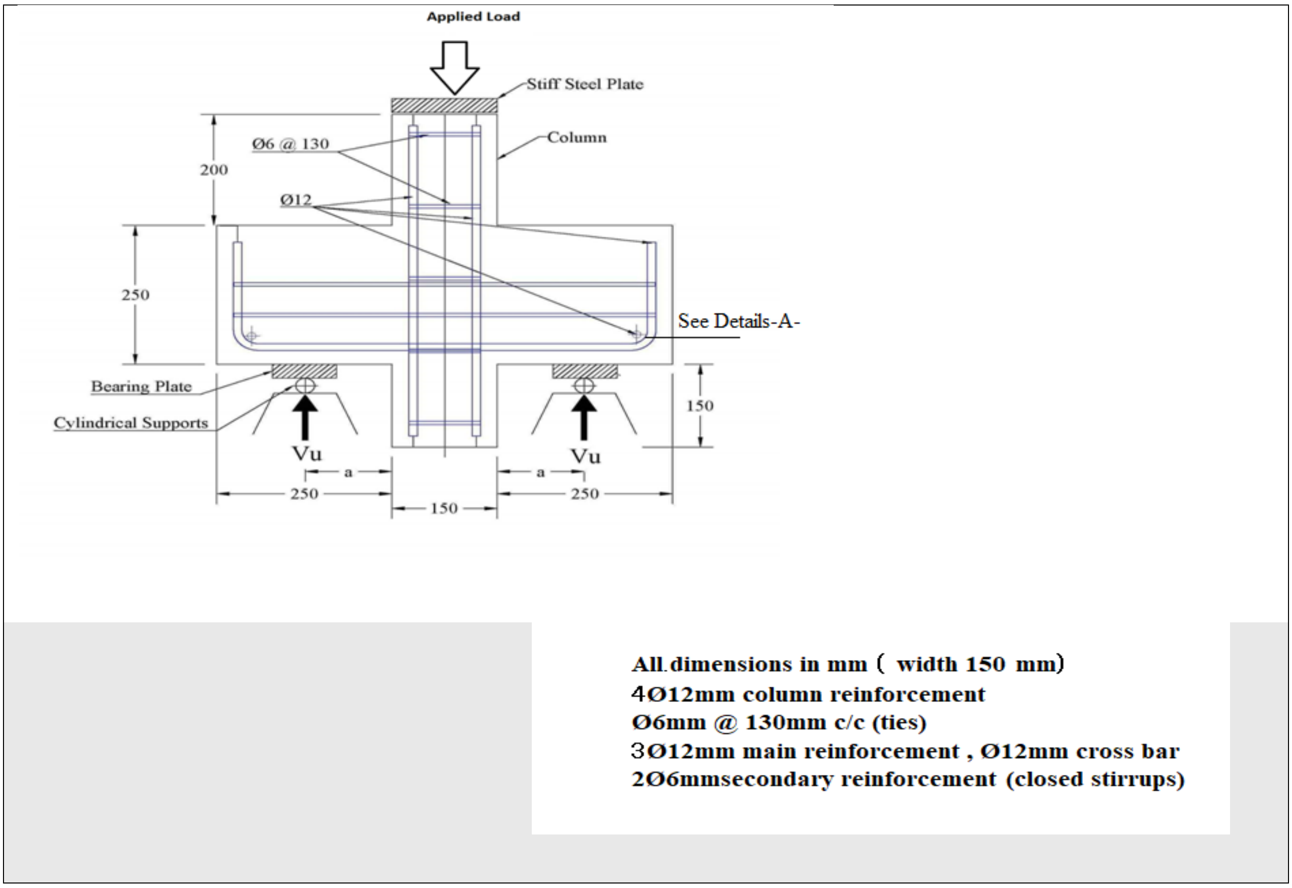


Fig.1. Dimensions and reinforcement details of the tested corbel.

According to ACI-code 318-14, the column dimensions are (150 x200) mm cross section and 600mm long while corbels have the length of 250 mm and (150x250)mm in cross section. Column is reinforced with four deformed 12 mm diameter bars, at the corners and supported with 6 mm diameter closed ties spaced at 130 mm center to center. Three 12 mm diameter deformed steel bars with cover 25mm placed at the tension side as main reinforcement of corbels and they are welded with cross bar of diameter 12mm close to the each end of corbel to provide additional anchorage. The secondary reinforcement are two closed horizontal stirrups of diameter 6mm deformed bars that distributed with 2/3 of the effective depth .

2.2. Materials Properties

Tests results of properties of used materials (cement, sand, gravel) satisfied the requirements of Iraqi Standard Specification (I.Q.S)[16] and the American Society for Testing and Materials (ASTM) [17].

-**Cement**: ordinary Portland cement (Type I) is used throughout this study.

-**Sand**: natural sand brought from Al-Ukhaidur region is used in production of the required concrete mix design. The maximum size of fine aggregate (4.75mm) with rounded partial shape with fineness modulus of (2.36) .

-**Gravel**: crushed gravel from Al-Niba'ee region with a maximum size of 12mm is used.

-**Water**: tap clean water is used for both mixing and curing of concrete corbels.

-**Superplasticizer**: to produce high strength concrete by reduce water content and adding the superplasticizer to satisfied workability, the used superplasticizer is commercially known as "ViscoCrete -5930" supplied by Sika company is used complies with (ASTM C494-05,2005) Types G and F [18].

-**Silica fume**: the micro silica fume used in the present study is commercially named (Mega Add MS(D). It is used as partial replacement of cement [19], stratify to requirements of ASTM C1240-04 [20].

-**Steel Reinforcement**: four sizes of deformed steel bars were used in this investigation, The yielding stress for the bars 12 and 6 mm were 540and 476 MPa respectively, stratify to requirements of ASTM A615M-05a [21].

