Analysis of Reinforced Concrete Brackets Strengthened with Steel Fiber

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Abstract. An experimental investigation into the structural behavior of brackets with plain and fibrous concrete and in the presence of steel bars is addressed in this research. Both brackets have the same shape and dimensions. Testing of nine steel fibrous reinforcement concrete specimens and one reinforced concrete with compressive strength (28.6) MPa under vertical repeated load. The test results in terms of load versus deflection curves, stiffness, ductility and crack patterns show the effectiveness of using steel fibrous concrete to ensure a superior strength and deformation capacity in reinforced concrete bracket. Test results showed that, addition of steel fibers (1.5) % by volume of concrete and horizontal stirrups improve both shear strength and ductility of the tested brackets, and results in a more ductile failure mode.

Keywords: Bracket, Fiber reinforced concrete, plain concrete, Steel Fiber, Repeated load

1. Introduction

Brackets may be described as short cantilevers that project from the inner face of concrete columns or walls to support heavy concentrated loads of cranes and precast beams. The bracket is generally built monolithically with the column or wall. The shear span-to-depth is often less than 1. Two design procedures are generally used for brackets, the shear friction provisions of the ACI Code when ratio a/v equal 1 or less, and the other design uses the strut-and-tie models when ratio a/v less than 2. Both design procedures give essentially the same results within the range of application of the ACI Code. Brackets are designed mainly to provide for the vertical reaction (V_u) at the end of the supported beam, but unless special precautions are taken to avoid horizontal forces caused by restrained shrinkage, creep or temperature change, they must also resist horizontal force (N_u). They are usually designed for direct shear using the shear friction theory [1]. Bracket is one important element of structure to support the pre-cast structural system such as pre-cast beam and pre-stressed beam [2]. Fattuhi, 1990) [3] The effects of column load and unequal loads on double fiber reinforced concrete brackets are tested. A total of eighteen (150 *150 *200) mm concrete brackets with main bars and steel fiber reinforcement were tested. The shear span to depth ratio, and also the number of main bars and fiber material, were all varied. The column section of eight specimens was subjected to a concentric load. In addition, the bracket segments of four of the double bracket specimens were subjected to unequal loads. The findings revealed that neither column loads nor unequal bracket loads have a major impact on bracket power, brackets reinforced with low percentages of main bars and/or measured at high shear span to depth ratios, where an almost elastic-plastic behavior was observed, showed significantly better improvement in ductility. The addition of steel fibers also increases the brackets' strength and ductility. And Gao and Zhang, 2010 [4] claimed that the use of steel fiber reinforced concrete in the prefabrication of brackets reduces the reinforcement ratio of the bracket and increases its strength and stiffness, thus improving its mechanical behavior. Also, Al-Zahawi, 2011 [5] Fifteen fibrous and non-fibrous reinforced concrete brackets with and without stirrups were tested. Both specimens had the same length,
thickness and the amount of main reinforcement, and were subjected to concentrated vertical load. The variables were the shear span to effective depth ratio, the quantity of carbon fibers, and the presence or absence of horizontal secondary reinforcement. And Deifalla & Mansour, 2020 [6] Tested seven full-scale reinforced concrete bracket specimens were tested to study performance of reinforced concrete bracket with and without steel fibers. The test variables were steel fiber content (Vf) % and shear span-to-depth ratio (a/d), with constants of concrete compressive strength (f\text{cu}), area of main steel reinforcement (A\text{s}) and presence of horizontal stirrups. Test results showed that, addition of steel fibers or/and horizontal stirrups improves both shear strength and ductility of the tested brackets, and results in a more ductile failure mode. The use of industrial waste fiber in fibrous reinforced concrete is doubly beneficial because it increases efficiency without raising the cost of the concrete.

2. Objective of the Research

The main objective of the current research work is to investigate the effect of steel fiber with different percentages (0.5%, 1.0% and 1.5%) by volume of concrete in different part of concrete (mean that the one specimen was casted with two different types of fibrous and non-fibrous concrete) subjected to vertical repeated load.

