Experimental Behavior of normal and hybrid strength concrete Corbels Strengthened With steel plate under repeated and monotonic Loading

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ABSTRACT

Several previous studies investigated the behavior of reinforced concrete blocks subjected to repeated loads, as well as the reinforcement of concrete corbels with various reinforcing materials such as carbon fiber tapes and steel fibers. In this current study, the variables are the type of concrete (normal and hybrid strength), reinforcement with steel plates, and load shedding (monotonic and repeated). Eight reinforced concrete cable samples were tested. During this investigation, three loading ratios were used based on the results of the selected samples: 25%, 50%, and 75% for each loading cycle. Vertical load testing was performed on four of the samples. The results were obtained with a shear extension to effective depth (a/d) ratio of 0.6. It can be seen that the load failure of samples tested under repeated loading systems is 7.74%, 16.21 %, 9.4 %, and 6.21 % lower than that of samples tested under monotonic loading systems, respectively. Because the amplitude of the first two cycles was less than the crushing load, 75 percent had the worst results in terms of maximum load reaching failure. The results showed that the first crack appeared in 25% of samples with monotonous loads and normal unreinforced concrete and in 18% of samples with repeated loads. The first loading rate of steel-reinforced concrete is 33.33% for monotonous and normal concrete samples and 22.35% for repeated load samples. New sloping cracks appeared and advanced along the shaft front when the load reached 75% of the failure load. These cracks widened and spread all the way to the upper shaft joint

Keywords: Concrete, concrete corbels

1-Introduction

In precast concrete construction, corbels—brackets that project from the faces of columns—are frequently employed to support main beams and girders. Short cantilevers having a shear span to effective depth ratio of under one are referred to as "corbels." Because of the tiny ratio [1], corbels are comparable to deep beams in that shear is primarily responsible for controlling their strength. The primary purpose of corbels is to endure the maximum horizontal and bending forces that the beam is capable of producing due to shrinkage, creep, or temperature changes. This article reviews earlier research on the behavior of corbels.**Hwang et al.** [3], A softened strut-and-tie model for determining corbel shear strength was offered. In order to compare the suggested method with 178 test specimens from the literature, The under-researched corbels have a variety of traits, including (av/d) ratios, unique strength categories, and horizontal reinforcement. The ACI empirical equations were found to be conservative for the chosen test data, with more evident conservatism identified for corbels built with high-strength concrete or low (av/d) concrete.Therefore, for a corbel with an a/d of 1, vertical stirrups are useless. The web reinforcement was found to be beneficial in the Hwang et al. model in two different ways: first, by creating tension linkages and providing shear transferring channels; and second, by controlling crack widths and delaying the softening of cracked concrete. The following criteria were chosen in order to cover the most typical range of practice: The values of (h fyh), (av/d), and (fc′) for normal strength concrete ranged from 0 to 8 MPa, 1/4 to 1, and 30 and 70 MPa, respectively, for high strength concrete. The value of (h fyh), which increases as the concrete strength increases, seems to be the upper limit value provided by the concrete strength.

Rezaei and colleagues [4] Due to column load, corbels were examined. A finite element computer program was used to model and analyze single and double corbels with various axial column loads (LUSAS version 14.1). A weight was added to the top of the column, gradually increasing it until it reached the predetermined level, and then a weight was applied to the corbels until failure was established after calculating the column's axial load capacity. It has been demonstrated that the axial column load has a greater impact on the strength of double corbels than it does on single corbels. It was found that the latter increased the stiffness of the corbels.

Fattuhi [5], To establish the improvement in shear characteristics brought on by the addition of steel fibers, 22 (150x150x200) mm concrete corbels reinforced with steel fibers were tested only under vertical pressure. The (av/d) ratio and fiber content were two of the variables examined. The addition of fibers increased shear strength, and the researchers came to the conclusion that stirrups might be preferable to fibers used as secondary reinforcement.Fattuhi [6], We put 18 concrete corbels that had been reinforced with steel fibers and main bars to the test. Secondary reinforcement was provided by the fibers. Changes were made to the primary and fibrous reinforcement quantities as well as the shear span-to-depth ratio. Four of the double corbels had their corbel segments subjected to asymmetrical weights, whereas eight examples had their column segments treated to a concentric load. The experiments showed that loading the specimen's left-side corbel or column segment had no influence on the corbels' ability to support loads, although it did delay the development of the first crack. The corbels were additionally strengthened and made more ductile by the use of steel fibers.