Strengthening and bonding materials consisted of:

a- A woven black unidirectional Carbon Fibers Reinforced Polymers CFRP fabric sheets, named Sika Wrap®-300 C, has thickness of 0.167 mm ,tensile strength of 4000 MPa and modulus of elasticity 230,000 MPa ,as supplied by manufacture.

b- A unidirectional pultruded corrosion resistant Carbon Fiber Reinforced Polymers CFRP plates, named Sika CarboDur S512, has thickness of 1.2 mm, modulus of elasticity of 165,000 MPa and tensile strength of more than 2800 MPa and ,as given by manufacture.

c- Two compatible epoxy resins, Sikadur®-330 and Sikadur-30LP manufactured by Sika Company.

2.3 Mix Design

According to ASTM method in (Nevile,2000) [22] [23], three trial mixes were made to obtain high strength concrete mix design of cement content of 500 kg/m3 and water/cement (w/c) of 0.25 with a slump of 100 mm. A proportion by weight (1:1.5:1.92) with superplasticizer ratio 2.5% of cement content and silica fume content of 10% of cement weight was found to obtain a compressive strength of 72.59 MPa.

2.4 Preparing of the Specimens

Casting and curing were carried out in the Structural Laboratory of University of Technology, Iraq. The concrete mixer was cleaned and moistened before use, all quantities were weighed and added in the following order, gravel and sand were first mixed in with required water, then silica fume and cement were added and mixed, finally superplasticizer with the mixing water were added and remixed for three minutes.

After 28 days of curing all specimens were left to dry and then the strengthening materials were applied.

2.5 Strengthening System

Three of the tested specimens are strengthened with fully horizontal CFRP strips wrapped around the faces of corbel (**C1H1W** ,**C1H2W** ,**C1H3W**), **C1H1W** specimen is strengthened with a (50mm) width horizontal strip, C1H2W with two and C1H3W with three horizontal strips (50mm) width with clear spacing (50mm) around faces as shown in Fig.2, while three specimens are strengthened with CFRP strips for inclined direction on each side face extended as ∩ shape (**C1I1W**, **C1I2W**, **C1I3W**), specimen **C1I1W** is strengthened with one inclined (50mm) width strip while **C1I2W** with two and **C1I3W** with three inclined strips (50 mm) on each side face extended as ∩ shape. Diagonal spacing of (50 mm) width between strips as shown in Fig. 2.

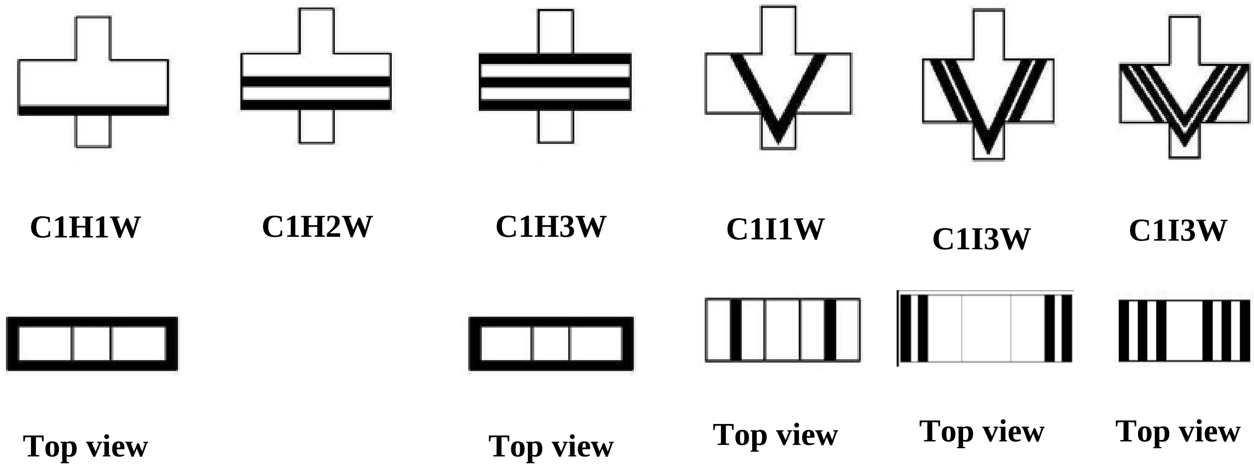


Fig. 2**.** Detail of strengthened corbels.

Two specimens are strengthened with CFRP plates, **C1H1P** with horizontal CFRP (50mm) width plate on two opposite faces of corbel only, **C1I1P** is strengthened with (50mm) width diagonal mirrored of angle 45^o CFRP plate on two opposite faces of corbel only, while specimens as shown in Fig.3**.** (**CON1**, **CON2**, **CON3**) were kept without strengthening to study the effect of shear span to effective depth ratio (a/d), **CON1** was considered as control corbel for comparison .

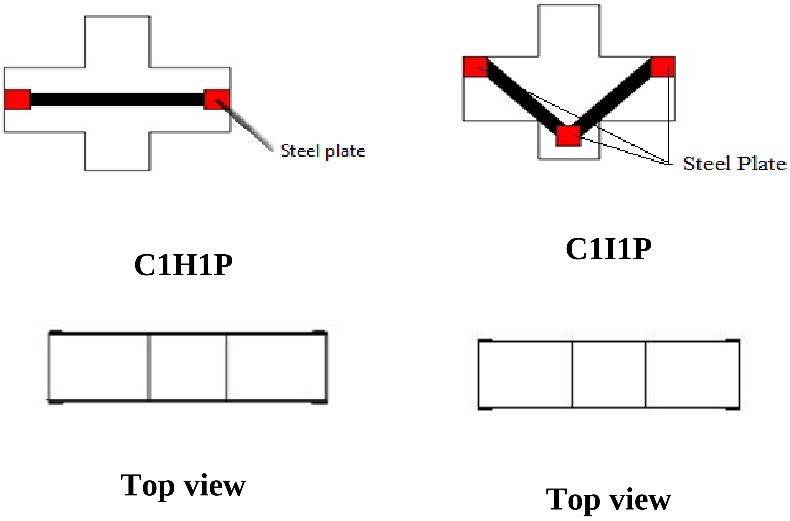


Fig.3. Detail of strengthened corbels.