3. Experimental work

The experimental program consisted of testing nine bracket specimens. The specimens are divided into three groups. The variables were the volume fraction of steel fiber and the location in the bracket as shown in table (1, 2).

As shown in Figure (1), the column supporting the two brackets cantilevering on opposite side was (250) mm by (250) mm in cross section and (750) mm long. Brackets had cantilever projection length of (250) mm, (250) mm width, and total depth of (500) mm at face of column and (250) mm at the free end, and the effective depth (469) mm with shear span (200) mm from column face. Column was reinforced with four deformed bars having a (12) mm diameter and stirrups having an (8) mm diameter placed at pitch of (100) mm. The primary reinforcement in bracket (main bars) having diameter (12) mm of steel reinforcement. The horizontal and vertical closed stirrup having diameter (8) mm of steel reinforcement at bracket. The effective cover is (25) mm.

![Figure 1. Details of Bracket (the shear friction provisions of the ACI Code)](image-url)
### Table 1. Details of Bracket Specimens

| group | corbel designation | loading regime | a/d | Concrete type     | Volume fraction of steel fiber |
|-------|--------------------|----------------|-----|-------------------|------------------------------|
|       |                    |                |     |                   |                              |
| CONTROL | Monotonic       | 0.43           | Normal concrete | 0%                           |
| A      | ACF1              | Repeated       | 0.43 | Fibrous concrete  | 0.5%                         |
|        | ACF2              | Repeated       | 0.43 | Fibrous concrete  | 1.0%                         |
|        | ACF3              | Repeated       | 0.43 | Fibrous concrete  | 1.5%                         |
| B      | BCF1              | repeated       | 0.43 | Fibrous concrete  | 0.5%                         |
|        | BCF2              | repeated       | 0.43 | Fibrous concrete  | 1.0%                         |
|        | BCF3              | repeated       | 0.43 | Fibrous concrete  | 1.5%                         |
| C      | CF1               | repeated       | 0.43 | Fibrous concrete  | 0.5%                         |
|        | CF2               | repeated       | 0.43 | Fibrous concrete  | 1.0%                         |
|        | CF3               | repeated       | 0.43 | Fibrous concrete  | 1.5%                         |

- CF = Bracket with Steel Fiber.

### Table 2. Summary of all Specimens

| Symbol | Area cast with mortar infiltrated fiber concrete | Case details | percentage of fiber (%) by volume |
|--------|-----------------------------------------------|---------------|----------------------------------|
| Control| normal strength concrete without steel fiber  |               | 0                                |
| ACF1   | normal strength concrete with hooked end steel fiber |               | 0.5                              |
| ACF2   | normal strength concrete with hooked end steel fiber |               | 1.0                              |
4. Material Characteristics

To evaluate the properties of the used materials, standard tests according to the American Society for Testing and Materials (ASTM) and Iraqi Standard Specification were conducted. Depending on the form and strength of concrete, various mixes have been used. To make two forms of concrete, proportions by weight were used in the analysis (normal and fibrous concrete). Use three percentage of hooked steel fiber (0.5%, 1% and 1.5%) by the volume of concrete.
Table 3. The mixing weight for normal concrete

| materials      | mix proportion |
|---------------|----------------|
| cement        | 300 kg/m³      |
| coarse aggregate | 1100 kg/m³   |
| fine aggregate | 830 kg/m³     |
| water         | 140 kg/m³     |
| w/c           | 0.46           |
| admixture     | 3.5 % of concrete |

Table (4) summarizes the mechanical characteristics effects of fibrous and non-fibrous concrete obtained at (28) days of age for various mixes. The compressive strength ($f'_c$), splitting tensile strength ($f_{ct}$), and modulus of rupture were all obtained ($f_r$).

Table 4. Mechanical properties of hardened concrete.

| Mix designation | $f'_c$ (MPa) | $f_{ct}$ (MPa) | $f_r$ (MPa) |
|-----------------|--------------|----------------|-------------|
| Normal concrete | 28.6         | 2.76           | 3.63        |
| Fibrous concrete (0.5%) | 30.12 | 3.08           | 4.23        |
| Fibrous concrete (1.0%) | 32.55 | 3.35           | 4.47        |
| Fibrous concrete (1.5%) | 34.6  | 4.11           | 5.82        |

4.1 Cement
Sulphate resisting cement was the type of cement used in this research, respect with the (IQS No. 5/1984) limitations [7].