Forster **et al.** [7], The performance of thirty corbels was tested while being loaded vertically. Concrete strength (45-105 MPa), (6500-15200 psi), shear span-to-depth ratio, and secondary reinforcing supply were the main factors evaluated. The concrete efficiency factor for members failing under compression was determined with extreme care. The behavior of the corbels was also compared to that of the plastic truss model and the ACI 318-89 design procedure. The outcomes demonstrated that the plastic truss can predict load distribution with accuracy. The results showed that corbels made of high-strength concrete behaved similarly to those made of normal-strength concrete. Furthermore, as the shear span-to-depth ratio increases, the flexural cracking load reduces. The initial fractures seen were flexural cracks spreading from the corbel-column junction. Additionally, it was found that secondary reinforcement reduced and changed the compression-failure beams' diagonal splitting to compression strut crushing as the primary mode of failure. They consequently recommended that a minimum quantity of horizontal stirrups be provided, equivalent to that utilized for normal-strength concrete, when building high-strength concrete corbels. Additionally, it was determined that the ACI 318-89 method should not be used to design corbels made of high and extremely high-strength concrete. **Farhan** [8] conducted theoretical and practical research on the tensile and deformation characteristics of reinforced concrete corbels that were loaded repeatedly and monotonously. 24 vibrated and self-compacting concrete (SCC) corbels with normal and high compressive strengths were cast and vertically tested in order to achieve this goal. The test results showed that corbels made of SCC improved the behavior and strength of the specimens (8.2 percent to 14.2 percent). **Heidayet et al**. [9], An experimental investigation focused on 18 damaged reinforced concrete corbels that were repaired with external steel plates after being subjected to vertical forces. Evaluations were done on the depth of the corbels, the shear span to depth ratio (av/d), as well as the primary and secondary reinforcements. The corbels were first loaded almost to their maximum capacity, mended with outside steel plates fastened together, and then loaded till they broke. The strength ratio of the repaired corbel to the original corbel ranged from 0.7 to 1.5, indicating that this repair strategy can be regarded as an efficient and affordable way to enhance existing structures.

2- Experimental Program

This study tested a total of eight specimens. Four different sample groups were created (A, B, C, and D). These types were classified based on the concrete (normal and hybrid strength), applied loads (monotonic and repeated), and strengthening (strengthened and unstrengthened with steel plates). To provide constant load distribution, a corbel of dimensions (150 mm depth X 200 mm width X 650 mm length) was used, with all corbels being the same size. Table No. (1) shows the specifics of the tested corbels, which show that all corbel samples had a fixed shear span to effective depth ratio (a/d) of 0.6.

Table 1 Details of corbel specimens

Group	Specimen	Strength of concrete	Loading regime	strengthening	a/d	Pcr (kN)	Pu (kN)
A	CN06M	Normal	monotonic	none	0.6	101.25	406.5
	CNS6M	Normal	monotonic	steel plate	0.6	169	507.25
B	CN06R	Normal	repeated	none	0.6	66.4	375
	CNS6R	Normal	repeated	steel plate	0.6	95	425
C	CHy06M	Hybrid	monotonic	none	0.6	152	497.5
	CHyS6M	Hybrid	monotonic	steel plate	0.6	219.72	593.25
D	CHy06R	Hybrid	repeated	none	0.6	120.3	450
	CHyS6R	Hybrid	repeated	steel plate	0.6	140.5	491

2.1. Material Properties

To determine the properties of the materials used Throughout the test, regular Portland cement, washed natural sand, and 12 mm coarse aggregates were used in accordance with Iraqi Specification No.5/1984 [10]. The physical properties of the fine and coarse aggregates were determined to meet Iraqi standard No. 45/1984 [11]. The main tensile reinforcement for the corbel and the longitudinal reinforcement of the supporting shaft were deformed steel bars with a diameter of 12 mm. As connecting rods for the shaft, deformed steel bars with a diameter of 8 mm were used. Reinforcing and frame bars are made up of 6 mm diameter bars. ASTM C370-05a [12] was used to evaluate three samples of each penis size. The yield strength of the structure was 498 MPa, 655 MPa, and 620 MPa, as shown in Figure 1. For the aim of manufacturing self-consolidating concretes, a superplasticizer known as (High Water Reducing Agent, HWRA) based on poly-carboxylic ether will be employed and added to the mix; it has the brand Glenium 51 [13], which is chloride-free and meets ASTM C494, kinds F and A. Furthermore, it is highly compatible with all types of Portland cement that meet internationally recognized requirements. The silica fume used in this investigation was Sika micro silica (manufactured by Sika Company). The study's findings show that the silica fume used in this investigation meets the chemical and physical standards of ASTM C-1240-05 [14].

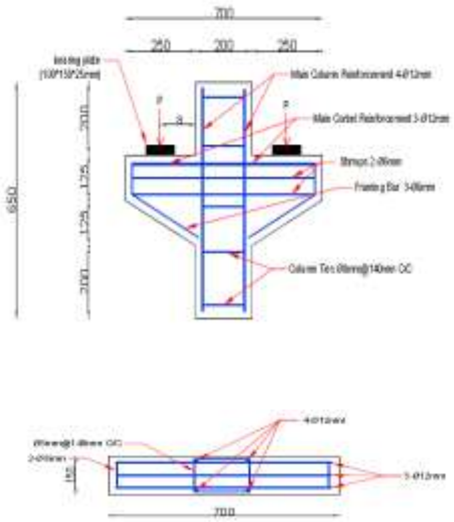

Figure 1. Details of tested corbel.