3. TESTING PROCEDURE

All beams have been tested in an inverted position using an "AVERY" testing machine with maximum load capacity of 250 tons. The system of loading includes hydraulic jack that load applied on top column and divided into two equal vertical load at location of supports applied to corbels . Before testing, dial gauge of accuracy (0.01mm) placed at center of the bottom column to record the vertical mid-span displacement (deflection) during each load step. The load was increased using constant rate of 20 kN up to failure.

4. RESULTS AND DISCUSSION

4.1 General Behavior

Test results of corbel specimens included the cracking load, the ultimate load, load versus deflection, the cracking patterns and modes of failures, which presented using pictures, graphics and tables. In general, at early stages of loading, corbels are free from any cracks and the full cross section was active in carrying the applied load. The first crack was a diagonal crack (shear crack) initiated at region of the supports and propagated towards the upper column-corbel interface. With the increasing of load, multiple shear (diagonal) cracks parallel to the first diagonal crack were run between the area near the edge of the bearing plate and the junction of the column and face of the corbel; the existing inclined (shear) and vertical cracks propagated slowly and were accompanied by formation of new cracks parallel to initial cracks. These cracks grew upward and started be to widen and caused de-bonding of CFRP strips and laminates in specimens externally strengthened CFRP strips and laminates.

Table .1. shows the cracking loads, ultimate loads, the cracking and ultimate deflection and modes of failure of the tested corbels.

Plate(1-4) Show crack pattern of specimens (**C1H2W, C1H2W, C1H3W, C1I1W, C1I2W, C1I3W, C1H1P, C1I1P**) .

Table(1)
Results of tested corbels specimens.

Specimen	a/d	P_{cr} (kN)	Δcr(mm)	Pu (kN)	Δu(mm)	Mode of Failure
CON1	0.6	220	1.73	380	2.9	Diagonal splitting
CON2	0.4	320	1.7	920	3.93	Diagonal splitting
CON3	0.8	220	3.24	300	4.63	Diagonal splitting
C1H1W	0.6	260	1.7	580	3.1	Diagonal splitting +CFRP de-bonding
C1H2W	0.6	280	1.42	630	2.7	Diagonal splitting +CFRP de-bonding
C1H3W	0.6	340	1.45	700	3.2	Diagonal splitting +CFRP de-bonding
C1I1W	0.6	280	1.29	710	3.70	Diagonal splitting +CFRP de-bonding
C1I2W	0.6	320	2.57	720	4.7	Diagonal splitting +CFRP de-bonding
C1I3W	0.6	480	3.33	730	4.37	Diagonal splitting +CFRP de-bonding
C1H1P	0.6	280	2.69	700	3.37	Diagonal splitting +CFRP de-bonding
C1I1P	0.6	340	2.8	480	3.58	Diagonal splitting +CFRP de-bonding

Plate(1) Crack pattern of control corbels (**CON1,CON2,CON3**)

Plate(2) Crack pattern of strengthened corbels (**C1H1W,C1H2W,C1H3W**)

Plate(3) Crack pattern of strengthened corbels (**C1I1W,C1I2W,C1I3W**)

Plate(4) Crack pattern of strengthened corbels (**C1H1P, C1I1P**)

4.2 Test Results of Un-Strengthened Corbels Specimens

Three reference corbel specimens with different (a/d) ratio (0.4, 0.6 and 0.8) were tested. The increase in (a/d) ratio from (0.6) to (0.8) resulted in decrease in ultimate load capacity only of 21.05% while decreasing a/d ratio from (0.6) to (0.4) resulted in an increase in cracking and ultimate load capacity of 45.45% and 142.11% respectively with decrease in values of deflection because failure cracks are delayed at the same rate of loading as shown in **Fig.4.**

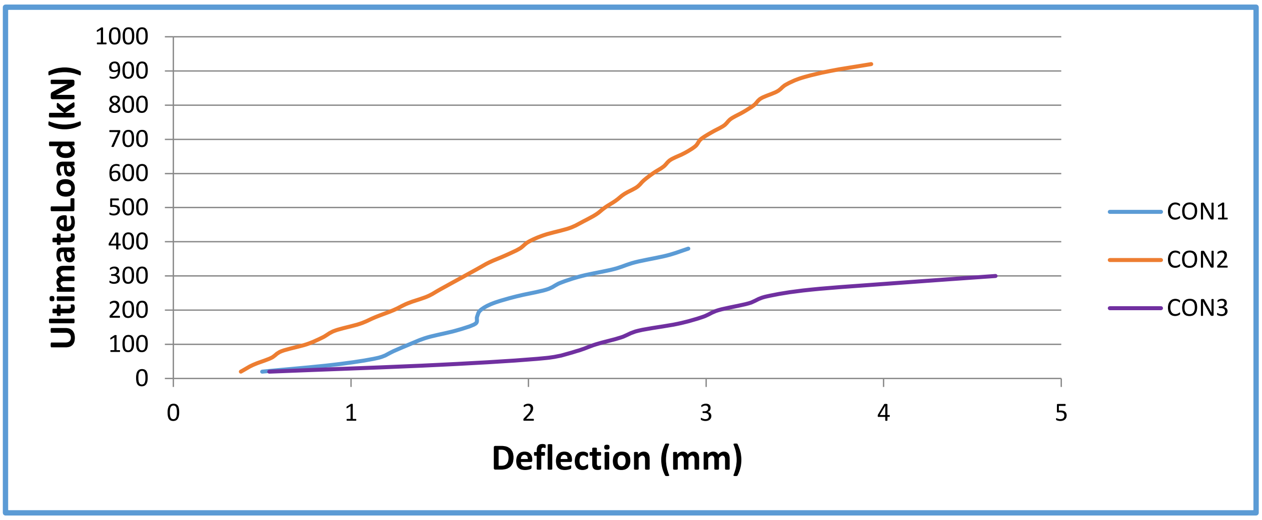


Fig.4. Load-Deflection curve of (**CON1**, **CON2**, **CON3**).