4.2 Fine Aggregate
Natural local sand conforms to the limits of Iraq specification (IQS No.30 /1984) and Consultative Reference Guide (No.500/1994) Weighted Method[8], was adopted.

4.3 Coarse Aggregate
Natural crashed gravel with a maximum size of (19) mm is used as the coarse aggregate in this work. Mechanical and chemical properties according to the requirements of (IQS No.30 /1984) and Consultative Reference Guide (No.500/1994) Weighted Method[8], was adopted.

4.5 Admixture.
Flocrete (SP90S) High range water reducing admixture with workability retention properties complies with ASTM C494, Type B, D and G, depending on the dose.1[9]

4.6 Steel Fibers
In this research used the fiber (SikaFiber® Force 1050) which is used hooked steel end fibers with a length of (50 mm) and a diameter of (1mm). The hooked fiber was supplied by Sika company in USA and (SikaFiber® Force 1050) meets the requirements of ASTM A820 as a Type I Fiber[10]. Table (5) indicates the technical properties of steel fibers used as provided by the manufacturer.
Table 5. Properties of steel fiber

| property                  | results of hooked end steel fiber |
|---------------------------|-----------------------------------|
| appearance                | bright and clean wire              |
| length (l), mm            | 50                                |
| diameter (d), mm          | 1                                 |
| aspect ratio(l/d)         | 50                                |
| density (kg/m3)           | 7800                              |
| tensile strength (mpa)    | 1050                              |

4.7 Reinforcing Steel

Deformed steel bars with two different diameters are used in this work. The tests are carried out on the (8 & 12 mm) nominal diameter bars. As shown in table (6).

Table 6. The recorded Reinforcing Steel data

| diameter (mm) | yield stress (MPa) | ultimate strength (MPa) | Modules of elasticity (MPa) |
|---------------|--------------------|-------------------------|-----------------------------|
| nominal       | measured           |                         |                             |
| 8             | 7.9                | 565                     | 706                         |
| 12            | 12.7               | 663                     | 828                         |

* Steel bars were tested with a universal measuring system at Al-Musayyib Technical Institute.

5. Casting, Compaction, and Curing Process of the Specimens

At the beginning of the work the wooden mold was prepared according to the designed dimensions. Then a ready-made concrete is prepared from the central mixer. The mean compressive strength of the concrete (fc') is (28.6) MPa after 28 days. The two types of concrete casting at the same time (normal and fibrous concrete) after filling the mold to the required level the slices of wood removed by a steady upward pull. Then use vibration to achieve the full bonding between the two types of concrete. The preparation of fibrous concrete is carried out using a pot mixer. Half a cubic meter capacity, soft concrete is added to the pot mixer, after which the fiber is added manually and the mixing process is done for 4-5 minutes to obtain a homogeneous fresh fibrous concrete.

6. The Process for Testing and the Analysis of the Results.

The brackets were measured upside-down, with a vertical load fitted to the upper end of the column using a self-auxiliary loading frame from a general hydraulic testing system with a capacity of (2000 kN), as shown in Figure (2). The brackets are mounted on steel supports with bearing plates measuring (250*100*20) mm in direct contact with the bracket's horizontal surface. (LVDTs, wires to test deflection at each increase of loading) stayed in the specimen's mid span before loading began. The load added on the brackets on both sides (left and right) of the column face the shear span (a) was constant. The specimens were only subjected to vertical load. The load was increased in equal (25) kN increments. The deflection was measured using LVDTs with wires (0.001 mm) accuracy at each load stage.

