sciendo

Civil and Environmental Engineering
Vol. 20, Issue 1, 555-570, DOI: 10.2478/cee-2024-0042

BEHAVIOR OF LIGHTWEIGHT AGGREGATE WIDE REINFORCED CONCRETE BEAMS WITH SHEAR STEEL PLATES UNDER REPEATED LOADING

Lubna MUFEED ABD-AL-GHAFOOR[1,*], Ibrahim S. I. HARBA[2]

[1] Department of Civil Engineering, College of Engineering, Al-Nahrain University, Jadriya, Baghdad, Iraq.
[*] corresponding author: lubnamufed@gmail.com

Abstract

This study describes an experimental research focusing on the behaviour of Lightweight Aggregate Wide Reinforced Concrete Beams (LAWRCB) using shear steel plates. This technique represents an inexpensive way which reduces structural and building complexities. Wide beams can provide adequate cross-sectional areas to meet the specified capacity in a shallower depth than a system of narrower beams placed similarly in the design. Also, WB treats the crowd of stirrups because the shear component provided by concrete is very small compared with high depth concrete Beams. This research is also trying to minimize the weight of a wide concrete beam using light weight concrete instead of using conventional concrete which has effects on the deflection, crack patterns, and load carrying capacity. This investigation consists of reviewing the previous work and an experimental program consisting of testing mixes to produce lightweight concrete. In addition, several simply supported wide beams with various parametric studies will be designed, cast, and tested. After the specimen tests are carried out, comparisons and discussions of the results will be made with code requirements.

Keywords:

Wide beam;
Lightweight aggregate;
LECA;
Shear steel plates;
Shear failure.

1 Introduction

Wide beams can be used to transfer direct forces or as main transfer elements. A system of wide beams may provide a practical and cost-effective solution for the transportation of column loads from the tower component over the relevant column-free zones on the platform or parking spaces below[1][2].To lower floor elevations and make it simpler to enable services beneath the floor, WRCB with a minimum width-to-depth ratio of two are utilized in structures like warehouses, commercial structures, parking complexes, and office structures [3][4]. And also R.C. joist flooring were employed in one method for structural and architectural reasons [5]. WRCB is advantage for decreasing reinforcement concentration in the flat slab system's column strip, improving control over bending and cracking criteria, without requiring the usage of drop panels or heavier slabs, and giving this system suitable punching shear resistance [6]. Many suitable construction systems, such as RC joists and ribbed slabs, can accommodate these components when their depth is equivalent to or slightly greater than the slab's depth [7]. Wide beams and thick slabs are distinguished by a large width that is at least two times higher than the depth [8] [9]. One of the many types of strengthening which can be used is shear steel plates. This type of reinforcement is often used because it is widely accessible, affordable, isotropic, simple to work with, and has a good ductility and resistance to fatigue [10]. Several research works have been conducted to examine the efficiency of utilizing steel plates in improving the shear behavior of conventional beams using a range of connecting procedures. Numerous studies have shown that when this type of strengthening is used, considerable benefits may be achieved [11][12]. Steel plates can be used to strengthen structural components or replace damaged elements by adhering the plates to the surface of beams with adhesive or bolts[13][14][15].Utilizing lightweight concrete, such as foamed concrete or LECA, offers the advantage of reducing a structure's self-weight while simultaneously enhancing its fire resistance, sound insulation, and thermal properties in comparison to

© Author(s) 2024. This work is distributed under the Creative Commons BY 4.0 license (https://creativecommons.org/licenses/by/4.0/).

conventional concrete [16] [17] [39]. Additionally, shear steel plates find application in ensuring the shear stability of thin plates on ships [18].

Dywany,2010 [19] The shear performances of ten wide beam samples were analyzed by Dywany. The findings revealed that the widths of the supports (100%, 50%, and 25%) relative to the width of the beam were investigated. It was observed that the thin support had minimal influence on the shear strength of concrete, and the concentration of flexural reinforcement across the beam width did not significantly impact shear strength either. The study also examined the placement of flexural strengthening throughout the beam width and investigated the presence of shear reinforcement in the form of vertical linkages. In all tested samples, the test configuration was consistently created, and two specimens failed in diagonal tension shear. This failure occurred because the applied loads were uniformly distributed over the breadth of the beam. However, when focusing the reinforcement for flexure within the support width, the efficiency of the links was restored to 100%, even after experiencing an 80% reduction due to the presence of a narrow support.

Shuraim in 2012 [20] Ihe investigation focused on several wide beams with varying transverse reinforcement spacing, leg number, and support widths. The findings of the study highlighted that commonly used design standards tend to overestimate the shear capabilities of wide beams. This overestimation occurs because these design standards do not consider crucial factors such as transverse reinforcement spacing, the number of legs in the reinforcement, and the width of the support.

Ali and Agarwal 2013 [21] The examination focused on four wide beam (WB) specimens, specifically analyzing their shear behavior. The third set of specimens comprised standard beams acting as control subjects, and concrete with integrated steel plates was employed to investigate the influence of support widths (100 percent of the beam width), the distribution of reinforcement for flexure across the beam width, and the presence of shear reinforcement. Although the test setup remained consistent across all specimens, a noteworthy distinction occurred during the occurrence of diagonal tension shear. In the control specimen, failure ensued when the load was applied at a distance of 300 mm*300 mm from the center of support. Conversely, the remaining examples failed in the flexural domain. The results of the study revealed that neither the wide beam with integrated plates nor the concentration of flexural reinforcement within the support width exerted any discernible impact on the shear strength of concrete.

Mohammadyan et al.,2015 [8], the research focused on the shear behavior of six wide beam internal-column specimens. Each specimen was subjected to various types of shear reinforcement to assess their effectiveness in enhancing the shear capacity of wide beams, considering scenarios both with and without vertical stirrups. The tested reinforcements included isolated bent-up bars, isolated horizontal bars at the middle depth, and straight stirrups with coiled bars. Furthermore, an additional specimen without stirrups but with approximately two-thirds of longitudinal reinforcement possessing flexural properties, placed in a column band, was tested to investigate the impact of this strengthening method on the wide beams' shear resistance. Various parameters such as deflection, fracture patterns, stresses in steel and concrete, ultimate load, and failure mechanisms were analyzed to evaluate the performance of the specimens. The results demonstrated that the use of isolated bent-up bars notably improved the ductility and shear capacity of wide beams. Although independent horizontal bars to some extent increased shear capacity, the beam exhibited lower ductility upon failure. Additionally, the findings suggested that the inclusion of banded primary reinforcement led to a higher load failure in the wide beams.

Ibrahim et al., 2015 [3] Employed experimental methods to investigate the shear behavior of wide beams (WBs) constructed with reinforced concrete. The experimental program included testing four WBs made of concrete with a compressive strength of 45 MPa, each with a shear ratio of span to depth (a/d) set at 4.52. One of the tested WBs served as a control specimen with web reinforcement, while the other three specimens featured vertical shear steel plates in lieu of transverse reinforcement to induce shear failure. The flexure mechanism of failure for each specimen was determined. The study specifically focused on examining the impact of the presence and orientation of vertical steel plates, both solid and hollow, on the shear capacity of the wide beams. The findings indicated a significant and direct correlation between shear strength and the presence of vertical steel plates. Across the tested beams relative to the control beam, the range of shear capacity increase was observed to be between 9.52% and 47.62%. Furthermore, the inclusion of transverse vertical steel plates with voids not only enhanced the ductility of wide beams but also contributed more effectively to their shear strength.