2.2 Mechanical properties of steel plate.

The technical data information of steel plate and bolts used in this work can be clearly seen from Tables (2) and (3) respectively

Taple (2): bolts properties.

Class and material chart	Nominal size range (millimeter)	Proof load (mpa)	Minimum yield strength (mpa)	Minimum tensile strength (mpa)
Class 10.9 steel ,quenched and tempered	5mm-100 mm	830	940	1040

Taple (3): Steel Plate Specifications and Tensile Test Results

Steel Specimens	**Thickness of Plates (mm)**	**Elongation %**	**Bonding Method**	**Yield Stress (N/mm2)**	**Ultimate Stress (N/mm2)**
Steel plate	6mm	9.34%	Anchor bolts	364.44	455.56

2.3 Steel plate Strengthened System

The reinforcement schemes were carefully chosen based on practical needs and field conditions, particularly the cracking pattern and practicality in reality and economics. Four reinforced concrete corbels were externally reinforced using steel plates in this study, as shown in Figure (2), and eight of these samples were tested. Corbels CH06M, CH06R, CN06M, CN06R are kept without reinforcement and are used as comparison control corbels.

Figure 2. Details steel plate.

2.4 Mix Design

Depending on the type and strength of the concrete, different combinations were utilized. In the current study, the weight-to-weight ratio of the mixtures was used to create two types of concrete: hybrid strength with an average of 28 days and cylinder compressive strength pprox (55.5 Mpa), where we used two types of high-strength concrete, 70 MPa and ordinary concrete, and normal strength with an average of (28) days, as shown in Figure No.

Figure 3. Corbel specimen Setup

Table 4 Mix properties

Cement kg/m3	Gravel kg/m3	Sand kg/m3	w/c	Superplasticizer (L/m3)	Silica Fume (Kg/m3)	Target Strength Mpa (f'c)
585	1136	651	0.27	7	58.42	70
400	1200	600	0.45	—	—	30

2-5Testing Procedure and Test Results

The corbels are upside-down in Figure 1. The top end of the column was subjected to a vertical load using a self-supporting loading frame of a universal hydraulic testing equipment with a 3000 kN capacity. The steel supports that the corbels were mounted on had bearing plates that were directly in touch with the corbels' horizontal surface and measured (150x100x25 mm). Prior to the start of loading, contact gauges were positioned on the concrete surface to detect deflection with each increment in load. Both a vertical load and an iterative load were applied to the samples. The load was increased in identical fixed increments of 5 kN. Using an electronic center dial gauge with 0.01 mm accuracy, the deflection was measured at each loading stage.

Figure 3. Corbel specimen Setup

3. Behavior of Tested Specimens

In the early stages of stress application, the specimens exhibit great stiffness and load resistance until the first fracture appears. At this stage, the specimens are firmer than at a later stage. There isn't much vertical movement, and there aren't any fractures. Once the first fractures appear, the rigidity continues to deteriorate and the vertical displacement begins to increase. At this point, flexural fractures form on the tension face of corbels near the column. With increasing force, the number and breadth of cracks increase until the steel bars yield. The deflection readings rapidly increase after the nonlinear behavior, indicating a decrease in stiffness. In the advanced stages of stress, diagonal shear fractures form near the supports and spread quickly towards the column face. The flexural cracks are less extensive than these fractures. The failure is abrupt and uncontrolled, with the exception of stronger specimens with steel plate, where the failure is more ductile than the unstrengthened specimens. The failure mechanism of the steel plate is such that there is no decoherence and normal stresses between the corbel surface and the steel plate due to interfacial shear concentration. Figure (3) depicts a failure condition for tested samples. Load failure is lower in samples tested under repeated loading systems than in samples tested under monotonous loading systems.

Figure 4. Cracks patterns of corbels after testing.
(a) Cracks patterns of corbel CHS6M
(b) Cracks patterns of corbel CNS6R
(c) Cracks patterns of corbels CH06M
(d) Cracks patterns of corbels CH06R
(e) Cracks patterns of corbels CN06M
(f) Cracks patterns of corbels CN06R
(g) Cracks patterns of corbels CNS6M
(e) Cracks patterns of corbels CNS6R

3-1 Influence of Repeated Loading Level

In the majority of earlier studies, reinforced concrete corbels subjected to loads that increased monotonically until failure were the only thing being studied. A structure may, in many situations, be subjected to high-intensity, repetitive proportional loading or non-proportional stress. Structures exposed to earthquakes, storms, or a high live load to dead load ratio [15,16,17] experience severe loading due to these factors. Comparing comparable corbels under monotonic and repeated loading will reveal how repeated loading affects a corbel's carrying capacity. We measured three ratios of repeated loading levels for comparable corbels that were subjected to monotonous loading (75 percent, 50 percent, and 25 percent) and compared them.

