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Improve the Flexural Behavior of One-Way Ribbed Slab by Using CFRP Sheet

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Keywords:
CFRP Sheet; Defection; Ribbed Slab; Strengthening; Ultimate-Load.

Highlights:

- *Flexural behavior of high- strength concrete one-way ribbed slab.*
- *Strengthening one-way ribbed slab with CFRP sheets.*
- *Comparative between an experimental work and theoretical analysis of ultimate load.*

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Abstract: One of the most important research projects in the recent years is strengthening structures. The significance of these studies was to modify the ability of buildings to withstand high loads without utilizing materials that hurt the environment. Six one-way ribbed slabs were experimentally tested in the present study to determine the effect of carbon fiber reinforcement polymer sheets on the structure. One of the specimens, used as a reference, was unstrengthen. Two specimens were strengthened with carbon sheets on 50% and 100% of the rib width. To prevent sheet debonding, two others used 50-mm-wide U-shaped strips. A complete rib wrap served as the final method of strengthening. All the specimens underwent concentrated load testing to investigate the ultimate capacity, deflection, stiffness, and ductility. According to the findings, all specimen's deflection decreased in a ratio ranging from 4% in whole rib wrap to 46%. Also, the stiffness increased in all specimens, and the width of the carbon sheet insignificantly affected the stiffness, while the way of strengthening did. In the end, strengthening with 50% width has no discernible effect on the ultimate load (3%), whereas strengthening with 100% width raised by 41%, while adding U-shaped stripes increased the ultimate load capacity by 74% and completely wrapping the ribs increased by 132%.

تحسين سلوك الانحناء للبلاطات الخرسانية المعصبة ذات الاتجاه الواحد باستخدام صفائح من الياف الكاربون البوليميرية

سلوى رائد جاسم، حيدر محمد جواد

قسم الهندسة المدنية / كلية الهندسة / جامعة بابل / بابل – العراق.

الخلاصة

توجد العديد من المباني والمنشآت الخدمية بحاجة ماسة الى تأهيلها وصيانتها لكونها بنيت في القرن الماضي. وهناك مجموعة من الابنية تم تغير هدف بنائها فيجب معالجتها او تقويتها لغرض تحمل المتطلبات الجديدة ومن أكثر الطرق الشائعة حديثا هي تقوية الابنية باستخدام الياف الكاربون لكونها غير ملوثة للبيئة واسعارها مناسبة ولا تحتاج الى خبرة ومجهود في تثبيتها وتم في هذه الدراسة تقوية ست من البلاطات الخرسانية المعصبة الاحادية الاتجاه بنسب مختلفة من الياف الكاربون البلاستيكية حيث تم تقوية اول نموذجين بشريحة تغطي ٥٠٪ و١٠٠٪ من عرض العصب تباعا. وتم اضافة شرائح بعرض ٥٠ ملم على شكل حرف U لغرض منع انفصال الاشرطة في ثاني نموذجين واما النموذج الاخير فتم تغطية العصب بشكل كامل وترك نموذج بدون تقوية لغرض المقارنة. جميع النماذج فحصت تحت حمل احادي مركز وتم مقارنة قوة تحمل النموذج والهطول واللدونة والصلابة وتم التوصل الى ان نسبة تقوية ٥٠٪ ليس لها تأثير يذكر واما عند تقوية النموذج بـ١٠٠٪ حصلت زيادة بالحمل الاقصى ٣١٪ وعند اضافة اشرطة التقوية U فالحمل الاقصى ازداد الى ٧٤٪ اما عن التغطية الكاملة للعصب فحصلت زيادة١٣٢٪ بالحمل الاقصى. واما عن الهطول فقد قل في جميع النماذج نتيجة قوة تحمل الياف الكاربون لإجهاد الشد فقد قل بنسبة تتراوح من ٤٪ الى ٤٦٪.

الكلمات الدالة: الحمل الاقصى، الهطول، الياف الكاربون البوليميرية، بلاطات خرسانية معصبة، تقوية.