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6.1 Analyzed the Behavior of a Specimens

At low load levels, all of the brackets tested were free of cracks and behaved elastically. The loads applied were proportional to the deflections. As a result, the stresses remained low, then the large a cross-section able to carry the loads used. The several diagonal cracks advanced near to the supports as the load remained increased. The initial shear crack seemed to be advancing in areas near to the bearing plate. Furthermore, it was discovered that the initial crack began at the corner and expanded along a column-bracket interface, while the second crack developed at the bearing plate's internal edge. The second crack was broadcast even more rapidly than the first. The first crack spread around the column face, while the second crack moved closer to the intersection of the column and a bracket's inclined face. The second crack, eventually developed the main or else major crack, entered between the inner edges of the bearing plate and a column-bracket contact at the inclined face, and was primarily in control for the bracket's failure.

Table 7.1st cracking load, ultimate loads, crack width, failure modes and effect of repeated loading of tested bracket.

| group     | corbel designation | a/d | 1st cracking load (kn) | ultimate load (kn) | crack width (mm) | mode of failure | Repeated load/static load ×100 | No. of cycles |
|-----------|--------------------|-----|------------------------|--------------------|------------------|-----------------|-------------------------------|---------------|
| CONTROL   | 0.43               | 300 | 800                    | 0.2                | Shear-flexural   |                 |                               |               |
| A         | ACF1               | 250 | 800                    | 0.38               | Shear            | 100%            | 8                             |               |
|           | ACF2               | 0.43| 275                    | 625                | 0.2              | 78.12%          | 7                             |               |
|           | ACF3               | 350 | 770                    | 0.18               | Shear            | 96.25%          | 8                             |               |
The first shear crack and ultimate loads for the control specimen, which was measured under monotonic load, were 300 kN and 800 kN, correspondingly. The additional three brackets in group (A) stayed subjected to repeated loading by (60 percent) of the reference bracket's ultimate load of 800 kN. On each measured bracket, eight cycles with constant increments regulating the testing machine increasing (during loading) and decreasing (during unloading). At each increment of loading, the load-deflection values were registered. The load carrying capacity of the bracket specimens in a group (A) reduction by a proportion of (3.75 percent to 21.8 percent) as related to the ultimate failure load of the orientation control specimen, as shown in Table (7). And increase in width crack (90%) in specimen (ACF1) as a compared with control specimen. The contribution of steel fibers in the cementitious matrix is mainly related to its random distribution, that is, as the cracks appear, fibers cross the cracks and transfer tension forces between the crack faces. Thus, the cracking process becomes more distributed in the cementitious matrix and do not concentrate in very small regions, thus resulting in a higher number of cracks of smaller sizes, which increases the ductility of the concrete.

The table below shows the load carrying capacity of different brackets under monotonic and repeated loading conditions.

|   | BCF1  | BCF2  | BCF3  | Shear |   |
|---|-------|-------|-------|-------|---|
| B | 250   | 769   | 0.4   | Shear | 96.12% |
|   | 0.43  | 275   | 0.6   | Shear | 100%  |
|   | 325   | 724   | 0.24  | Shear | 90.5% |
|   |       |       |       |       |   |
|   |       |       |       |       |   |
| C | CCF1  | 450   | 798   | 0.9   | Shear | 99.75% |
|   | 0.43  | 300   | 775   | 0.24  | Shear | 96.87% |
|   | 425   | 775   | 0.64  | Shear | 96.87% |

Figure 3. After Testing the Brackets, Showed the Cracks Pattern (A).

When comparing the ultimate failure load of the reference control specimen to the load carrying capacity of brackets group(B) lower than repeated loading, Table (7) shows that the load carrying capacity of brackets group(B) reductions by a minor proportion (3.8 percent to 9.5 percent). As compared to brackets of group (A), the effects of group (B) wobbling in the load carrying capacity under repeated loading can be observed. In compared with the control specimen, a width of a crack in brackets of group (B) increased by (20 to 200) percent.
Figure 4. After Testing the Brackets, Showed the Cracks Pattern (B)

Increase in width crack (20%-350%) in brackets of group (C) as a compare with control specimen. The group (C) has the largest crack width as compared with group (A) and group (B).

Figure 5. After Testing the Brackets, Showed the Cracks Pattern (C)
6.1.1. The Effects of Repeated Loading.