In comparison the effect of type of loading on the failure load of the tested solid deep beams having the same type of concrete, same volume fraction, for the specimens (CNO6M, CN06R) and (CHy06M,CHy06R) and (CNS6M,CNS6R),(CHyS6M,CHyS6R) the following observations can be noted:

1. The failure load of the specimen CNO6M, CNS6M, CHy06M, and CHyS6M is greater than the failure load of the specimen CNO6R, CNS6R, CHy06R, and CHyS6R by 7.749%, 16.21%, 9.54%, and 17.23% sequentially.
2. The cracking loads of the specimens CNO6M, CNS6M, CHy06M, and CHyS6M are 34.42%, 43.78%, 20.85%, and 36.05% higher, respectively, than the cracking loads of the specimens CNO6R, CNS6R, CHy06R, and CHyS6R. As shown in figure (5).

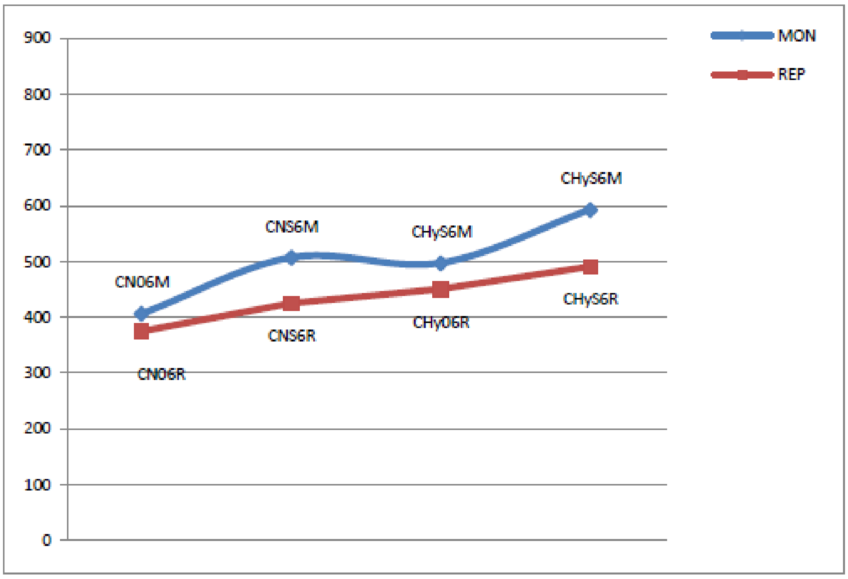

Figure **5** Influence of Repeated and monotonic loads on cracking and failure loads for corbels

3-2 Influence of steel plate on Cracking and failure Loads

The use of steel plate for reinforcement improves performance and strength, effectively increasing the final strength of the samples. It should also be noted that the appearance of the first crack was delayed as a result of this strength. The results showed an improvement in reinforcement for failure loads of about (19.24%, 9.11%, 13.32, and 24.78%) and cracking loads of about (44.55%, 16.79%, 43.07%, and 66.91%) for specimens CHyS6M, CHyS6R, CNS6R, and CNS6M, with the effective shear extension ratio to the effective depth (0.6) as shown in figures (6, 7, 8, and 9).

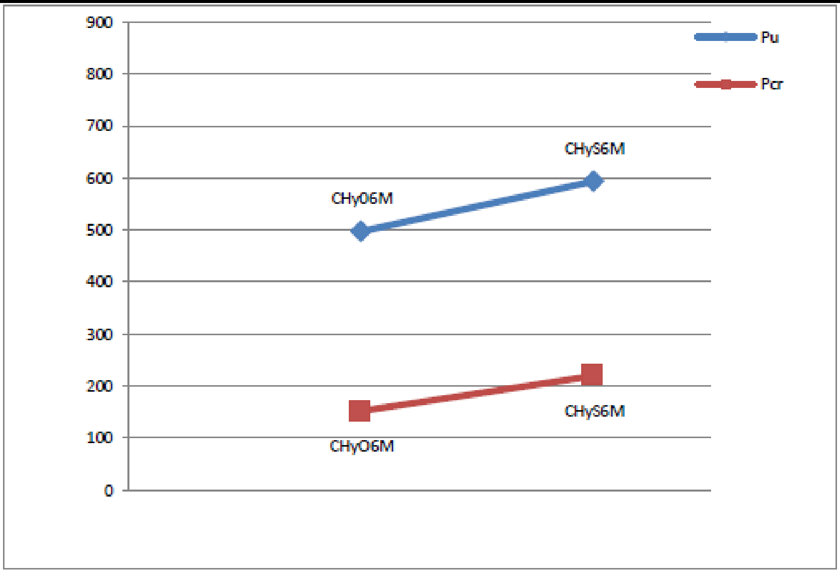

Figure (6) Influence of steel plate cracking and failure loads for hybrid strength concrete corbels under monotonic Loading