4.3 Effect of Strengthening Using CFRP Fabric Sheets

In order to investigate the effect of using externally bounded CFRP fabric sheets technique and the effect of CFRP strips pattern on the behavior and strength of corbel, three corbel specimens were strengthened, (**C1H1W, C1H2W, C1H3W**) that bonded with horizontal CFRP strips full wrapped showed an increase in ultimate load of 52.63%,65.79% and 84.21% respectively and an increase in cracking load of 18.18%, 27.72%, 54.54% respectively compared to un-strengthened corbel **CON1**. While (**C1I1W, C1I2W, C1I3W**) which bonded with inclined CFRP strips wrapped show an improvement in ultimate load of 86.84%, 89.47% and 92.1% respectively and in cracking load 27.27%, 45.45%, 118.18% respectively compared to un-strengthened specimen **CON1**. The load carrying capacity of corbel is increased with the increase of the amount of CFRP strips, also strengthening with CFRP strips for inclined direction is a more effective in strengthening especially for specimen **C1I3W** where three CFRP strips are used with an angle 45° perpendicular to diagonal cracks and there was a decrease in the values of deflection at the same load level compared with control specimen **CON1** as well as other bonded corbels with CFRP fabric sheets.

It was found that an increase in the amount of CFRP strips leads to an increase in ultimate load carrying capacity of horizontally strengthened corbels while increasing the inclined strips (from one to two strips) resulted in 1.38% increased in ultimate load and from two to three strips have no noticeable increase that by 1.38% in ultimate load. Fig.(5-10). Show the load deflection curve for each case compared with the reference specimen (**CON1**).

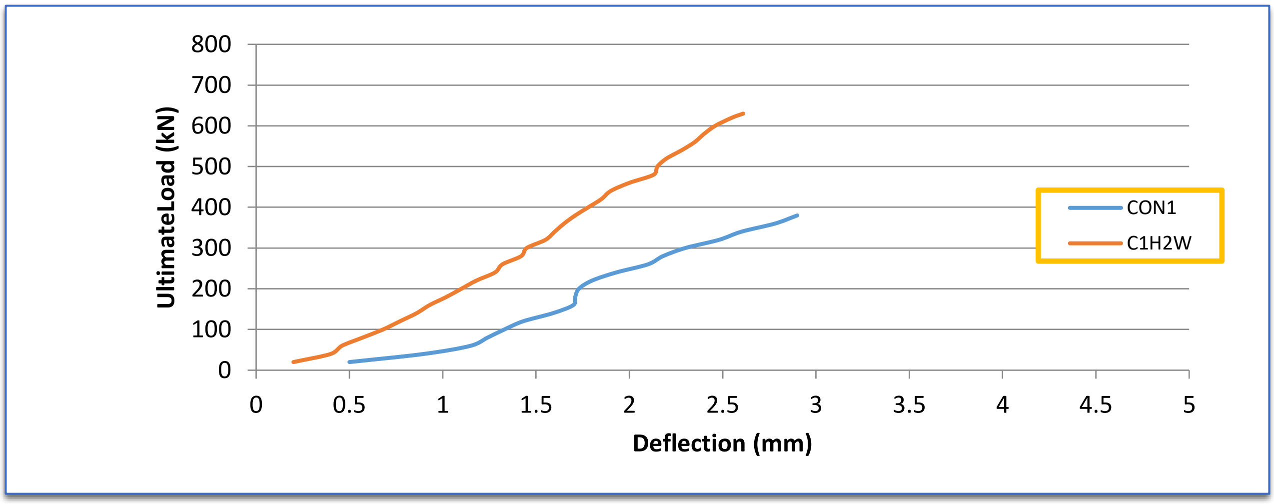


Fig.5. Load -Deflection curve of strengthened corbel (**C1H1W**) and control corbel(**CON1**).