1.INTRODUCTION

These days, many buildings were built in the forties or sixties of the last century need maintenance, and some buildings' capacity changed by changing their function, like big houses that changed to baby daycare. So, there is a need to strengthen the building to withstand the new loading. Also, there is a clear need to increase housing units, service buildings, and schools due to population growth and people moving to cities. Also, factories, theaters, garages, malls, stores, and other structures require a large space that may make the slabs do not withstand their weight, increase using the ribbed slab to reduce the load applied to the columns, reduce their volume and weight and minimize footing [1-8]. Strengthening the building is also necessary to improve its stability, stiffness, and ability to carry load [9]. Most buildings have been deteriorating because of the harsh environment. Most of the structures were made of reinforced concrete, and it is well known that the occurrence of cracks in the concrete decreases the capacity of structures and is also the primary cause of steel corrosion. FRP was used to strengthen or repair the buildings. The sheet or laminate of CFRP, in particular, has been extensively researched [10-14], where strengthening structures with it will increase their capability to withstand heavier loads due to their low thickness and comparatively simple application. Fiber-reinforced polymers (FRPs) have emerged as solutions for strengthening and retrofitting structures, being lighter and more durable in various situations than conventional materials. FRPs also have a very high strength advantage. Rehabilitation processes are made considerably easier in small places by the lightweight FRP. Furthermore, FRP applications do not require an expensive machine [15]. Abdullah [16] used a CFRP sheet to strengthen the one-way slab. One-point loading tests were performed on six samples, and CFRP strips were used to strengthen the first two at varying spacing (30 and 37.5mm) in the long direction. The final two were strengthened similarly to the first two and added stripes, but in a short direction and spaced by (100 and 200) mm. The first two were strengthened similarly to the last two but in two layers, it was found that increasing the carbon width (area) was preferable to increasing the thickness. Al-Rousan et al. [17] used CFR studies to strengthen one-way slabs with CFRP sheets. The specimens were strengthened twice, i,e once with a sheet and the other with stripes. It was discovered that when the sheet was used instead of the stripes, the ultimate load increased, and the crack width decreased. However, the structure's ductility decreased. The objective of this study is to strengthen one-way ribbed slabs with minimum steel reinforcement by CFRP sheets only to improve the flexural behavior of ribbed slabs to reach ultra-weight reduced with better strength. To achieve this goal, experimental work was conducted on six specimens with different strengthening ways to determine the ultimate load, deflection, stiffness, and ductility. All the specimens were tested under one concentrated load.

2.EXPERIMENTAL PROGRAM

2.1.Tested Slab and Material

Six one-way ribbed slabs (600× 200 × 2000) mm were examined and tested for flexural failure, with one test serving as a control. All the specimens had the minimum reinforcement required by the ACI code [18]. Each rib had two 6 mm diameter deformed steel bars in tension and the same in compression zone utilized in a rectangular stirrup with a 4 mm bar diameter. Steel reinforcement mesh(Ø4@150) was used for shrinkage and temperature requirements. The deformed steel bar tensile was tested in a laboratory, i.e., fy=420MPa and modulus of elasticity 199.99 GPa. All tested slabs had a 15 mm cover in all directions. High strength concrete was used to cast the ribbed slab with mechanical properties achieved from testing standard cube, cylinder, and prism. It was found that f_c'=66.963MPa (average), f_t= 5.753MPa and f_r=7.09MPa on average. The CFRP sheet with 0.167 mm thickness had a modulus of elasticity 220000MPa, and tensile stress of 4500MPa. Fig. 1 shows the geometric dimensions and reinforcement details for the one way tested slabs.

2.2. Strengthening Procedure

At the end of 28 days of curing concrete, the specimens were smoothed by a disk grinder and cleaned by airbrush at high pressure. The epoxy was prepared by mixing with an electric mixer, the two components A (resin) and B (hardener) in a ratio of 4:1 until it became uniformly grey. The CFRP sheet's places were pointed on the ribs, then the epoxy was applied to the specimens. In the next step, the carbon sheet was applied, and another layer of epoxy was applied on the CFRP sheet if it was necessary to saturate the sheet and ensure the bonding between the concrete and carbon sheet. A deformed roller was then used to interlock the epoxy with the carbon sheet. The specimens were left to cure for one week and then transported to the lab for testing. Fig. 2 shows the strengthening procedure.

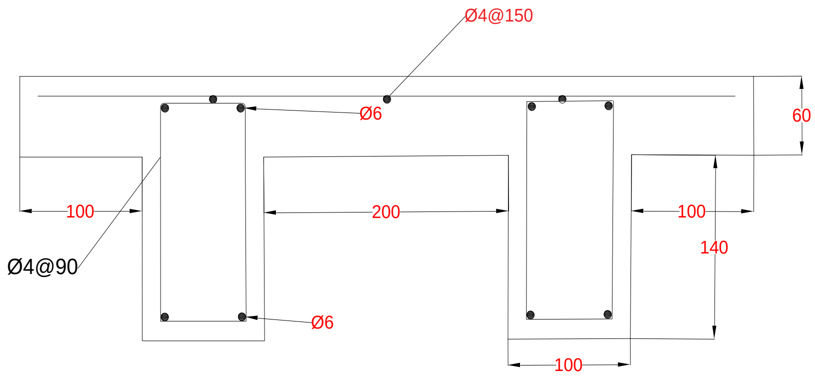

Fig. 1 Dimensions and Reinforcement Details for All Tested Ribbed Slab.