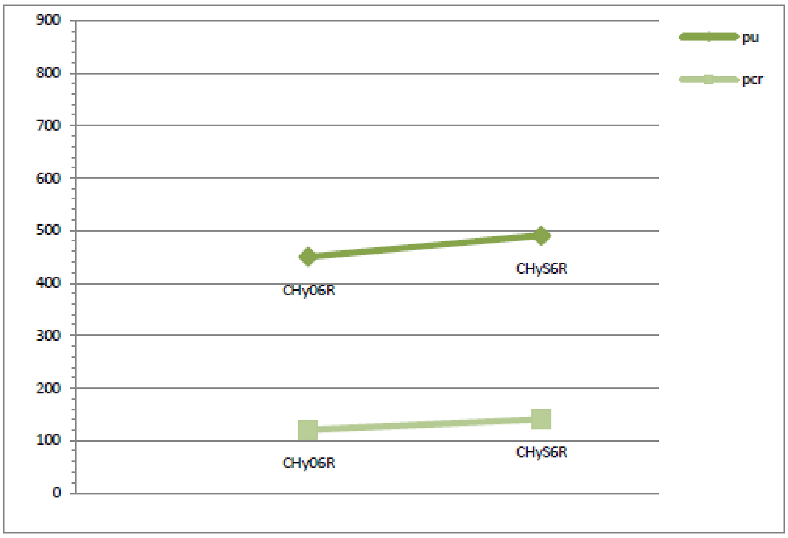

Figure (7) Influence of steel plate cracking and failure loads for hybrid strength concrete corbels under Repeated Loading

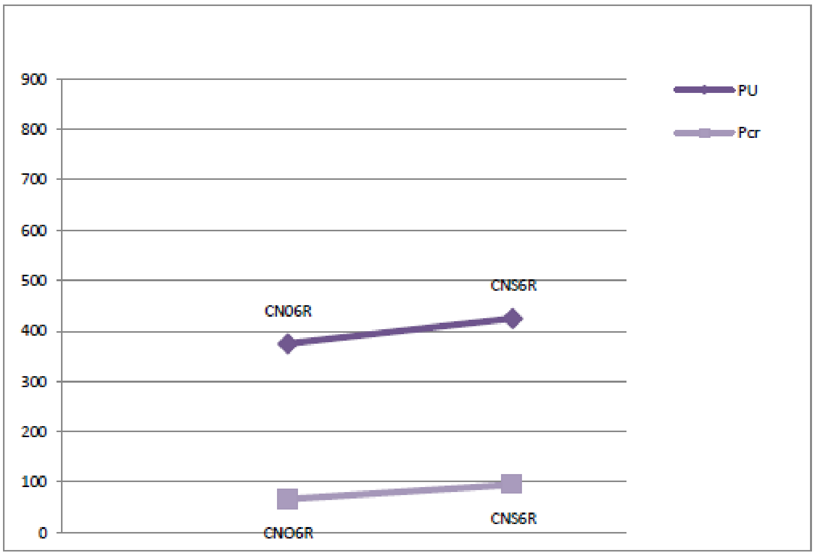

Figure (8) Influence of steel plate cracking and failure loads for normal strength concrete corbels under Repeated Loading

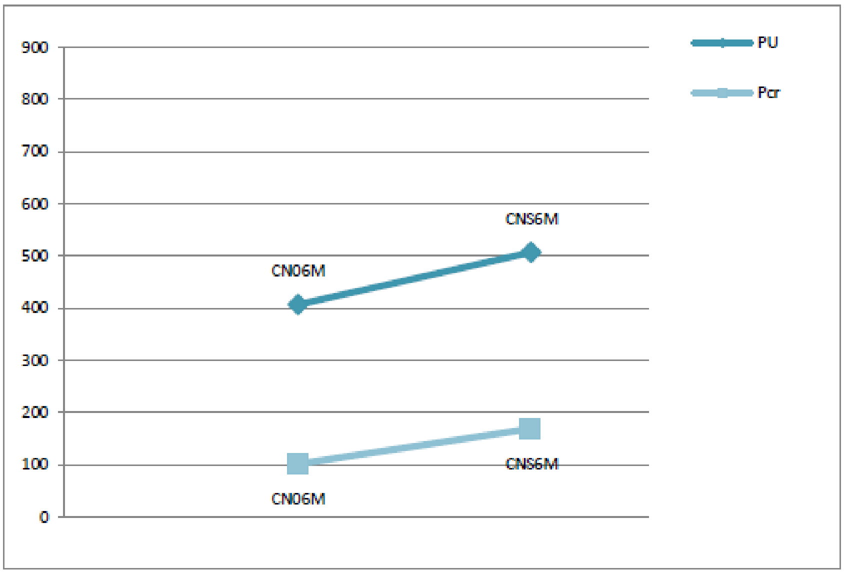

Figure (9) Influence of steel plate cracking and failure loads for normal strength concrete corbels under monotonic Loading