Mansoor,2016 [22] The behavior and strength of bubbling wide rectangular concrete beams (WRCB) with shear steel plates were investigated through experimental examination. The study involves 16 WRCB specimens measuring 215x560x1800 mm. Various factors are considered, including the use of steel plates with thicknesses of (3, 4,5) mm in both horizontal and vertical orientations, replacing

traditional strengthening stirrups. Additionally, half of the specimens are made using recycled PVC spherical bubbles. The study also examines the effect and shape of the openings in shear steel plates and their separation from each other. The findings indicated that employing circular-opening shear steel plates, as a substitute for stirrups or other shear reinforcement, had a negligible impact on yield and ultimate load, with a difference of only about 5% in the experimental program. However, for rectangular openings, yield and ultimate load differences were approximately 7.5% and 13.6%, respectively. The use of bubbles as a substitute for stirrups led to a 10% reduction in the recorded yield load. On the other hand, for specimens with shear steel plates, the yield load increased by an average of 1.5% when compared to identical specimens without bubbles. The study concluded that satisfactory consensus on ultimate load, yield, and deflection could be achieved by using bubbles or substituting longitudinal steel plates for stirrups in WRCB specimens.

Iman Majid, 2016 [23] The investigation focused on the use of steel plates as a substitute for stirrups in shear reinforcement for self-compacted concrete (SCC) beams. The study also examined the effects of various parameters, including the spacing, thickness, and inclination (45°) of these steel plates. Nine SCC beams underwent destructive testing in the experimental work, subjected to stresses at two points. The primary objective of the investigation was to assess the impact of employing steel plates for shear reinforcement in SCC beams, compared to traditional reinforcing bars (stirrups), and to analyze the effects of plate spacing, thickness, and inclination. In all beams strengthened with steel plates, the average deflection at the yield load was found to be greater by 12%. Additionally, six beams underwent a theoretical study using the finite element tool ANSYS (version 15). A parametric analysis was carried out to investigate the impact of reinforcement ratio, reinforcement yield strength, plate thickness, and limb width. The parametric study revealed that the ultimate capacity of beams using steel plates for shear reinforcement was, on average, 6.11% higher, considering the thickness and width of limbs, resulting in lower strain in the shear steel plates and longitudinal reinforcement. Furthermore, the ultimate capacity was found to be, on average, 9.8% higher, considering a higher reinforcement ratio with the same yield strength for stirrups and shear steel plates.

Kuang et al., 2017 [24], the researchers investigate the seismic performance of reinforced concrete wide beam-column (WB-column) connections based on the analysis of 26 internal WB-column test results that are readily available. The primary objective was to examine the influence of key factors on the behavior of these wide beam-column connections. To achieve this, the researchers create an analytically derived effective beam-width model using the equivalent-frame representation. This model took into account the effects of transverse beam torsion and flexure around the joint core. The flexural strengths of test specimens, which encompassed a diverse range of design elements, were utilized to validate the validity of the model. The study then utilized a straightforward and precise design method to determine the beam width restriction of WB-column connections. This method combined the suggested effective beam-width model with a rational analytical technique, providing a comprehensive understanding of how various influencing elements affect the seismic performance of RC WB-column connections.

Behnam et al., 2018 [25] The theoretical framework of Concrete Damaged Plasticity (CDP) theory was utilized for the finite element analysis (FEA) of reinforced concrete wide beam-column (RCWB) connections. The study validated the predictive capacity of the model by employing it to simulate the behavior of four full-scale external WB column connections subjected to reversed cyclic loading conditions. A concise description of the test program was provided, and the study demonstrated a high level of agreement between the test findings and the results obtained from finite element models in various aspects, including lateral load-displacement response, reinforcement yielding, crack patterns, and failure mechanisms. The discussion delved into the sensitivity of the outcomes to diverse model factors, encompassing the viscosity parameter, pore size, dilation angle, yielding surface elements, crack energy, damage dimension, and style of analysis. The study identified key parameters of the model along with their unique features. Moreover, the research conducted a parametric numerical analysis to investigate how the performance of external WB-column connections was influenced by various parameters. These parameters included the column axial load, column and beam diameters, beam bar anchoring ratio, and spandrel beam reinforcing. The comprehensive analysis provided valuable insights into the behavior of RCWB-column connections under different conditions.

Abass and Yousif 2019 [6] Investigate the efficacy of using carbon fiber-reinforced polymer (CFRP) as shear reinforcement to enhance the shear capacity of reinforced concrete wide beams (RCWBs). The study presents findings based on four full-scale WRCBs, with two of them reinforced using a stirrup-free, vertically inclined sheet of CFRP. Additionally, one of the beams was modeled using the ANSYS program. Each beam was cast with standard concrete strength of 30 MPa, subjected to two-

point loads, and supported simplistically. Various parameters such as mode of failure, deflection, stresses in concrete and steel, fracture patterns, and ultimate load were considered to assess the performance of the beams. The results indicated that, in comparison to the control beam, the ultimate loads of the beams strengthened with vertically inclined CFRP and shear reinforcement increased by 19.9%, 7.14%, and 39.8%, respectively. This suggests that externally bonded CFRP has the potential to substitute internal shear reinforcement, showcasing its effectiveness in enhancing the shear capacity of RCWBs.

Mohamed et al., 2020 [26] The investigation focuses on the shear behavior of shallow wide beams (WBs) reinforced with shear by utilizing Strain-Hardening Cementations Compounds (SHCC) as external layers. The study aimed to explore the impact of shallower WBs' shear strength in comparison to vertical stirrups, specifically through shear strengthening using SHCC along shear spans in the form of a jacket with two sides or a U-shape. The use of SHCC in this context involved elements that could contribute to different qualities in the most optimal and effective ways, surpassing the performance of standard cement mortar. The experimental program comprised eleven samples divided into three groups, with the main objective of examining the shear behavior of shallow WBs with and without stirrups. The study also investigated the impact of SHCC's depth and grade for shear reinforcement, considering different jacketing designs that either included or excluded external stirrups. The investigation involved comparisons between the predicted outcomes and experimental results based on certain international code provisions. Additionally, the recommended equations took into account factors such as the lateral reinforcement ratio, shear span to depth ratio, and beam axis, along with considerations for concrete/SHCC grades. The study also considered the size impact, containment by jacketing, and inclination of compressive stresses in its examination of the shallow WBs' shear behavior.

Mawlood et al.,2021 [27], the shear performance and capacity of shallow wide beams (WBs) were investigated both experimentally and theoretically. The aim is to assess the impact of the ratio of beam width to height (b/h), which varied between 0.67 and 3, the shear reinforcement ratio ranging from 0% to 0.222%, and the amount of carbon fiber ranging from 0% to 0.53%. A total of seven beam specimens were evaluated, considering varying reinforcement and loading details. The study's findings revealed that the shear strength of the beam decreased as the width to height ratio increased. Additionally, the results suggested that using the requirements specified in the code (ACI318-14) for predicting the shear capacity of shallow WBs may not provide accurate results. This indicates the importance of considering the specific characteristics and parameters of shallow WBs when assessing their shear behavior, as the standard code provisions may not fully capture the unique performance aspects of such structures.