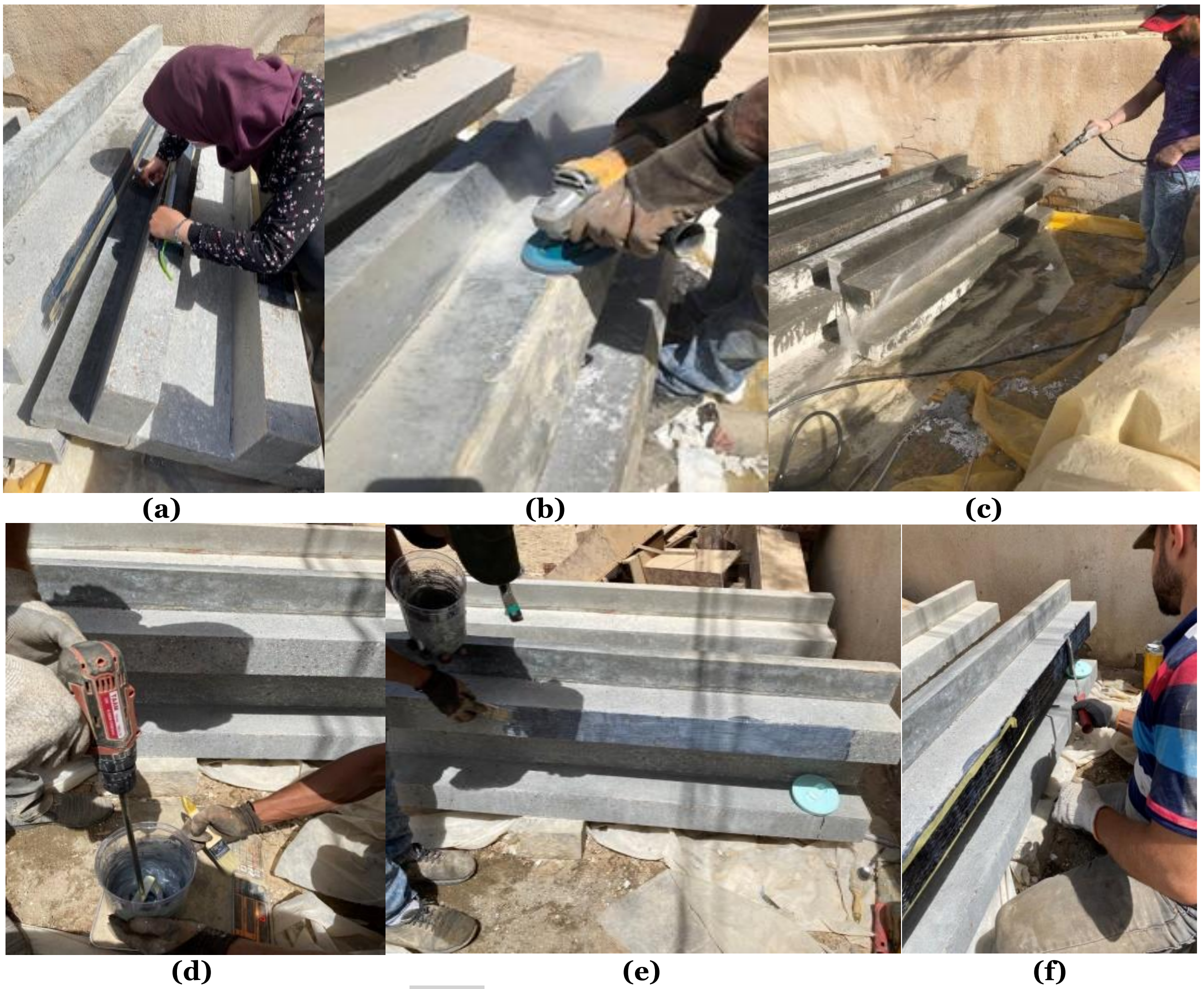

Fig. 2 Strengthening Procedure.

2.3.Specimens Description

As a control slab, one of the specimens was tested without strengthening, and the other five are detailed in Table 1 and Fig 3. respectively.

Table 1 Strengthening Details of Tested Slabs.

Ribs Strength Description	Specimens Design Name
50 mm sheet at 1700 length	HCS-R50
100mm sheet at 1700 length	HCS-R100
50mm with 7U-shape strips	HCSS-R50
100mm with 7U-shap strips	HCSS-R100
Whole rib wrapped	HCS-WR
No strengthening	HC

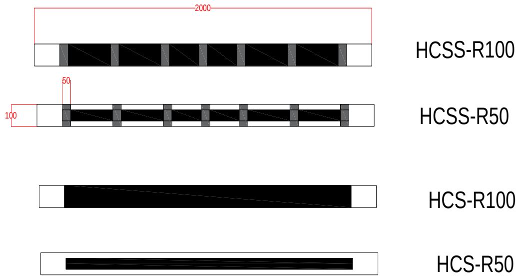

Fig. 3 Bottom View of Rib for Each Strengthened Specimen (All Dimensions in mm).

2.4.Test Procedure and Instrument.

This study tested the slab under one concentrated line load using a universal instrument that applied pressure with a capacity of 600 kN. The slab tested was simply supported. Then, the load was measured by an electrical load cell, while the deflection was measured by a vertical linear variable differential transducer (LVDT) with 0.0001 accuracy, connecting to a data logger. The data logger was connected to a computer to save the data. Four LVDTs were used for this purpose two were in the middle of each rib, and the other two were installed at one-third of the ribs to check the ribs' symmetry. The instruments and supporting frame shown in Fig. 4.