3-3 Influence of Concrete Compressive Strength

The compressive strength of concrete, together with other characteristics such as section size and reinforcement ratio, is the key parameter that impacts specimen capacity. The comparison of the specimens in this investigation clearly shows the favorable influence of compressive strength. CN06M, specimen CHyS6M with reference specimen CNS6M, specimen CHy06R with reference specimen CN06R, and specimen CHyS6R with reference specimen CNS6R, with increasing ultimate capacity percentages of 61.95%, 49.53%, 59.04%, and 67.37, respectively. When the compressive strength of concrete is increased by raising the flexural stiffness of the component, the cracking capacity improves dramatically, delaying the emergence of the first crack. Figures (10,11) show that enhancement increases by approximately 116.73%, 79.52%, 156.02%, and 110.52% for specimens CHy06M, CHyS6M, CHy06R, and CHyS6R when compared to reference specimens CN06M, CNS6M, CN6R, and CNS6R[19,20].

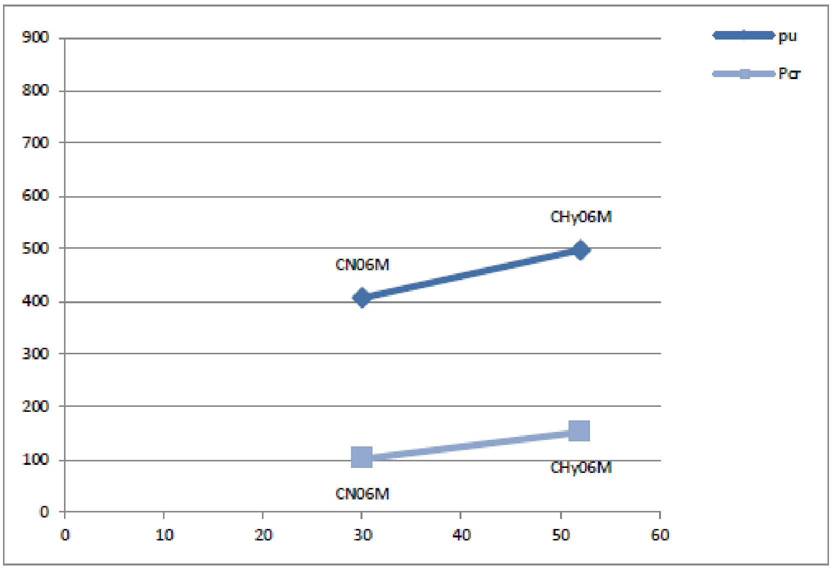

Figure (10) Influence of concrete compressive strength on corbels cracking and failure loads under monotonic Loading

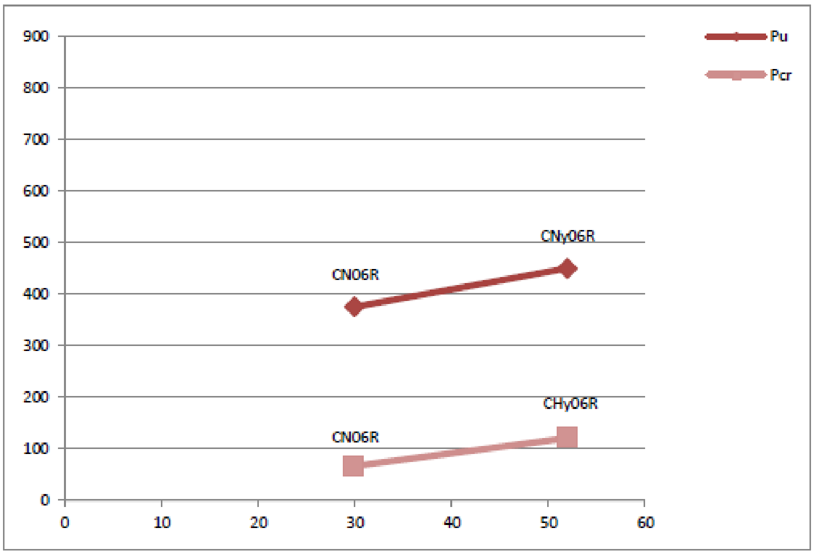

Figure (11) Influence of concrete compressive strength on corbels cracking and failure loads under Repeated Loading