Abduljabar, 2022 [29] A comprehensive investigation was carried out using a test system involving the casting and evaluation of twenty beam specimens. The study aims to determine the structural behavior of wide beams made of steel fiber-reinforced concrete. Various parameters were considered, including shear spans to depth ratios ranging from 2.5 to 3.5 and two nominal levels of strength: 30 MPa for "Normal strength concrete" and 60 MPa for "high-grade concrete." Two types of steel fibers, namely "End Hocked" and "Staggered," were employed, with volume fractions of 0.5% and 1.5% for each. The findings of the study demonstrated that the inclusion of steel fibers significantly improve the ensuing mechanical characteristics and structural behavior of wide beams. Additionally, the inclusion of steel fibers altered the shear failure mechanism from shear to "flexural." The initial cracking load in "Normal strength" increased by 21.95% to 73.73% with the addition of "End Hocked" and by 12.19% to 45.45% with the addition of "Staggered." In the "High strength" range, "End Hocked" showed an increase of (15.95-45.76%), while "Staggered" ranged from (7.25-28.81%). Furthermore, the ultimate load in "Normal strength" was enhanced by 19.75% to 65.98% with the addition of "End Hocked" and by (10.52-43.81%) with the addition of "Staggered." In the "High strength" range, the ultimate load increase was recorded as (13.5-43.57%) for "End Hocked" and 7.25% to 29.29% for "Staggered." These results highlight the significant influence of steel fibers on the mechanical and structural performance of wide beams, providing valuable insights into the enhancement of their load-carrying capacity and failure mechanisms.

No available literatures on Lightweight Aggregate concrete wide beam with shear steel plate under repeated loading, so that the historic review of previous research for normal weight concrete, therefore, the present study will be on LAWRCB with Shear Steel Plates under monotonic and repeated loading.

The objectives of the research:

1) Examining the effect of shear steel plates on LAWRCB under monotonic and repeated loading.
2) Comparing the behaviour of shear steel plate with conventional shear reinforcement (stirrups) under repeated and monotonic loading.

3) Examining the impact of raising the thicknesses of plates on the ultimate strength and cracks behavior.

2 Experimental works

The research investigated the influence of experimental work on the shear behavior of Lightweight Aggregate Wide Reinforced Concrete Beams (LAWRCB) reinforced with shear steel plates of various thicknesses (3, 4, 6 mm) in the transverse direction, along with stirrups. The stirrups had an area equal to the area of steel plates for each thickness. Fourteen simply supported concrete wide beams with the same rectangular cross-sectional area were utilized in the study. The beams were subjected to testing under two-point loads, and the experimental setup included both monotonic and repeated loading conditions. The beams were specifically designed to fail in shear according to the provisions outlined in ACI 318M-19 [30].

2.1 Materials

Materials used in this experimental work:

1) Ordinary Portland cement (Maas) conforming to Iraq standard specification I.Q.S No, 5/2019 [31].

2) Fine aggregate (sand) from the area of (Al-Ukhaidher) conforming to the Iraqi specifications (I.Q.S No. 45, 2021) [32].

3) Light Expanded clay aggregate (LECA) as a replacement of coarse aggregate its grade (0-8) mm from Iran.

4) Use Tap water to wash aggregates, mix concrete, and cure specimens.

5) The ASTM A615 2016 specification [33] and ASTM A(496M-07) specification [34] provide the following dimensions for the steel reinforcement: Ø 10 mm for all stirrups and top bars, with a yield strength of 586.1 MPa, and Ø 16 mm for bottom longitudinal bars.

6) Shear steel plates with various thicknesses (3,4,6) mm in transvers direction designed according to [22] which have three circular hollow shown in figure1 by laser machine and tested, the results of test shown in table 1. Plates area using in calculation is located along the mid- height of the plate.

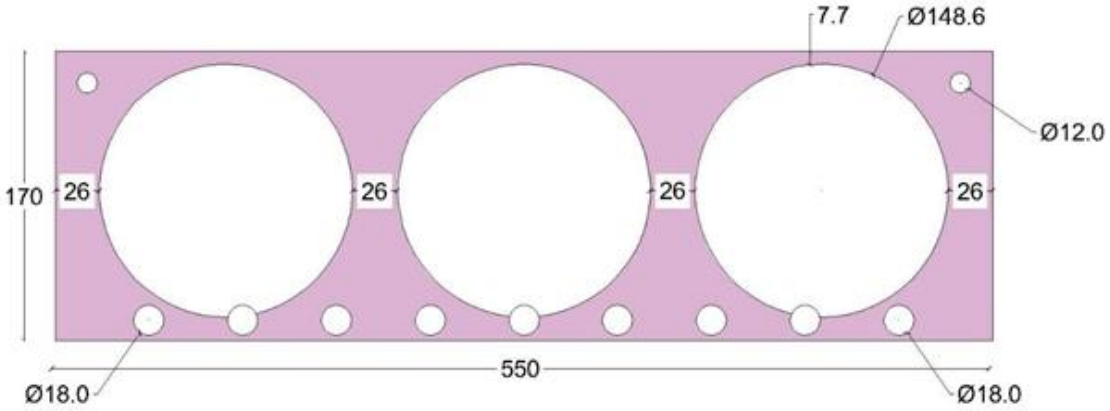


Fig. 1**:** The shape and dimensions of steel plates.

Table 1: Plate test result.

Thickness of tested steel plate [mm]	Average of yield tensile strength [MPa]	Average of ultimate tensile strength [MPa	% Elongation at ultimate stress
6	320.12	400.3	21.5
4	295.05	393.23	32.5
3	321.11	395.41	22.5

7) Superplastisizer Admixture PCE 600 was used mainly and was applied in the manufacture of precast concrete and lightweight aerated concrete. The advantages of this type have an effect on the strength and the ratio of W / C, as when adding it, the ratio of W / C is reduced, which increases the strength of concrete see Table 2. shows the usual characteristics of the used admixture PCE 600.

Table 2: Properties of Super plasticizer.

Properties	Concrete super plasticizer
Appearance	Yellow to brown liquid
Specific gravity	1.07 ± 0.03
Air entrainment	Maximum 1%
Chloride content	Nil to BS 5075: 1982
Nitrate content	Nil
Handling	No special precautions
Freezing point	-1
Storage life	At least one years (it should be kept away from heat)

The properties are given in accordance with the datasheet provided by the manufacturer.

2.2 Concrete mixes

The objective of the mix is to achieve optimal workability and attain a favorable compressive strength as per ASTM C330M-17A [35]. Assessment of the compressive strength of the mixture was conducted at both seven and twenty-eight days. The results were derived from the average of three cubes. The pertinent details of the mix design are presented in Table 3.

Table 3: Percentage of mix design.

Cement kg/m³	Sand kg/m³	LECA kg/m³	PC600 L/m³	W/C	f_{cu}/ 7 days MPa	f_{cu}/ 28 days MPa	Density kg/m³
400	960	240	4.38	0.23	27.27	35.45	1795

2.3 Mixing and casting

Step1**:** Fourteen timber mold were constructed to cast all WBs. The molds sides were bolted together, making it simple to remove them from the concrete beam.

Step 2: In order to confirm the cover, install the spacers with bars (2.5cm). is in compliance with the (ACI 318M-2019) specification, after which insert the reinforcement into the molds.

Step 3: The LECA, PC600, Sand, cement, and amount of water were put to the mixer. The last of the water was then added, and everything was combined.

Step 4: The combination of ingredients was placed into the molds by double shooter after step 3 was completed. 15 seconds of vibrator use is required to reach complete compaction. Samples are kept for 28 days in the field.

To find the compressive strength of the mix, cubes 150 x 150 x 150 mm, cylinders 150 x 300 mm, and prisms 100 x 100 x 400 mm were cast, dry density for lightweight concrete, splitting tensile strengths, elastic modulus, and flexural strength. Every specimen was demolded and cured in water for a total of 28 days after a 24-hour period; Figure 2 illustrates every stage of this process.

Fig. 2: Wide beam specimens, casting, and the curing process.