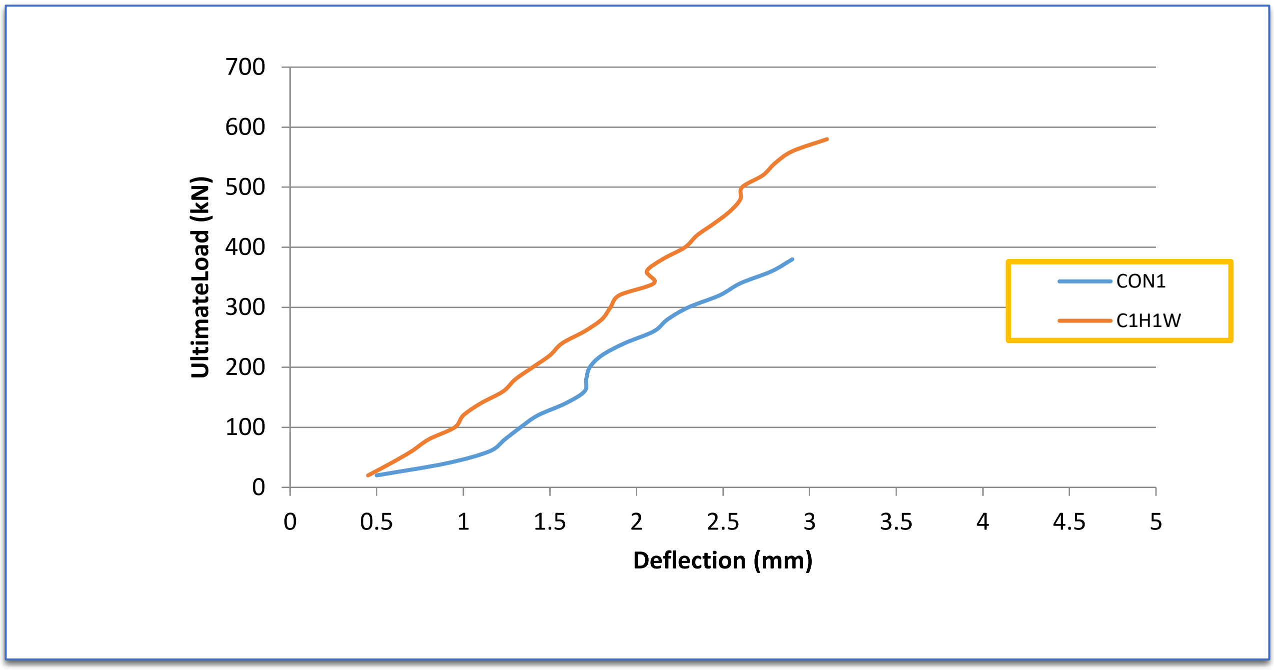


Fig.6. Load -Deflection curve of strengthened corbel (**C1H2W**) and control corbel(**CON1**).

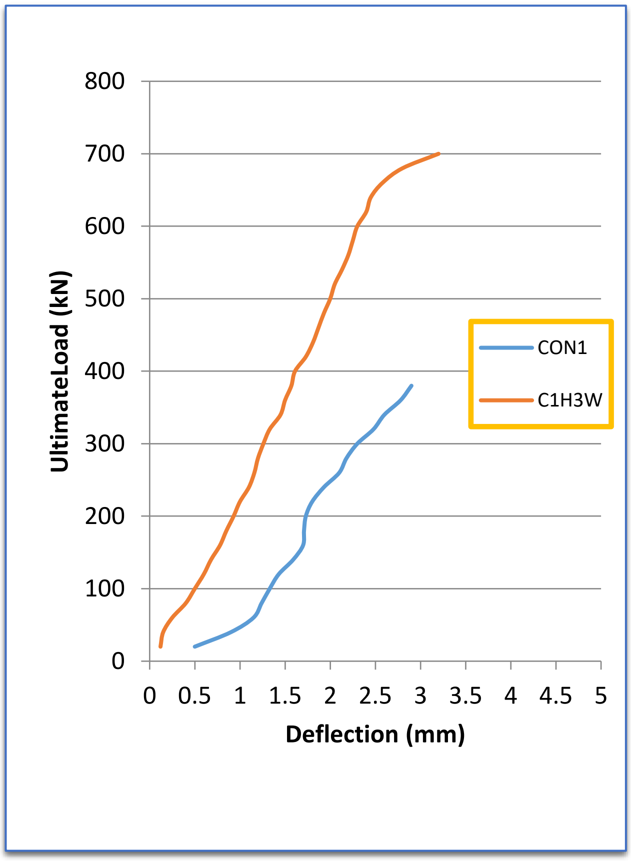


Fig.7. Load -Deflection curve of strengthened corbel(**C1H3W**)and control corbel(**CON1**)

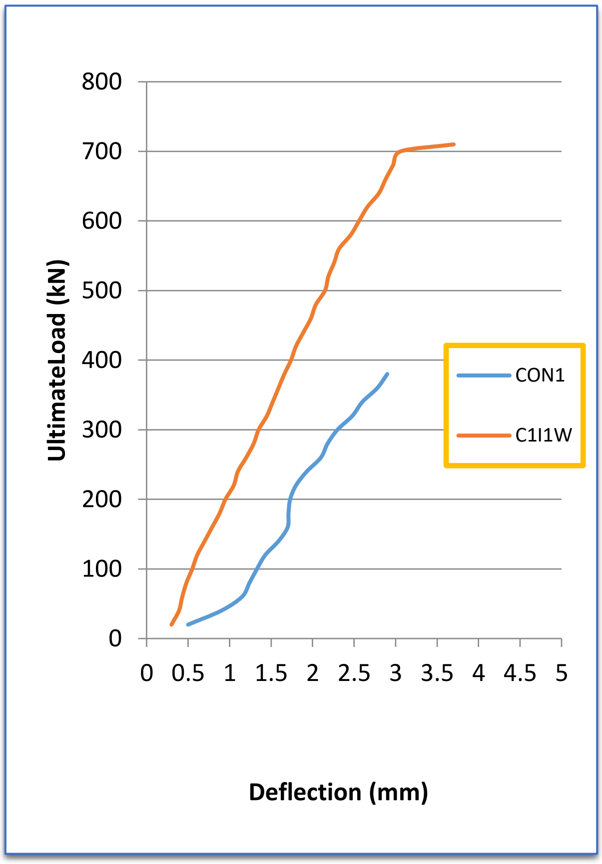


Fig.8. Load -Deflection curve of strengthened corbel (**C1I1W**) and control corbel(**CON1**)

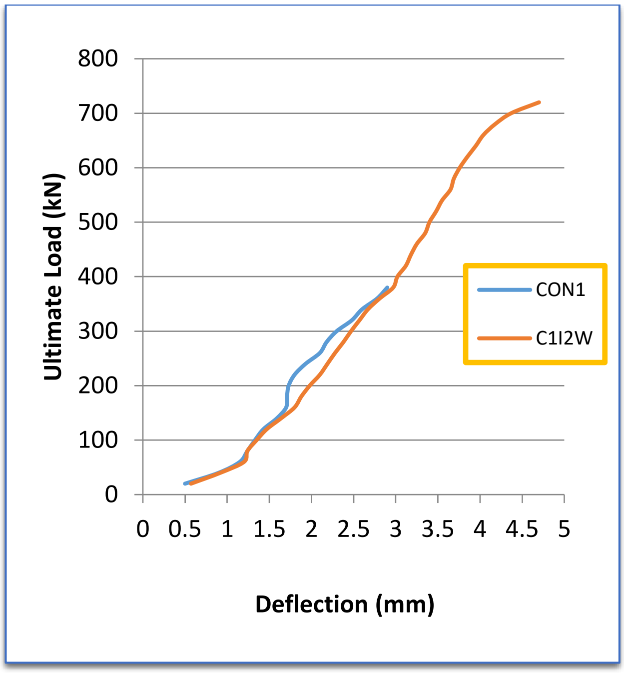


Fig.9. Load -Deflection curve of strengthened corbel (**C1I2W**) and control corbel(**CON1**)