3-4 Load Deflection Relationship

The repeated loading regimen following the load was an observational investigation technique in this study; the target recurrent loading value in a monotonic loading system is determined by the failure load of the tested control samples. The applied load is gradually increased for each load cycle until it reaches the target load, which was a percentage of the failure load for monotony. The load gradually decreased to zero from the target load, which was a percentage of the failure load for the monotony of the tested control sample. Repeated according to the loading log that was chosen. Depending on the results of the selected samples, three loading percentages were applied during this examination until failure occurred: 25%, 50%, and 75% for each loading cycle. The load-displacement responses for the specimens CN06M, CNS6M, CHy06M, CHyS6M, CN06R, CNS6R, CHy06R and CHyS6R are given in Fig. (12) (15). Testing was stopped when the specimen failed, which was indicated by damage or when the load could no longer be raised or began to drop due to the ongoing rise in deflection. The deflection indicates the loading jack's motions, which correspond to the deflection at the center of the column that supports the double corbels. For the specimens that were tested: CN06M, CNS6M, CHy06M, CHyS6M, CN06R, CNS6R, CHy06R and CHyS6R, the final vertical loads recorded, Pu, were 406.5 kN, 507.25 kN, 497.5 kN, 593.25 kN, 375 kN, 425 Kn, 450 kn and 491 kN correspondingly. The curves show that at the early phases of loading, the curves were linear with a practically constant slope, as predicted because the specimens were in their elastic stage. Following the commencement of the first fractures, the curves took a nonlinear shape with varied slopes; the nonlinear form remained as the load amount increased until failure occurred. Figures 13, 14, and 16 depict the influence of concrete type, steel plate reinforcement, and shear period to efficient depth ratio (a/d) on the behavior of guard corbels.

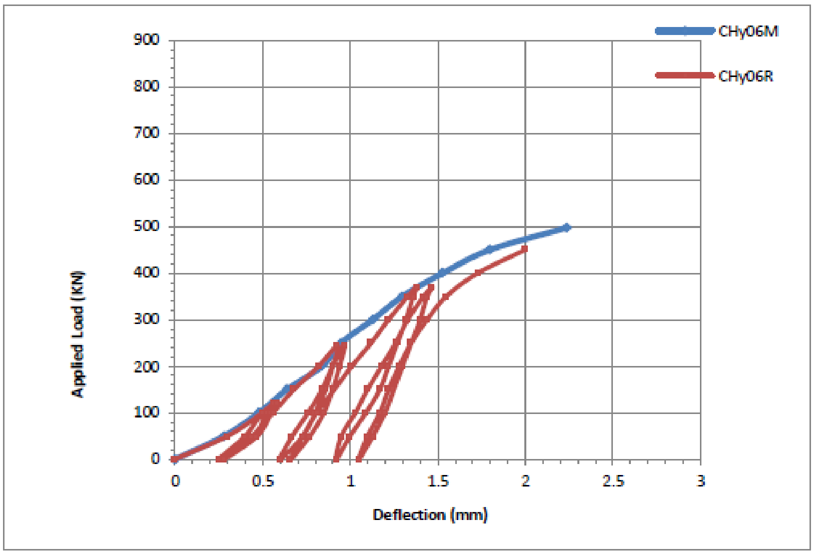

Figure (12) Load- deflection response under repeated loading for corbel HySC (25%,50%,75 loading level) a/d ratio (0.6)

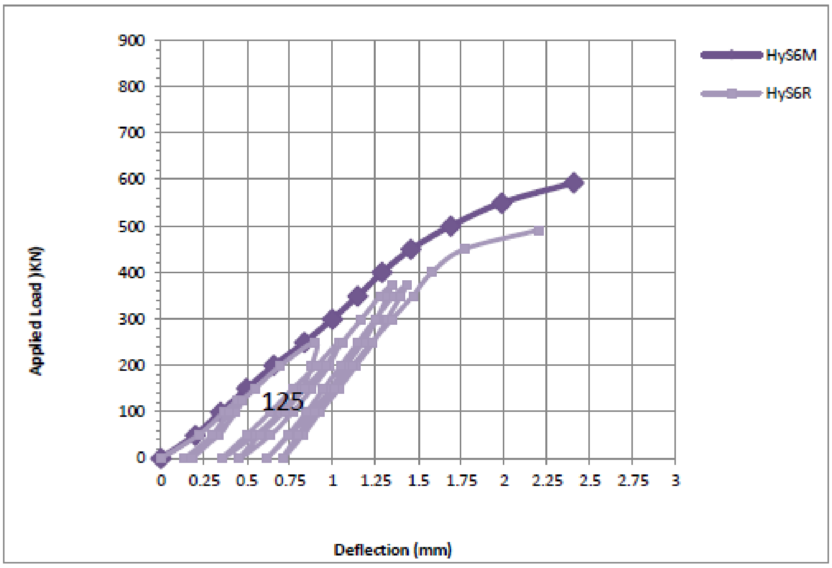

Figure (13) Load- deflection response under repeated loading for corbel HySC (25%,50%,75 loading level) a/d ratio (0.6) Strengthened with steel plate