3.RESULTS AND DISCUSSION

3.1.Load- Deflection Response

The load-deflection curve for all specimens in this study showed typical performance under concentrated load. It showed liner behavior before cracking, then changed the slope and remaining liner until it reached the yield point and changed from linearity to non-linearity [19]. In the elastic stage (before cracking), all the specimens were the same, and the strengthening specimens started to separate from the control in the second stage. In this stage, the strengthening slab separated from the control beam, and the CFRP increased the structures' stiffness due to its high tensile stress. The CFRP sheet provided a stiff layer in the tension zone of the ribbed slab that reduced deflection and increased the ultimate load. Although the concrete crack appeared and began to widen, the CFRP sheet prevented that until it could no longer resist. Using CFRP, the ultimate load increased from 18% to 167%, as shown in Table 2, except when using 50 mm, where the ultimate load increased by just 3%. In every fracture in the CFRP sheet in one rib, the curve is straightly concaved down and retains to concave up by redistribution of the loads on the other rib and the remaining CFRP, as shown in Figs. 5 and 6. The result was confirmed by Mahmoud et al. [19], findings where that the ultimate load increased by 70% to 378% when strengthening a thin slab cast in C70 concrete and had a low reinforcement with CFRP laminate. Also, from the result, it noticed that the U-shaped strips and the CFRP in the lateral face affected the flexural behavior by increasing the ultimate load capacity and that the result indicated by Niu et al. [20] and found that using CFRP in the tensile area or the lateral faces raised the ultimate load in the ratio range from 41% to 125%.

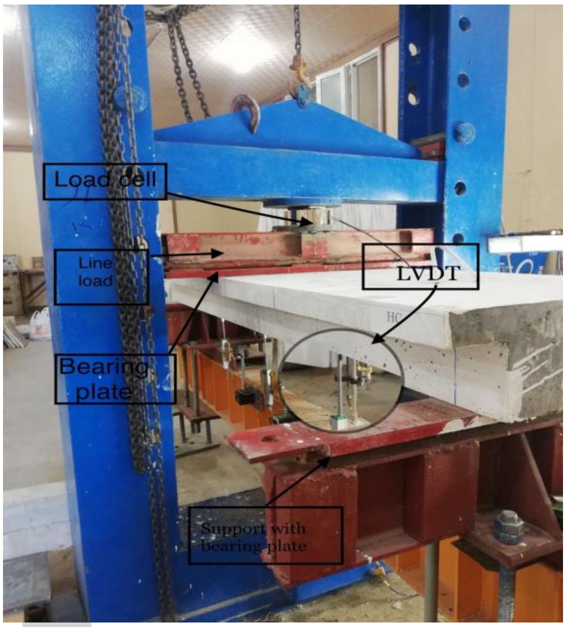

Fig.4 The Specimens Under Testing Device.

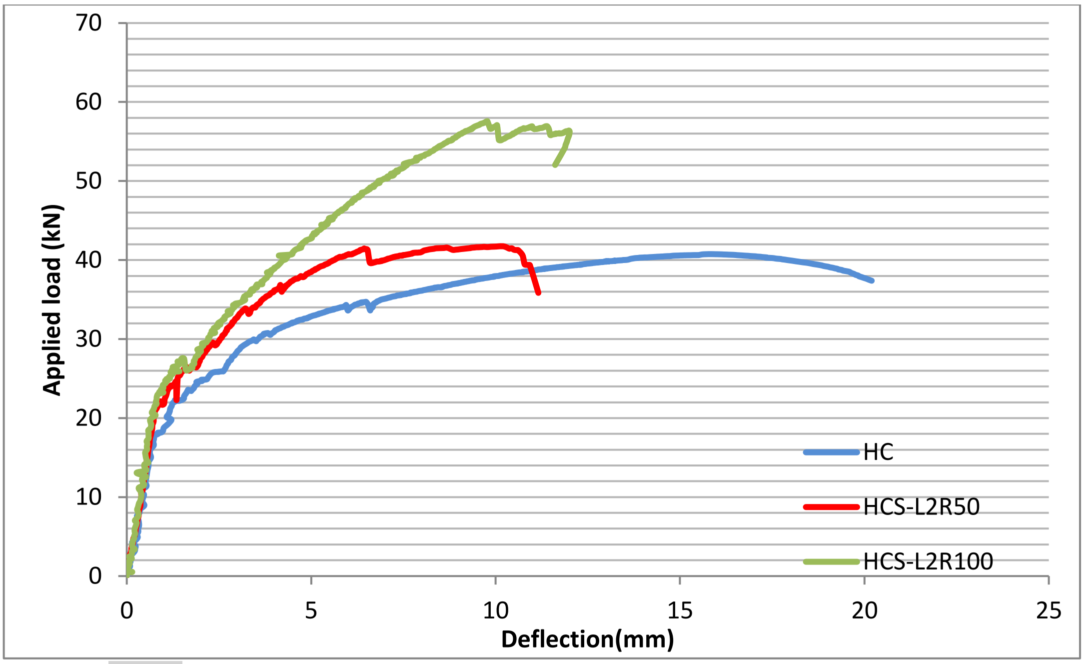

Fig. 5 Load Deflection Curve for Specimens without CFRP Strengthening.