2.4 Wide Beam designation and information

To investigate shear behavior of LAWRCB, Fourteen simply provided support for wide concrete beams with a same rectangular cross section of (L×W×H) (1.8m×0.6m ×0.22m) and the distance (d) between the outer fiber of the concrete beam's compression side and the center of tension reinforcement is (177mm). The beams were tested under two points load and were intended to fail under shear according to ACI 318 M-19. see figure 3 the details of refrences beam. All beams are classified into two groups depinding on the type of load the first group (A) contain 7 beams which tested under monotonic load and the second group (B) also contain 7 beams tested under repeated load. as shown in Table 4 Group (A) consists reference wide beam (WBM0) without reinforcing, three beams reinforced with stirrups and three reinforced with shear steel plate. Group (B) is the same as (A) but tested under repeated.

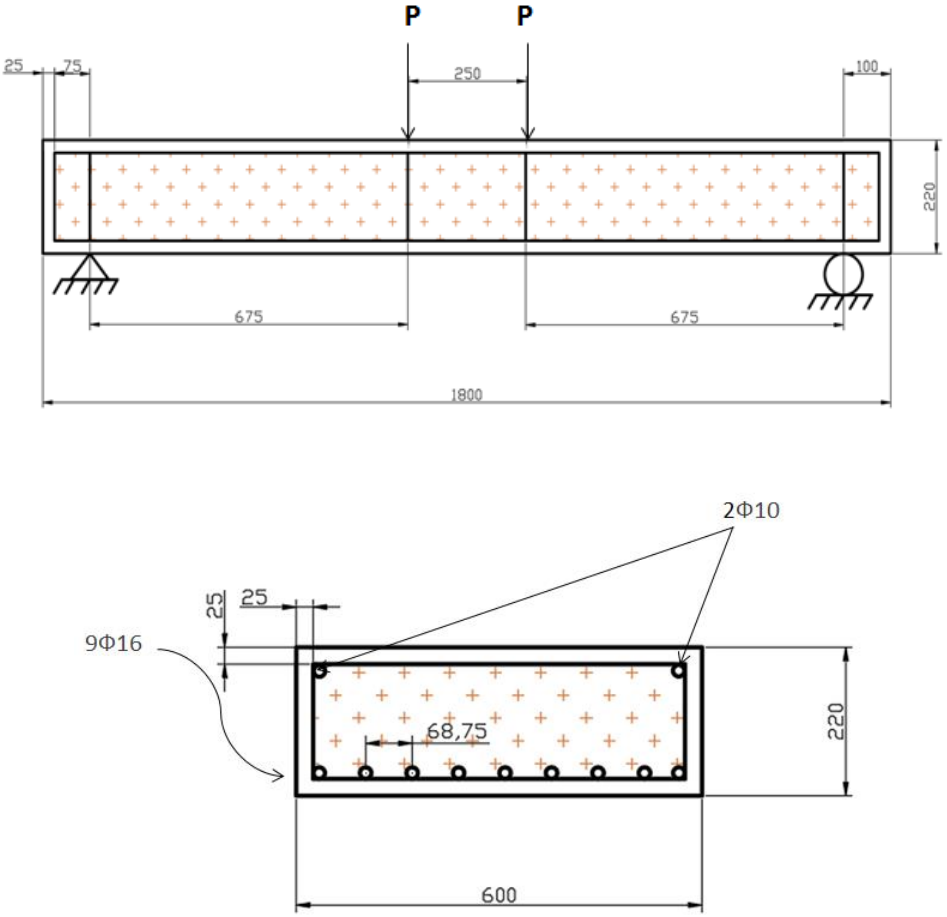


Fig. 3: Some typical details of the reference wide beams (WB).

Table 4: Shear reinforcement details for each beam.

Specimen no.	Type of Loading	Type of reinforcement	Type of Loading	Repeated Load	Area of shear reinforcement [mm^2]	Spacing of stirrups or steel plates [mm]
1	Monotonic	Without stirrups	Repeated	Without stirrups	.....	.....
2	Monotonic	Shear plate 3 mm	Repeated	Shear plate 3 mm	312	275
3	Monotonic	Shear plate 4 mm	Repeated	Shear plate 4 mm	416	275
4	Monotonic	Shear plate 6 mm	Repeated	Shear plate 6 mm	624	275
5	Monotonic	Stirrups $V_{s\ Stirrups}{}^{*} = V_{s\ plate\ **3\ mm}$	Repeated	Stirrups $V_{s\ Stirrups} = V_{s\ plate\ 3\ mm}$	157	250
6	Monotonic	Stirrups $V_{s\ Stirrups} = V_{s\ plate\ 4\ mm}$	Repeated	Stirrups $V_{s\ Stirrups} = V_{s\ plate\ 4\ mm}$	157	200
7	Monotonic	Stirrups $V_{s\ Stirrups} = V_{s\ plate\ 6mm}$	Repeated	Stirrups $V_{s\ Stirrups} = V_{s\ plate\ 6\ mm}$	157	125

$^{*}V_{s\ Stirrups}$ – shear resistance by shear reinforcement (stirrups),

$^{**}V_s$ – shear resistance by shear plate, according to ACI 318 M-19 $Vs = \frac{Av * Fy * d}{s}$.

Where:

Av – cross section area of steel (mm^2),

Fy – yield tensile strength (MPa),

d – effective depth of concrete (mm),

s – spacing (mm).

$V_{s\ plate} = V_{s\ stirrups}$ - equality of Vs due to differences in Fy of stirrups and steel plate because this plate is only available in local market, so therefore $V_{s\ plate} = V_{s\ stirrups}$ led to variation in spacing to ensure equality of Vs.

2.5 Testing setup

The hydraulic testing apparatus including a maximum capacity of 2000 kN was employed to evaluate all beams as shown in Figure (4). All beams were put to the test under monotonous and repeated loading. Up to the ultimate load at the College of Engineering's structural laboratory at Al-Nahrain University. The wide beams that were put to the test were just supported at both ends along a span of 1600 mm from center to center of supports. All WBs tested under two point load, the distance between these points is 250 mm. The samples had white paint applied to them to aid in the detection of the initial crack and to make crack patterns more obvious. In addition, to detect the spread of cracks. Also illustrated the location of two-point load and location of supports. The support point and loading point were labeled, as well as the beams themselves. The centerline supports, and load arms of the beam specimens were all put in place on the testing equipment. To begin the loading procedure, a one-point load from the testing machine is applied to the upper midpoint of the loading beam. The single load was then split evenly between the two points loads that are transferred to the concrete beams through two arms attached to the beam. The load-deflection behavior of every WB was noted by dial gauge with accuracy at bottom of midspan. The beam was loaded incrementally until it failed. As a simply supported wide beam, all beams were evaluated under pressures of two points. Until the failure, the monotonic load was applied at a steady rate. During the repeated (non reverse) loaded history, the first stage of low cycle fatigue applies ten cycles of deformation amplitude, i.e., $\Delta 1 = 0.1\Delta u$, followed by three further cycles of amplitude 1.2 times the first stage, i.e., $\Delta 2 = 1.2\Delta 1$. While subjecting the specimen to three cycles until complete damage [36][37]. Figure (5) illustrated the history load. For example, the max deflection of control specimen tested under monotonic load (WBM0) is ($\Delta u_{max=}$ 14.42). The deflection of the first stage for similar specimen but tested under repeated load (WBR0) is Δu_1= 1.44,for other stage $\Delta 2$=1.73, $\Delta 3$=2.08, $\Delta 4$=2.49, etc.