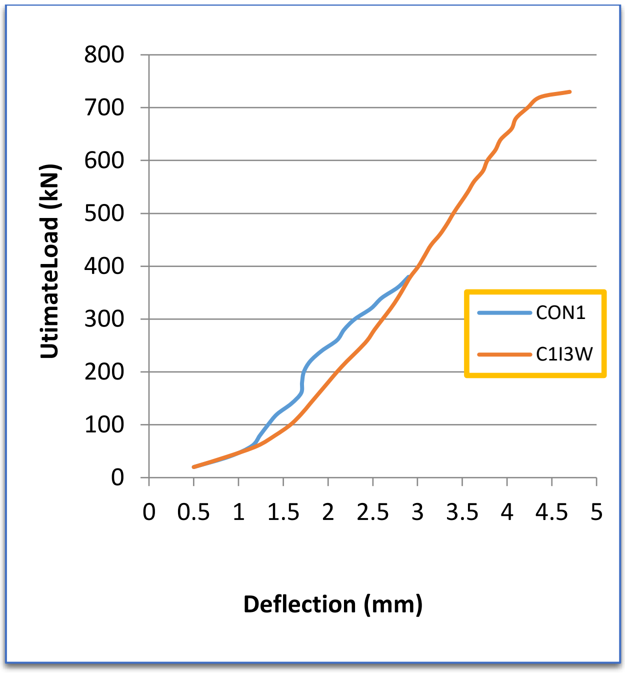
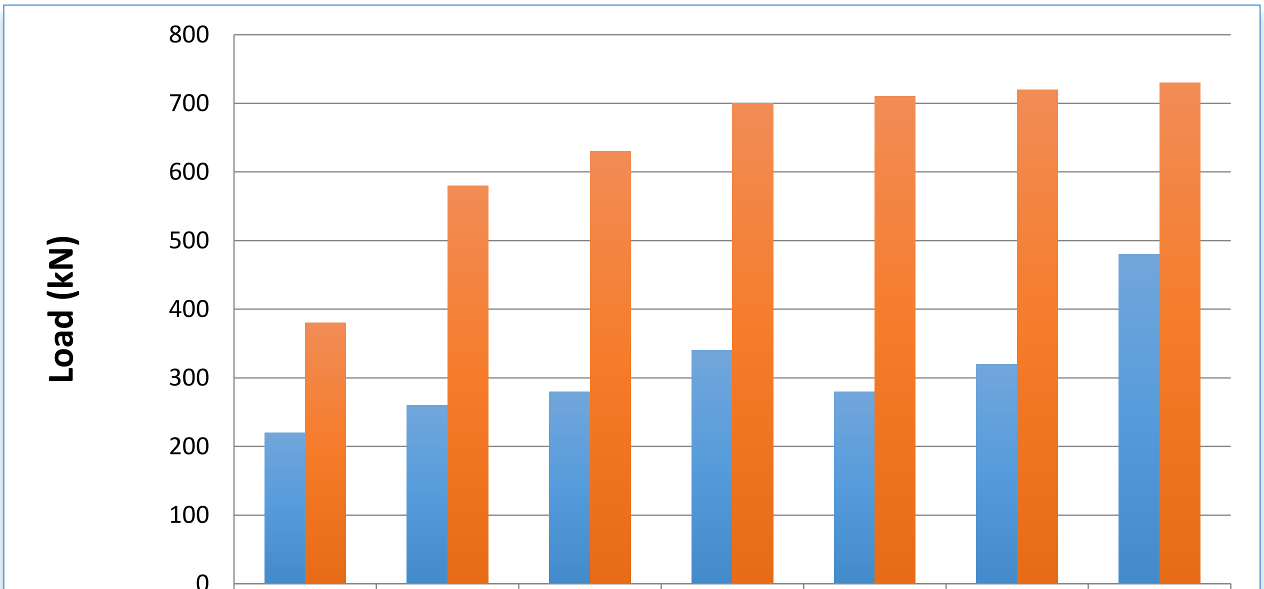


Fig.10. Load -Deflection curve of strengthened corbel (**C1I3W**) and control corbel(**CON1**)



	con1	C1H1W	C1H2W	C1H3W	C1I1W	C1I2W	C1I3W
Cracking load	220	260	280	340	280	320	480
Ultimate load	380	580	630	700	710	720	730

Fig. 11. Cracking and ultimate loads for strengthened specimens and control specimen (**CON1**)

4.4 Effect of Strengthening Using CFRP Plates

The effect of using CFRP Plates on the behavior and strength of corbel with different directions and locations , using external anchorage steel plates (50 x70) mm fixed over the two ends of CFRP laminate is studied. These anchorage plates were applied in order to resist the propagation of CFRP de-bonding from the surface of concrete specimen. The results indicated an increase in ultimate load of 84.21% and 26.31% while the increase in cracking was 27.27% and 54.54% for strengthening by horizontal and inclined orientation respectively compared to reference specimen **CON1**. It was concluded that **C1HIP** strengthening by horizontal direction gave better improvment in strength than strengthening by inclined direction for specimen **C1I1P** due to debonding of carbon fiber reinforced polymers (CFRP) at the ends of the CFRP Plates. Fig.12**.** and Fig.13 show the load -deflection curve for **C1HIP** and **C1I1P** specimens compared with the reference specimen (**CON1**). For these specimen debonding of (CFRP) at the ends of the CFRP reinforcement play an important role in failure of specimen C1I1P due to more ends near flexure and shear cracks and area of highest stresses in this strengthening configuration.