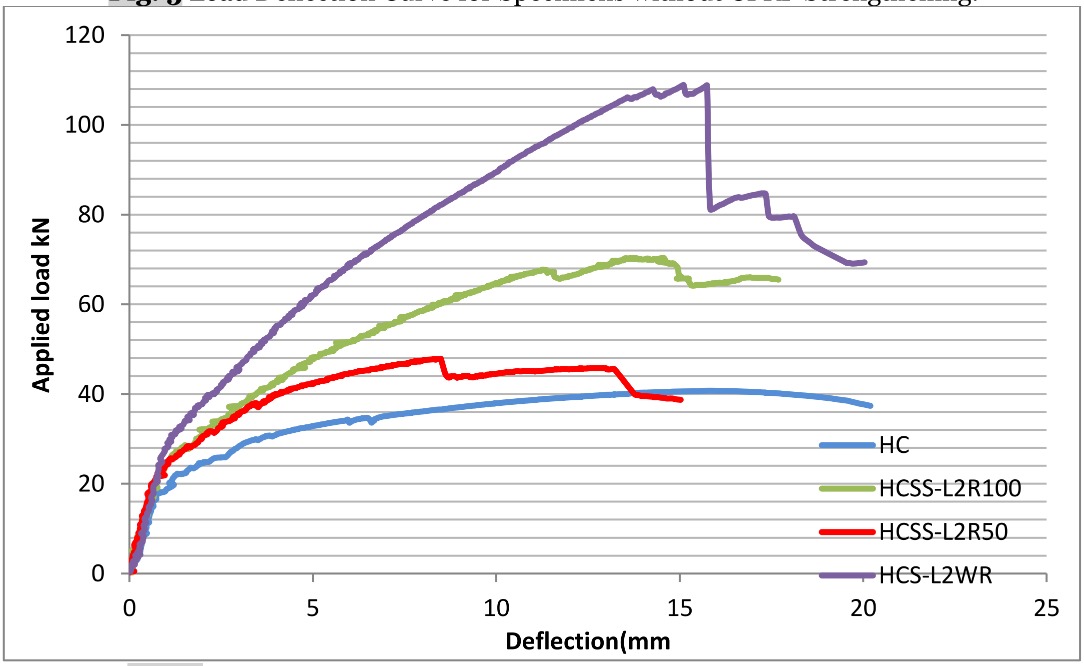

Fig. 6 Load Deflection Curve for Specimens with CFRP Strengthening.

Table 2 The Result of the Testing Specimens.

Specimens Name	Pu(kN)	δu	Stiffness
HC	40.75095892	15.77534	7.79790546
HCS-R100	57.58275747	9.777778	8.47799827
HCS-R50	41.74899817	10.17582	11.5410991
HCSS-R100	70.32058239	14.56899	8.37750538
HCSS-R50	47.86309719	8.4884	11.9999622
HCS-WR	108.8392711	15.10867	9.77691171

3.2.Ductility

This study describes the research approach of RC elements' ductility, defined as its ability to resist inelastic deformation without any decrease in its load-carrying capacity up to failure [21]. It calculates by dividing the ultimate deflection by the yield deflection. Since carbon fiber is a brittle material, its strengthening reduced the ductility of the RC structure. However, the reduction percentage in ductility ranged from 34% to 46% as shown in Fig. 8. The whole warping ribs have the lowest value. Generally, in this group, ductility increased with CFRP sheet width and decreased for specimens without CFRP strips, while specimens with strips' ductility increased.

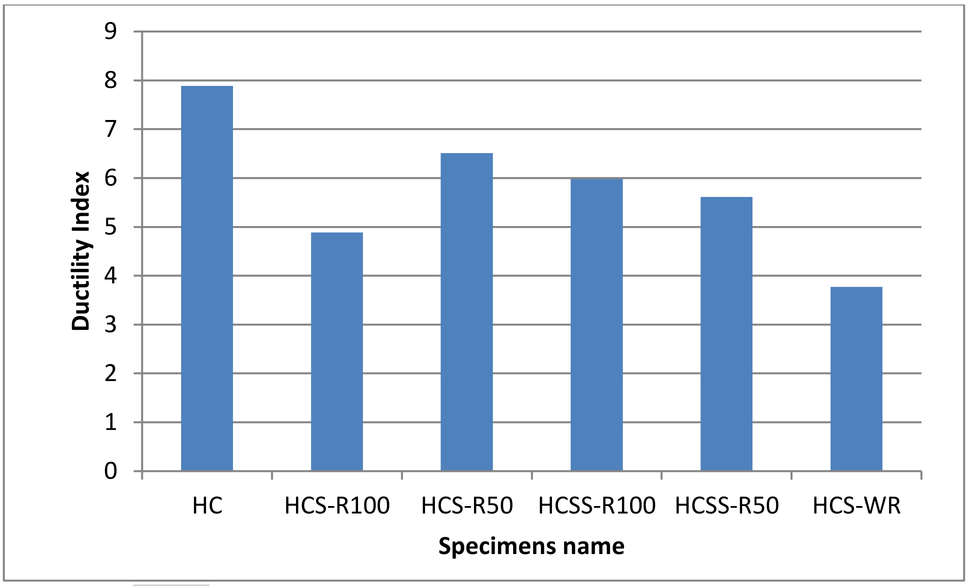

Fig. 8 Comparative between the Ductility of the Specimens.