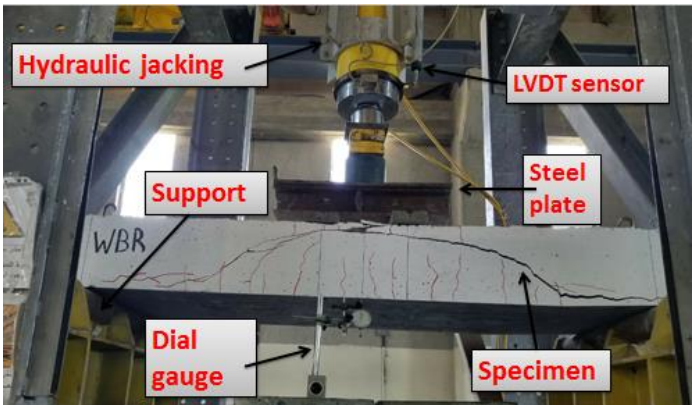


Fig. 4: Test Setup for Beam Specimen.

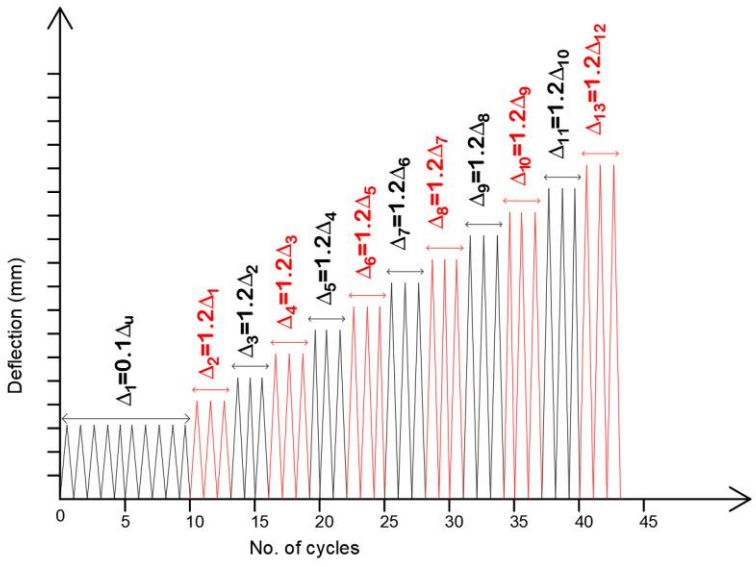


Fig. 5: History of Repeated Load.

3 Test results

3.1 Mechanical properties

In accordance with ASTM C496/C496M-11 [38], cubes of 150 x 150 x 150 mm and cylinders measuring 150 x 150 mm were tested to ascertain the concrete's compressive strengths, dry density, splitting tensile strengths, elastic modulus, and rupture modulus after 28 days. The concrete lab at the University of Al-Nahrain was used for these experiments. Table 5 presents the findings.

Table 5: Mechanical Characteristics of Results.

Specimens	F_{cu} [MPa]	$f`_{cyl}$ [MPa]	ft [MPa]	Ec [GPa]	fr [MPa]	ρ_d [kg/m^3]
Cubes	37.6	-	-	-	-	-
Cylinders	-	32	3.3	25	-	1750
Prisms	-	-	-	-	3.7	-

3.2 Testing and beams results

The fundamental actions of the LAWRCB are described as follows specimens that were being tested under monotonic and repeated load. Flexural failure is avoided because of the manner the WBs were reinforced. This suggested that before the flexural reinforcement yields, a shear failure mechanism arises. The concrete's tensile strength determines the shear failure process in parts lacking shear reinforcement. The imparted force was reflected in the mid-span deflections. Shear fractures were the first to appear in the beam, and they began in the lower part of the beam and extended vertically between the loading points (tension zone). All beams under repeated load failed in ultimate load fewer than monotonic load but deflection is more than deflection in monotonic. Every one of the WRC beams' findings are displayed in Table 6.

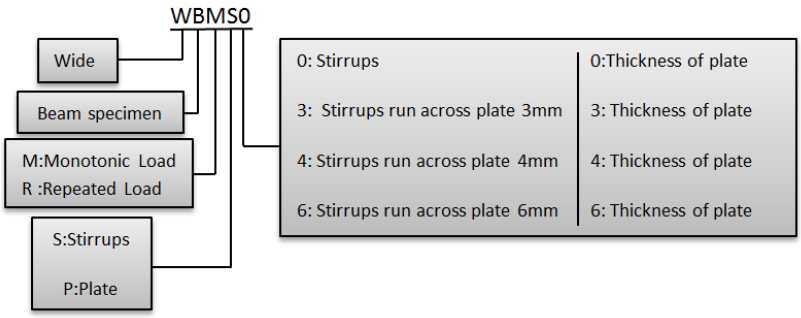
Table 6: The WBs' experimental result.

Group	Beams symbol	Ultimate load Pu [kN]	Deflection at ultimate load Δu [mm]	Increase in Pu [%]*	Increase in Deflection [%]*	No. of cycles	Mode of failure
A	**WBM0**	310.39	14.42	---	---	---	shear
	WBMS$_3$	347.30	18.16	11.89	25.94	---	shear
	WBMS$_4$	363.19	17.02	17.01	18.03	---	shear
	WBMS$_6$	375.14	20.24	20.86	40.36	---	shear
	WBMP$_3$	393.96	19.55	26.92	35.58	---	shear
	WBMP$_4$	420.02	20.42	35.32	41.61	---	shear
	WBMP$_6$	453.24	21.81	46.02	51.25	---	shear
B	**WBR0**	308.26	16.11	---	---	52	shear
	WBRS$_3$	340.59	19.55	10.49	21.35	49	shear
	WBRS$_4$	360.22	18.11	16.86	12.41	52	shear
	WBRS$_6$	373	20.95	21	30.03	49	shear
	WBRP$_3$	390.34	20.64	26.62	28.12	49	shear
	WBRP$_4$	418.34	21.51	35.71	33.52	49	shear
	WBRP$_6$	451.14	22.29	46.35	38.36	52	shear

*Increase in Pu monotonic (%) = [(Pu new – 310.39) / 310.39] × 100%, Increase in Δu (%) = [(Δu new – 14.42) / 14.42] × 100%.

**Increase in Pu repeated (%) = [(Pu new – 308.26) / 308.26] × 100%, Increase in Δu (%) = [(Δu new – 16.11) / 16.11] × 100%.

Where:



3.3 Structural behavior, cracking pattern, and failure mode

The crack patterns of all wide beams (WBs) at various loading phases are depicted in Figures 6. As observed in these figures, with an increase in the applied load, a sequence of fractures initiates randomly at the middle third of the beams on the bottom face, gradually extending upward. Due to the presence of both shear forces and moments, inclined cracks originating on both sides of the beam exhibit a more pronounced inclination and are situated farther away from the central zone. The additional stress contributes to the expansion and widening of these cracks, ultimately leading to the collapse of the beams. Additionally, new shear cracks form in the intermediate zone towards the lower portion of the beam. The ultimate load achieved was 310.39 kN for WBM0 and 308.26 kN for WBR0, resulting in ultimate deflections of 14.42 mm and 16.11 mm at the mid-span, respectively. These observations provide valuable insights into the progressive development of cracks under increasing loads and highlight the structural response of the wide beams, ultimately leading to failure.