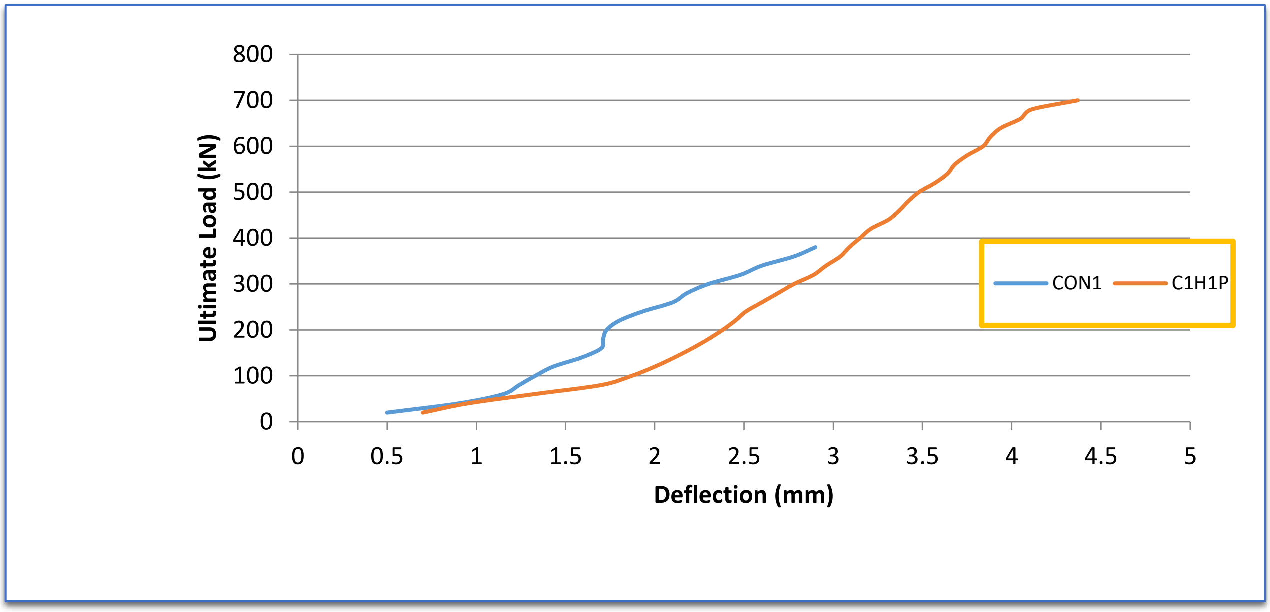


Fig.12. Load-Deflection Curve of strengthened corbel (**C1H1P**) and control corbel(**CON1**).

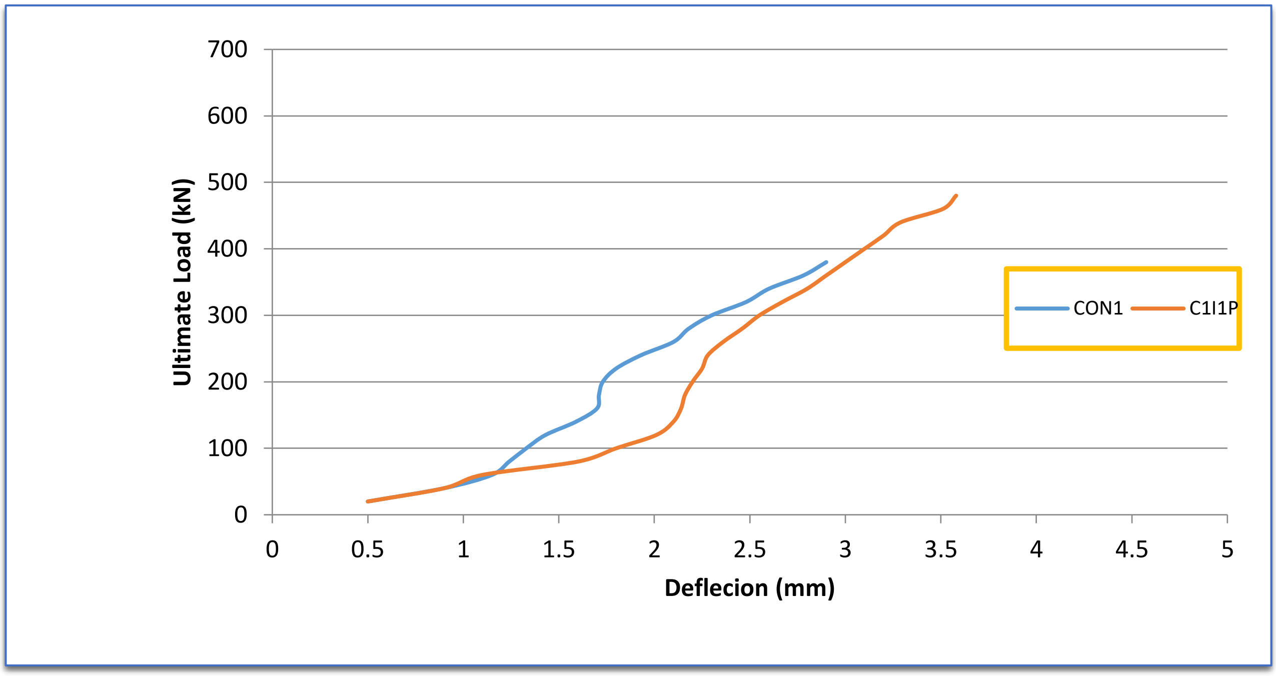


Fig.13. Load-Deflection Curve of strengthened corbel (**C1I1P**) and control corbel(**CON1**).