3.3.Failure Mode

There are various modes of failure. In the present study, when the load was concentrated on the slab, flexural cracks developed at the tension zone in the middle of the span. In this research, as the load lined up, the cracks widened and applied stress on the sheet, and when the stress exceeded the carbon strength, the CFRP sheet ruptured. As a result, the control beam and the specimen HCS-R50 failed due to steel yielding. Its carbon fiber sheet did not fail, while other specimens failed due to carbon fracture due to shear force from widening off cracks. However, the HCSS-R100 specimen's CFRP sheet failed mainly due to the CFRP rupture caused by a horizontal crack parallel to the cover because the CFRP sheet was separated from the concrete near the support and could not be deboned because of the strips Figs. (9-12) show the specimens' failure modes.

Fig. 9 Failure in HCS-R50.

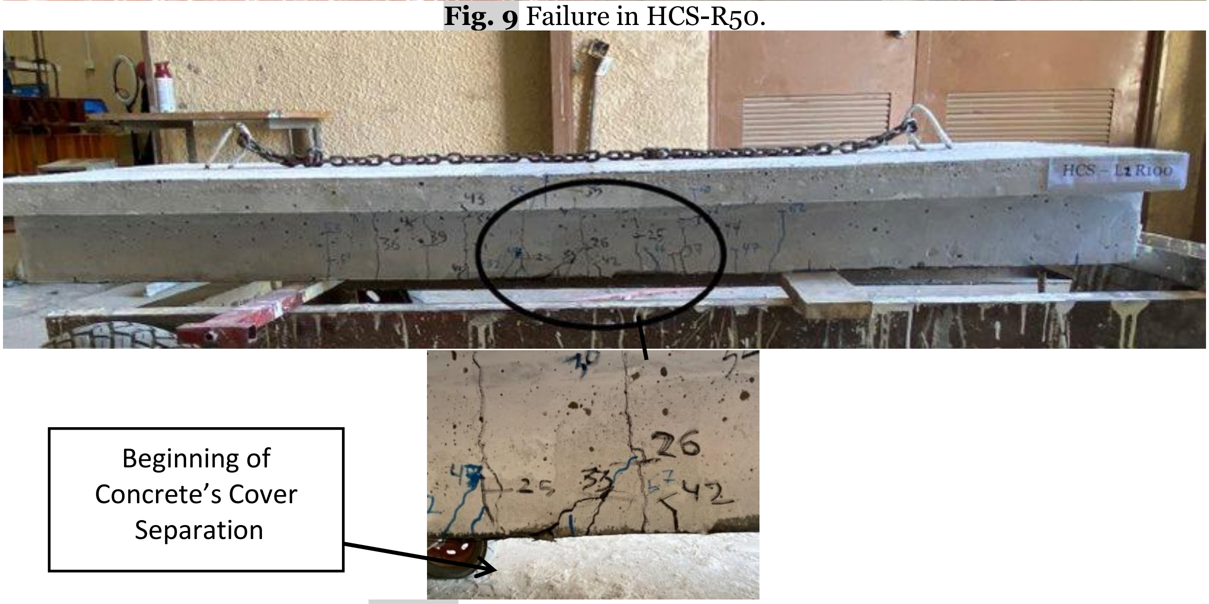

Fig. 10 Failure in HCS-R100 Specimen.