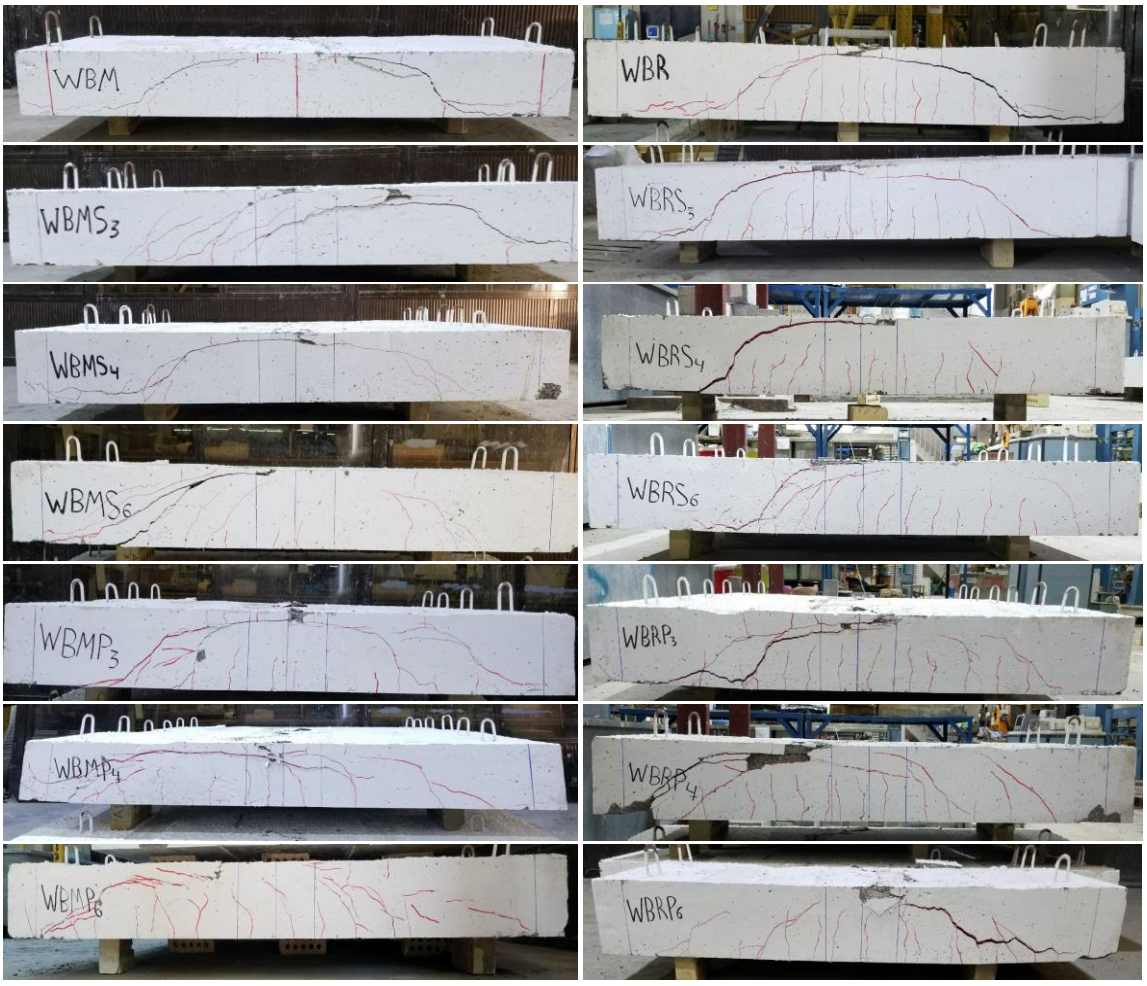


Fig. 6: Crack patterns and failure mode.

3.4 Comparison Between Test Results, Under Monotonic and Repeated Load

The behavior of Lightweight Aggregate Wide Reinforced Concrete Beams (LAWRCB) exhibits differences under monotonic and repeated loads. The results indicate that the ultimate load values for the wide beam specimens subjected to repeated loads were lower than those under monotonic loads. This discrepancy is attributed to the deterioration of concrete as the number of cracks increases during the loading and unloading processes of repeated loads. The separation between concrete and steel also increases with the progression of cracks.The impact of repeated loading is illustrated in Figure (7), demonstrating how the concrete experiences degradation and reduced load-carrying capacity over successive loading cycles. Additionally, Figure (8) reveals that the ultimate deflection of the wide beams under repeated loads is greater than the deflection observed under monotonic loads.

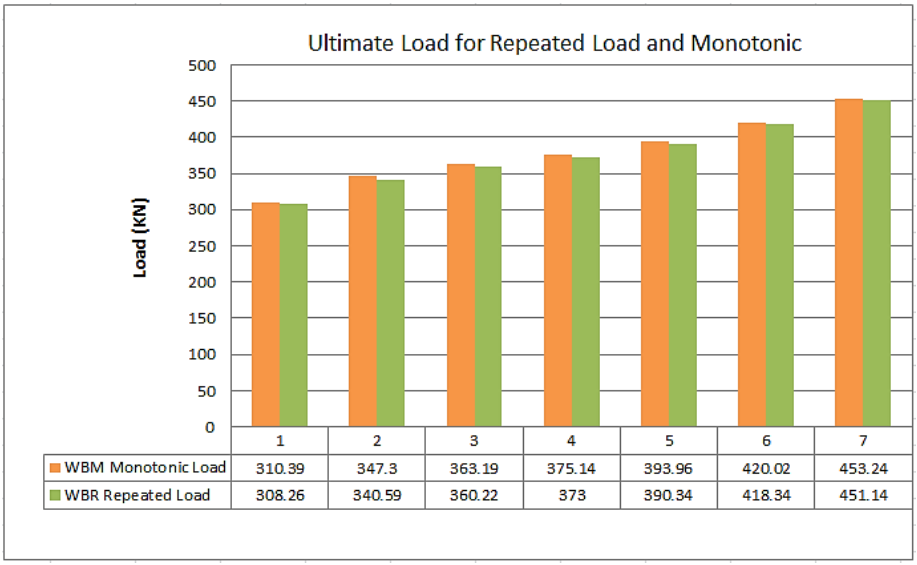


Fig. 7: Deference Between the Ultimate Load of Monotonic and Repeated Load for the Similar Specimen Beams.

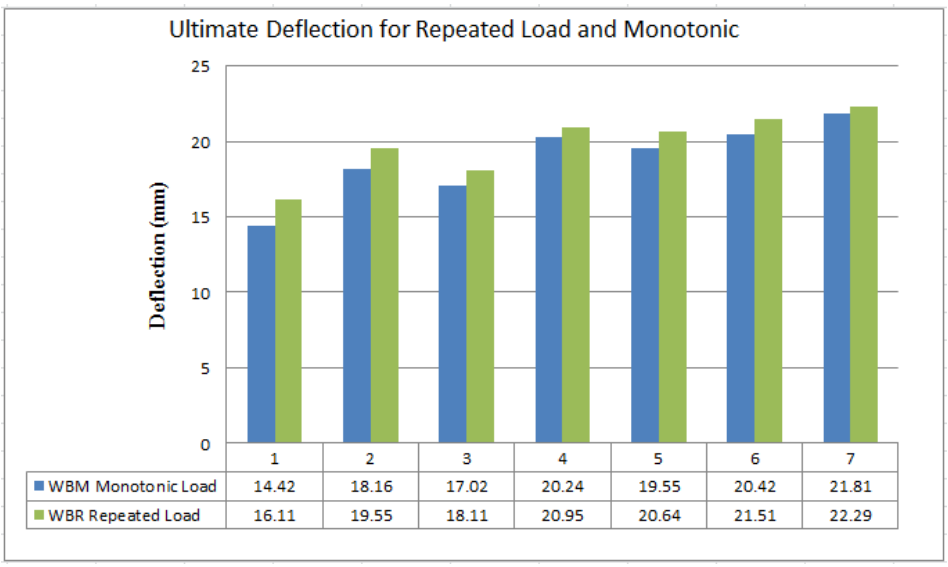


Fig. 8: Deference Between the Deflection of Monotonic and Repeated Load for the Similar Specimen Wide Beams.