5. CONCLUSIONS

1–It was found that the decrease in the shear span to effective depth ratio (a/d) from 0.6 to 0.4 increases the cracking load by 45% and increases the ultimate load by 142.1% while by increasing the (a/d) ratio from 0.6 to 0.8, there was no variation in the cracking load and decrease in the ultimate load by about 21% is occurred**.**

2- Tests results of strengthening HSC corbels with CFRP strips showed an improvement in the resistance for cracking of these corbels, the increase in the cracking load reached to 54.54 % for horizontal full wrapped configuration and 118.18% for inclined configuration

3-An increase in corbel cracking load and ultimate load was observed with an increase the amount of CFRP strips in horizontal and diagonal orientation

4-The location, direction, and amount of CFRP strips play an important role in enhancing the stiffness, cracking and ultimate loads; therefore the diagonal wrapped as ∩ shape configuration strengthening technique was found to give better results (additional increasing of cracking load and ultimate load) as compared to specimens that were un-strengthened or strengthened with horizontal full wrapped as a box shape**.**

5-Externally bonded with CFRP plates generally showed a significant increase in ultimate loads which reached to 84.1 % for corbels strengthened with CFRP plates as horizontal layers on two faces of corbel only while the increase in ultimate loads of 26.31% for strengthened for inclined orientation compared to reference specimen **CON1.**

6-Strengthening with CFRP plates showed higher load bearing capacity and higher deflection up to failure compared with the same amount of CFRP fabric sheets used in strengthening corbels.

REFERENCES

[1]Campione, G., Mendola ,L. La. and Papia M. ,"Flexural Behaviour Of Concrete Corbels Containing Steel Fibers Or Wrapped With FRP Sheets", *Materials and Structures*, 2005, 617-625.

[2] Kriz, L.B. and Raths, C.H. , "Connections in Precast Concrete Structures-Strength of Corbels", *PCI journal*, 1965, 10 (1) , 16-61.

[3] Yousif , A. R., " Prediction Of Ultimate Load Capacity Of High-Strength Reinforced Concrete Corbels ", *Al-Rafidain Engineering*, 2009, 17 (4).

[4] Klaiber, F.W., Wipf, j.j. and Kempers, B.j. ,"Repair of Damaged Prestressed Concrete Bridges Using CFRP", Ames, Iowa State University, 2003.

[5] ACI Committee 363 2R-11, "Guide to Quality Control and Assurance of High-Strength Concrete", 2011, American Concrete Institute.

[6] ACI committee 440. XR, "Report on Fiber-Reinforced Polymer (FRP) Reinforcement for Concrete Structures" ,2006, American Concrete Institute, Michigan USA, 348.

[7] AlShadidi, R. M. , Hassan, H. F. and Mohammed, M.H., "Shear Behavior Of High Strength Concrete Beams Reinforced With GFRP Bars And Strengthened By CFRP Sheets", *journal of Engineering and Development*, 2016, 20 (1).

[8] Abdulrahman MB, Rashid HM., "Repairing of Reactive Powder Concrete T-beams Containing Web Opening by CFRP Strips.", *Tikrit journal of Engineering Sciences*,2019, 26(1), 9-19.

[9] Abdulrahman MB, Mahmood SM., "Strength of Reinforced Reactive Powder Concrete Hollow Beams.", *Tikrit journal of Engineering Sciences*; 2019, 26(2),15-22.

[10] Spadea, G., Bencardino, F., and Swamy, R. N., "Structural Behavior of Composite RC Beams with Externally Bonded CFRP" *journal of composite for Construction*, 1998, 2 (3).

[11] Aziz ,O.Q. and Yaseen ,S.O., "Optimum Position of Shear Reinforcement of High-Strength Reinforced Concrete Beams". *Eng. &Tech. journal*, 2013, 31, (1).

[12] Zeller, W., "Conclusions from Tests on Corbels", IABSE Colloquium, Structural Concrete, International Association for Bridge and Structural Engineering, Stuttgart, 1991,577-582.

[13] Attiya, M.A.," Behavior Of Reinforced Concrete Corbels Strengthened With Carbon Fibre Reinforced Polymer Strips", PhD thesis, University of Basrah, Iraq ,2012.

[14] Kadhim, M.M.M., "Experimental Investigation Of Reinforced Concrete Corbels Strengthened With CFRP Laminates", M.S.C Thesis, University of Babylon, Iraq, 2015.

[15] Yassin ,L.A.G., "Behavior of RC Corbels Strengthened With CFRP under Monotonic and Repeated Loading ", PhD thesis, ,University of Technology, 2017,

[16] Iraqi standard specifications No.5/1984,"Portland Cement", Central Agency for Standardization and Quality Control, Planning Council, Baghdad, IRAQ,(in Arabic)

[17] Iraqi standard specifications No.45/1984, "Aggregate from Natural Sources for Concrete", Central Agency for Standardization and Quality Control, Planning Council, Baghdad, IRAQ, (in Arabic).

[18] ASTM C494/C494M-05a, "Standard Specification for Chemical Admixtures for Concrete", ASTM International, West Conshohocken, 2005, 9.

[19] BS EN 13263-1, "Silica fume for concrete", Part 1 "Definitions, requirements and conformity criteria",2005, Part 2 Conformity evaluation.

[20] ASTM C 1240 – 05 "Standard Specification for Silica Fume Used in Cementations Mixtures",2005, 4,(2).

[21]ASTM A615M-05a, "Standard Specification for Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement", ASTM International, West Conshohocken",2003, 7.

[22] Neville, A. M., “Properties of Concrete” Fourth Edition, Prentice Hall, London,2000.

[23] Abdul-Rahman MB, Ali AA, Younus AM., " Effecting of Steel Fibers and Fly Ash on the Properties of Concrete", *Tikrit Journal of Engineering Sciences*, 2018, 25 (4), 30-36.