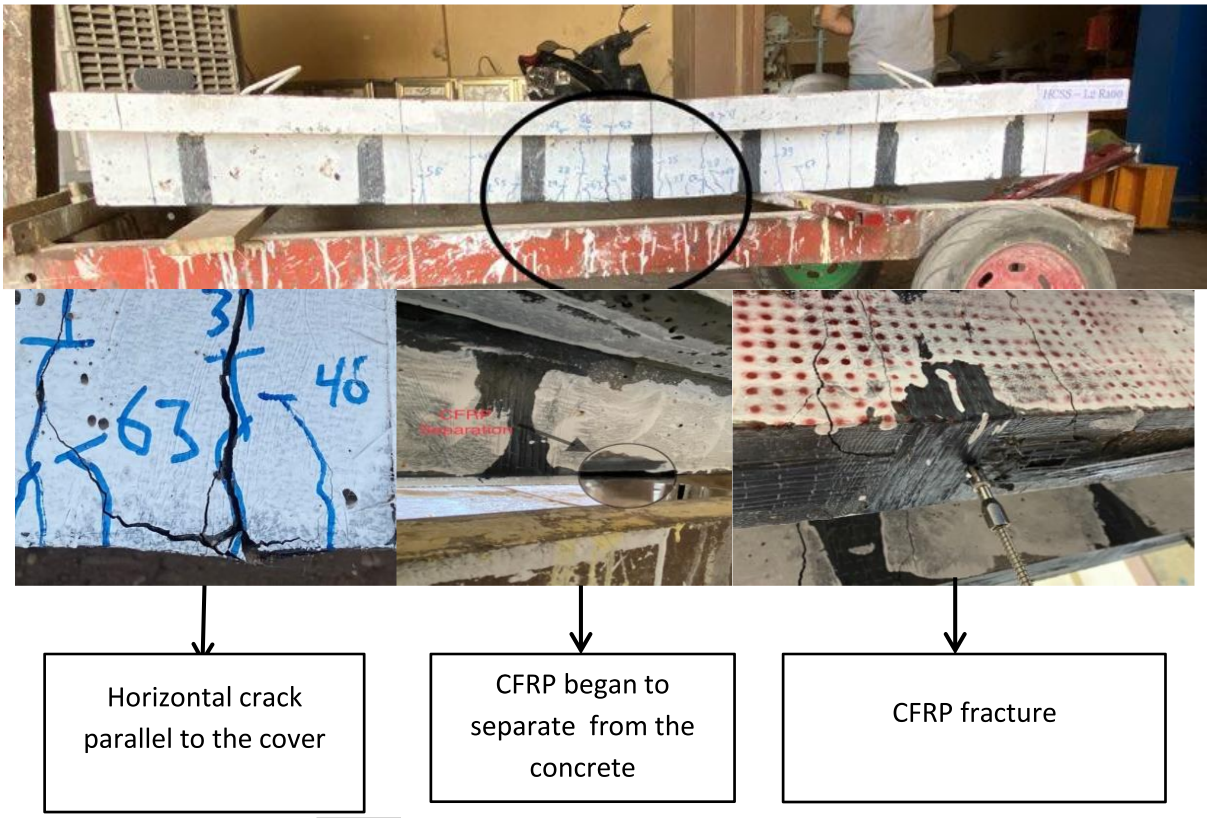

Fig. 11 The Failure of the HCSS-R100 Specimen.

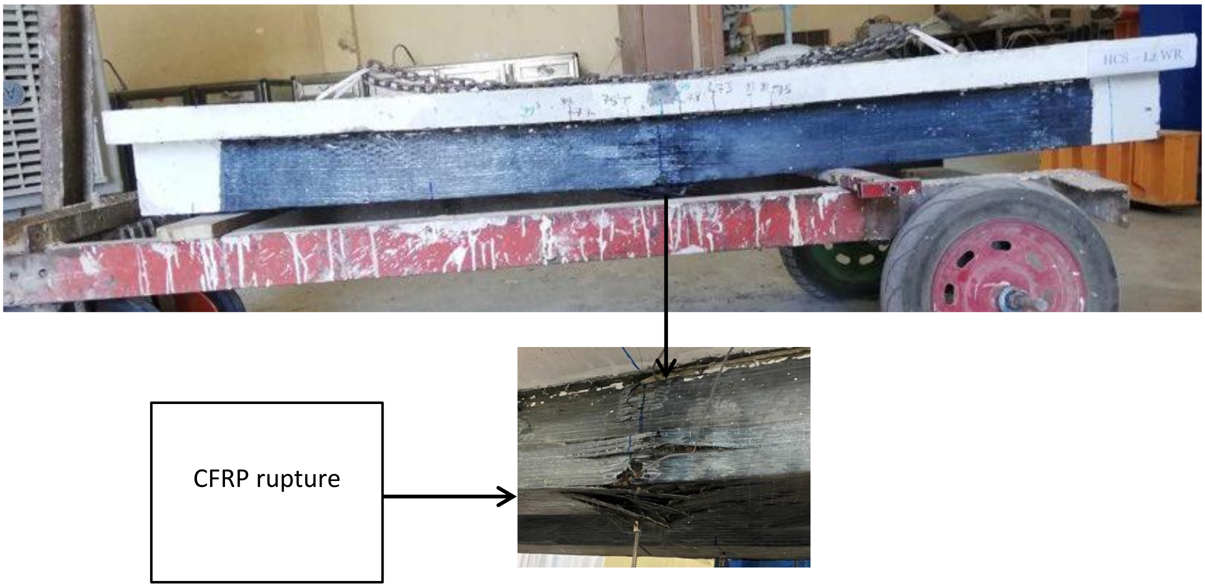

Fig. 12 Failure in HCS-WR Specimen.