3.5 Load-deflection Relationship

The load deflection relationship of all specimen tested under monotonic load is linear until the cracks occure and began to increase the inclination in curve begin in all specimens. For Repeated Load similar behavior of the specimens tested under monotonic load. Show the results from table 6 and see figures from 9 to 12.

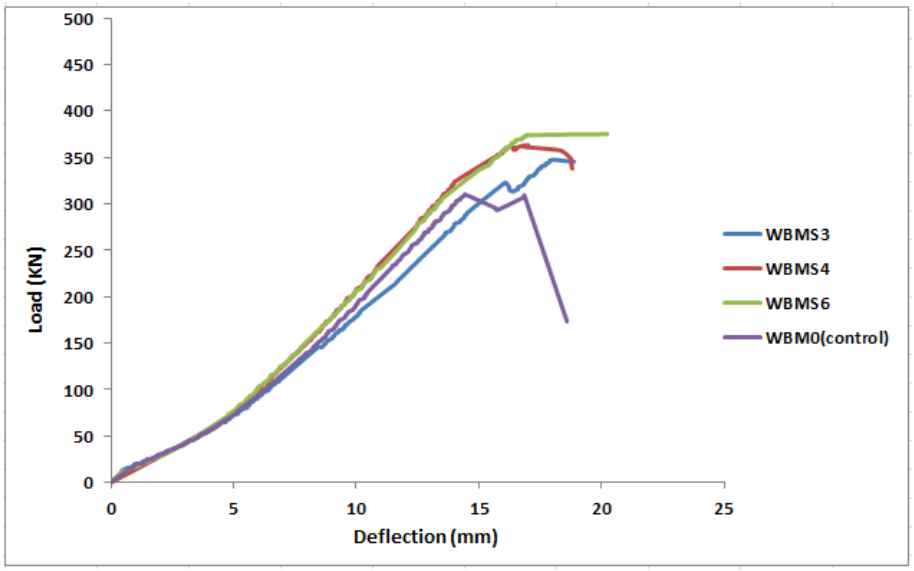


Fig. 9: Curve of load-deflection for control WB stirrups (Monotonic).

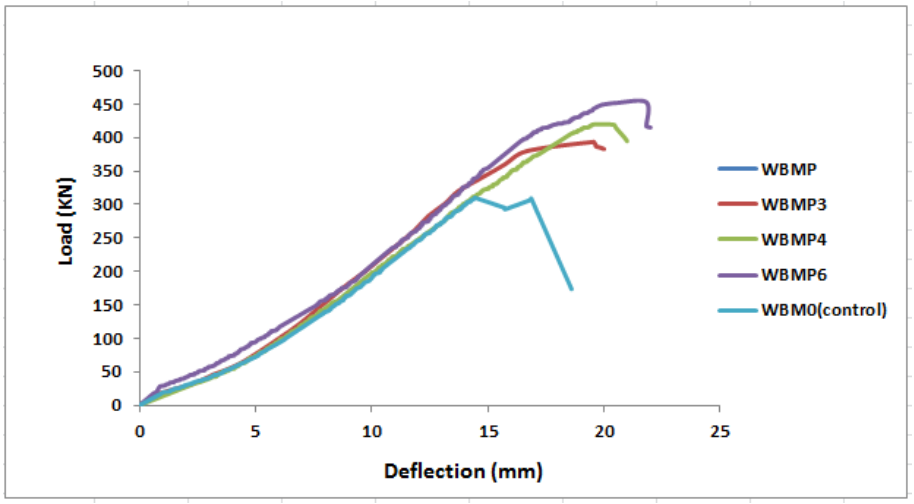


Fig. 10: Curve of load-deflection for control WB and plate renforcement (Monotonic).

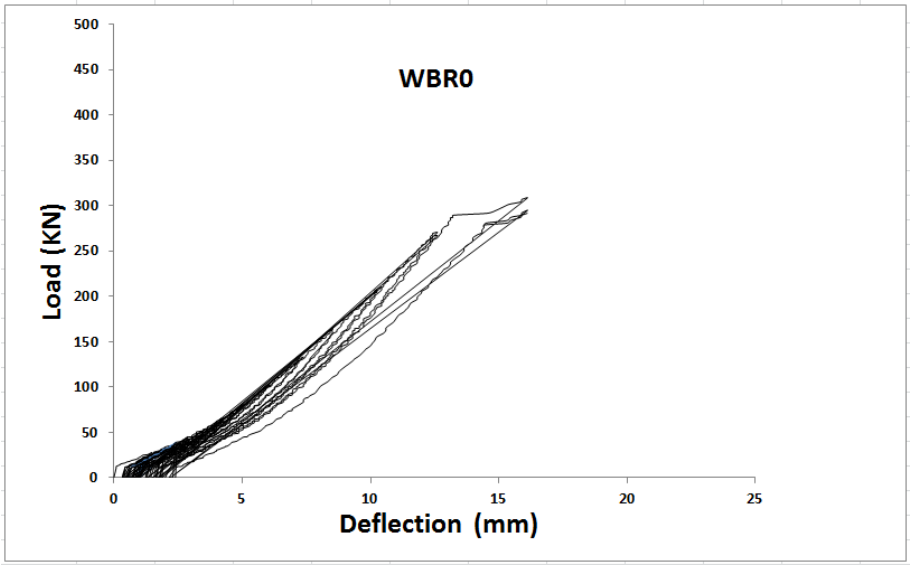
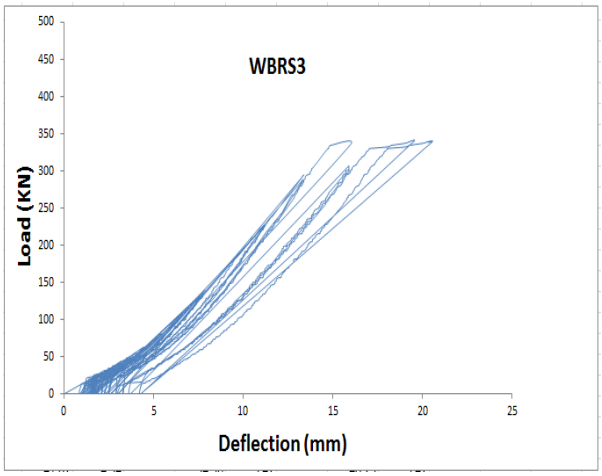
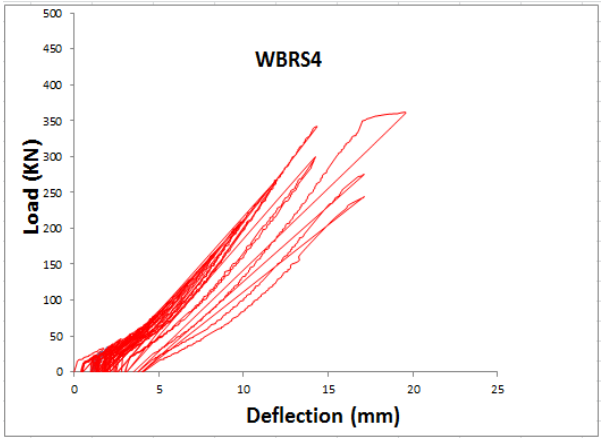


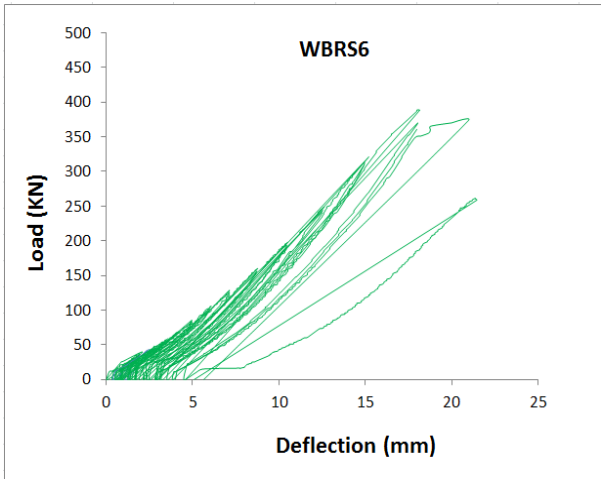
Fig. 11: Curve of load-deflection for control WB (Repeated).