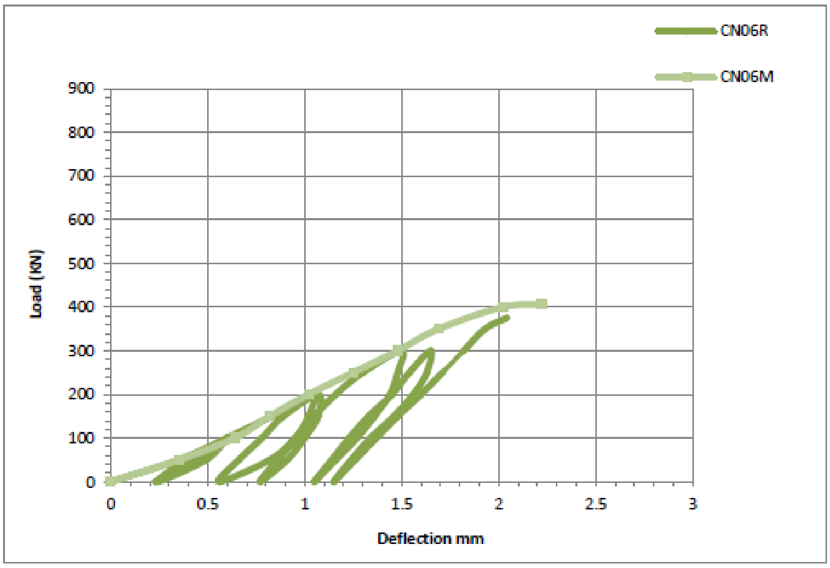

Figure (14) Load- deflection response under repeated loading for corbel NSC (25%,50%,75 loading level) a/d ratio (0.6)

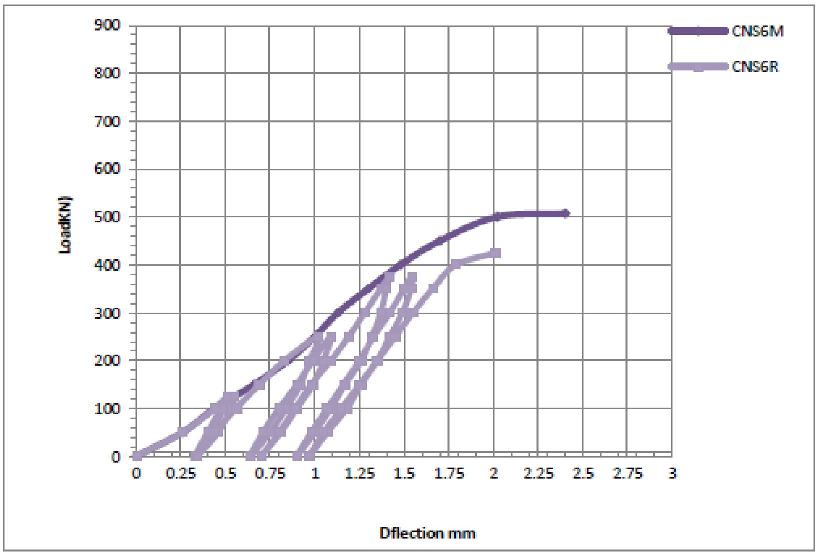

Figure (15) Load- deflection response under repeated loading for corbel NSC (25%,50%,75 loading level) a/d ratio (0.6) Strengthened with steel plate

4.Conclusions

- Steel plates have a minor effect on compressive strength, but they have a large effect on deformation in the last stages of failure, as seen in the figures.
- Reinforcement by steel plates leads to an increase in ductility and, consequently, an increase in the load to reach the final failure. The results showed that the reinforcement with steel plates increased the final load by (19.42%, 9.11%, 24.78 and 13.33%) for the samples CHyS6M, CHyS6R, CNS6M and CNS6R.
- The results showed the positive effect of compressive strength, CHy06M with reference sample CN06M and CHy06R with reference sample CN06R, which have a percentage increase of final capacity of about 22.38% and 20%, respectively, and greatly improve the crushing capacity, where the improvement increased by about 50.12% and 81.17% for samples CHy06M and CHy06R when compared with the reference samples CN06M and CN06R.
- The models that were examined under the influence of repetitive loads show that there is a residual vertical displacement when the total load is removed, in addition to the remaining part of the stresses as a result of the occurrence of plastic stresses from the work of shedding the repeated load.
- We note that when the load is stable and for different load cycles, the increase in the number of cycles applied to the model increases the amount of precipitation for the same load.
- As a result of repeated loading, the concrete member is exposed to a decrease in ductility due to the crushing that occurs in the model as a result of the loading cycles it is exposed to.
- When loading and lifting loads, the upward curve does not follow the same path as the descending curve. the same path as the descending curve. The difference between the two curves is the amount of energy wasted and lost from the process of loading and lifting.
- The stiffness decreases with the increase in the number of loading cycles due to the crushing that occurs in the model as a result of repeated loading and lifting in each cycle.

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