4.THEORETICAL ANALYSIS AND EXPRESSIONS

In this research, the ultimate moment was calculated and compared with the experimental moment capacity. Also, the theoretical position of the neutral axis was examined. However, all tested slabs were simply supported and tested under concentrated load. Therefore, the calculated bending moment from Eq. (1) is:

$$M_n = P \times a \quad (1)$$

where P is the ultimate load achieved from the experimental test, and a is the distance from the applied load to the support's center, which was equal to 900 mm, while the theoretical moment was obtained from Eq. (2),

$$Mn = As\,fy\,(ds - (\beta c/2) + Af\,Ff\,(df - (\beta c/2) + As'fy(ds - d') \quad (2)$$

and c can be calculated from Eq. (3), taken from ACI 440-2R [10,22].

$$k_1C^2 + k_2C + k_3 = 0 \quad (3)$$

$k_1 = 0.85\, f'_c\, b\, \beta + A_s'\, f_y\, d'$

$k_2 = -(A_s f_y - \varepsilon_{cu} A_f E_f)$

$k_3 = -(A_f E_f \varepsilon_{cu} d_f)$

Where, A_s and A_f are the steel and carbon fiber areas, respectively, E_s is the steel modulus of elasticity, ds and d_f are the steel and carbon fiber areas, E_F is the fiber modulus of elasticity, and d_s and d_f are the steel and fiber depths. F_f is the tensile stress for carbon fiber, and F_y is the steel's yielding stress. The ACI code calculates the fiber sheet area on the tension face and neglects the other by assuming it would only affect the shear force. However, the experimental work found that the additional strips and the rib wrapping improved the flexural strength. Therefore, the assumption has been made, if the additional CFRP strips were used, the area of CFRP would double (as when using two layers of CFRP sheet). In the case of whole ribs wrapped, the width of CFRP would be calculated in the tensile zone and on the sides of the ribs. The comparison between the theoretical and experimental work shown in Fig. 13.

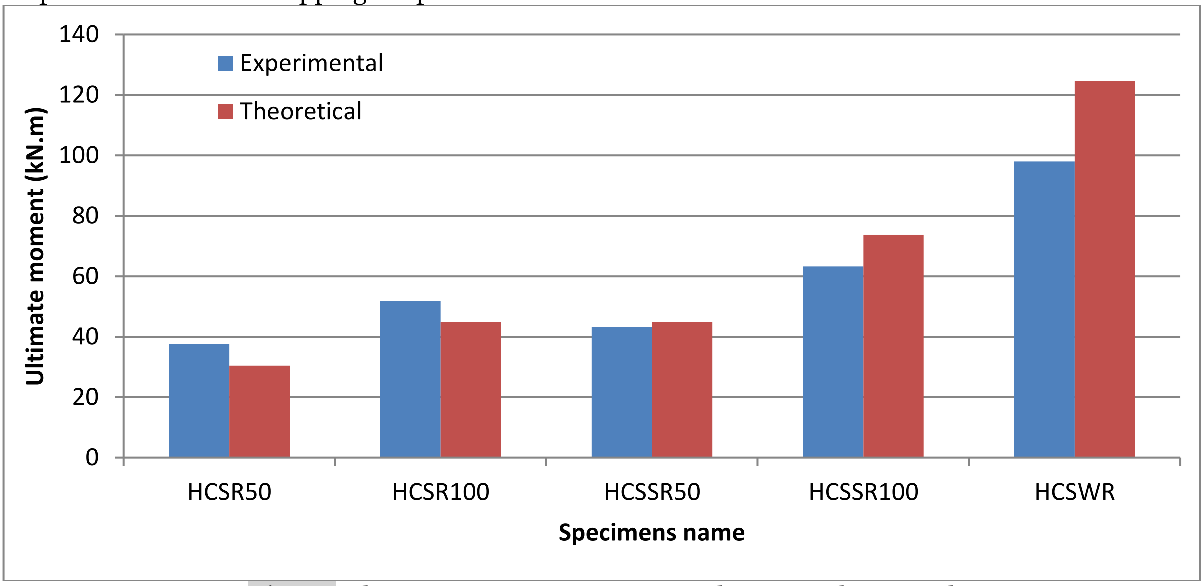

Fig. 13 Ultimate Moment Comparative between Theoretical Analysis and Experimental Work.

5.CONCLUSION

The present study performed experimental work and theoretical analysis on six one-way ribbed slabs. The results are summarized below:

- The CFRP improved the flexural behavior and increased the ribbed slab's capacity. The load bearing capacity for specimens HCS-R50, HCS-R100, HCSS-R50, HCSS-R100 and HCS-WR raised by 3%, 41%, 18%, 73% and 167% respectively, compared to the control ribbed slab.
- A 50mm width of CFRP strips was insufficient to improve flexural behavior.
- Additional U-shaped CFRP strips with 50 mm width and 250 mm spacing (clear space) affected the strength by raising the structure capacity by 23% approximately and reduced the structure's ductility less than those without strips.
- Using whole- wrapped ribs, the capacity increased to 167% reducing the structure's ductility by 52%.
- Using additional strips in spaces close to one another under the point load influenced on the flexural behavior and wrapping all the rips also affected the flexural and shear.
- The theoretical analysis of the specimens' ultimate moment calculations showed that additional U-shaped strips affect the flexural behavior by raising the ultimate strength.
- An assumption was made by taking the U-shaped strips, and the side of CFRP in the whole rib wrap was considered in the calculations. Assuming the additional U-shaped CFRP strips as layer number two and calculating the area in the tension zone and on the side in the case of whole rib wrap. The ratio of experimental to theoretical moments for HCS-R50, HCS-R100, HCSS-R50, HCSS-R100, and HCS-WR were 1.2, 1.15, 0.79, 0.86, and 0.96 respectively.

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