The majority of previous research had focused solely on reinforced concrete brackets subjected to loads that were gradually increased before failure. In reality, a structure may be subjected to high intensity repetitive proportional or non-proportional loading, which becomes important in structures subjected to earthquake, hurricane, or a strong live load to dead load ratio[12]. Table (7) shows the result of repeated loading on the mode of failure, the first cracking load, crack width and decrease in the strength of the checked brackets with brackets subjected to monotonic loads, the mode of failure was nearly identical. Under monotonic loading, but, the number of cracks and their spreading were significantly unlike. Below repeated loading, brackets become less brittle as a result of this. The explanation for this may be that specimens subjected to repeated loading display extra distortions in the main bars as well as deflections on the loading stage. Table (7) includes the greatest load carrying ability of brackets subjected to repeated loading stages of (60%) compared to equivalent brackets subjected to monotonic loading before failure. As can be shown, the ratio (load capacity with repeated loading/ monotonic load capacity) covers a wide range (78.12%-100%) for group (A)and (90.5% - 100%) for group (B) and (99.75% – 96.87%) for group (C).

6.1.2. Load Deflection Relationship

Figures (6,7and 8) display the experimental load-deflection curves obtained for the studied brackets. The deflection of the bracket structure describes the actions of the loading jack (i.e., deflection at the middle line connecting the double brackets). Each of these curves starts in a lined form with a regular slope. The load deflection response after cracking takings on a nonlinear shape with a variable slope. The shape of the various load-deflection curves at the post-cracking and closed-to-maximum-load stages looks to depend on the form of applied load (monotonous or repeated load). The curve gotten after repeated loading is referred to as a "hysteresis curve." Hysteresis response accurately represents the action of reinforced concrete brackets subjected to repeated loading. The region within the cycle of the load-deflection curve is a critical parameter for repeated response since it is a degree of the energy absorbed after sever cycling. This shows how repeated loading affects stiffness and strength weakening [11,12]. The load against deflection hysteresis loops for completely nine specimens tested display a decrease into load carrying capacity over frequent cycles. The load-deflection curves exhibit a significant feature in that region bounded by the hysteresis loop reduces with increasing cycles at a stable ductility ratio [13].

![Figure 6. Load- deflection response for corbels group (A, B, C) (60% loading level) (continue)](image-url)
Figure 7. Load-deflection response for corbels group (A, B, C) (60% loading level) (continue)
Figure 8. Load-deflection response for corbels group (A, B, C) (60% loading level) (continued)

For study and comparison between the groups (A, B, C) Take last cycle for repeated load as shown in figures. The batter case from group (A) is (ACF1.5%). And batter case from group (B) is (BCF1%). And batter case from group (C) is (CCF1%). And the batter specimen for all tested brackets is (ACF1.5%).

Figure 9. Load-deflection response for corbels group (A, B, C) last cycle (60% loading level) (continue)
Figure 10. Load- deflection response for corbels group (A, B, C) last cycle (60% loading level) (continued)

Figure 11. Load- deflection response for best brackets in group (A, B, C) last cycle (60% loading level)
7. Summary.

1- The congested bracket reinforcement provided by (ACI-318M-11) Code requirements, as well as the small size of brackets in comparison to another structural components, make the usage of fibrous concrete a well solution than the usage of normal concrete.

2- The specimens formed with a percentage of steel fiber and checked below repeated loading have a upper first cracking load than the specimens formed with normal concrete.

3- The width of crack was increased (20%-200%) for fibrous concrete under repeated load with respect normal concrete under monotonic load.

4- As compared to monotonic loading, brackets subjected to repeated loading failed in a more ductile form. Moreover, repeated loads were discovered to increase overall deflection at failure as compared to brackets subjected to monotonic loading at failure.

5- Brackets subjected to repeated loading normally show an improvement in deflection in subsequent cycles. Besides that, it was discovered that the serial increments of deflection with repeated loads were reduced.

6- The best fraction of adding steel fiber was (1.5%) by the volume of concrete as compared with percentage (0.5%,1.0%) by the volume of concrete.

7- As compared to other specimens, the specimen for fibrous concrete (BCF3) had the lowest value for the load-deflection curve.

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