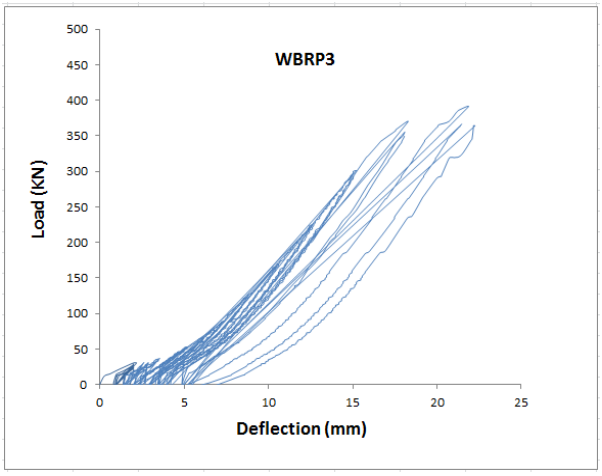
a) load-deflection diagram for specimen WBRS3



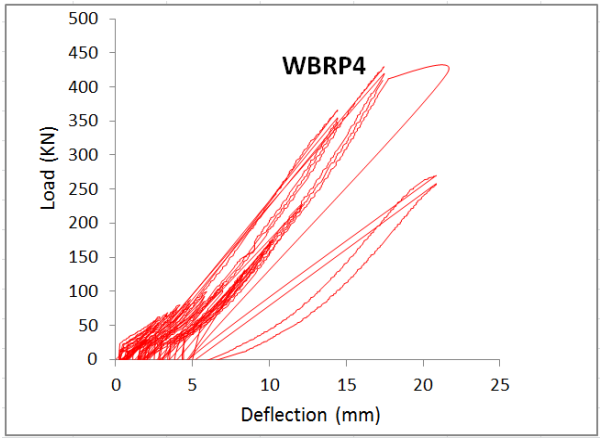
b) load-deflection diagram for specimen WBRS4



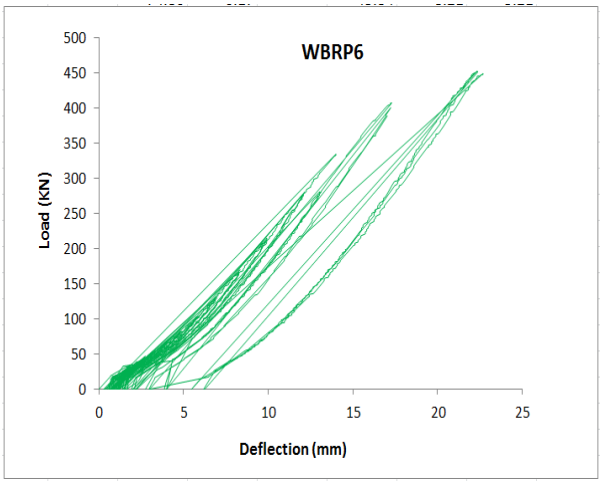
c) load-deflection diagram for specimen WBRS6



d) load-deflection diagram for specimen WBRP3



e) load-deflection diagram for specimen WBRP4



f) load-deflection diagram for specimen WBRP6

Fig. 12: Curves of load-deflection (Repeated).

4 Conclusion

The following summarizes the main findings that may be made after looking at the complete study:

1) In beams with shear steel plates, the deflection at yield load was more than beams reinforced with stirrups by an average of (7.6%), (20%), (7.75%), while ultimate load (13.44%), (15.7%), (20.82%) for (3,4,6) mm respectively.

2) The ultimate carrying capacity of the WB increased noticeably as a result of the use of thicker steel plates.

3) The parametric investigation that matched an increased steel ratio with an equivalent yield strength in shear steel plates and stirrups revealed that the ultimate load on beams increased and that the failure mode of the beams shifted to shear failure.

4) The differences in ultimate load and deflection between monotonic and repeated load was very close for the same specimens.

5) Failure occurs in specimen subjected to repeated load before specimen subjected to monotonic load due to loading and unloading piston on the specimen led to weak in beam. This operation is the same as seismic condition and its effect on the structures.

6) Computing the cost-benefit ratio while taking productivity and time into account when deciding whether to utilize shear steel plates in RCWB rather than stirrups.

7) Because concrete and longitudinal reinforcing have the same characteristics, there is little variation in the measured crack loads of all specimens.

8) Compared to other methods of reinforcement, the shear capacity of a WB is somewhat increased by a mid-depth steel plate, and failure occurs suddenly with this type of reinforcement.

9) In WBs with steel plate reinforcement, load bearing increases after the initial shear fracture and displacement compared to beams with alternative shear reinforcement types that exhibit better ductility and a progressive failure.

10) Using steel plate in wide beams that need a large number of flexural reinforcement is much easier than providing stirrup legs in cross sectional area of these beams.

11) For shallow wide beams without web reinforcement, the shear strength generally increases as the concrete compressive strength increased.

12) The vertical steel plate has a considerable impact on the shear behavior of WBs by enhancing the dowel action and preventing inclined shear fractures from emerging. As a result, its influence on the wide beams' shear capacity should be taken into account.

References

[1] SAID, M. - ELRAKIB, T. M.: Enhancement of shear strength and ductility for reinforced concrete wide beams due to web reinforcement. Hbrc Journal 9.3 (2013) 235-242.

[2] ELSOURI, A. M. - HARAJILI, M. H.: Interior RC wide beam-narrow column joints: potential for improving seismic resistance, Engineering structures 99, (2015), pp. 42-55.

[3] IBRAHIM AMER, M., - WISSAM SALMAN, D. - QUSAY AHMED, W.: Effect of steel plates on shear strength of wide reinforced concrete beams. Journal of Engineering and Sustainable Development19.3 (2015) 96-109.

[4] MOHAMMADYAN YASOUJ, S. E. et al.,: Wide Beam Shear Behavior With Diverse Types Of Reinforcement, ACI Structural Journal, MS, No. S-2013-360.R4, 2013.

[5] SHURAIM, A. B. - Al-NEGHEIMISH, A. I.: Design consideration for joist floor with wide – shallow beams ،ACI Structural Journal, 108 (2), 2011, 188-196.

[6] ABASS, A. L. – YOUSIF, R. H.: Shear behavior of reinforced concrete wide beams strengthened with CFRP sheet without stirrups. Diyala Journal of Engineering Sciences 12.1 (2019) 80.

[7] FADHIL, A. A. – RAID, F. A.: A Review to the structural behavior of reinforced concrete wide beams. 49.07 (2022).

[8] MOHAMMADYAN YASOUJ, S. E. - MARSONO, A. K. - ABDULAH, R. - MOGHADASI, M.: Wide beam shear behavior with diverse types of reinforcement ،ACI Structural Journal, 112 (2), 2015, 199-208.

[9] HAIDOA, J. H. - MUSA, I. H.: Cracking strength of steel fiber reinforced concrete shallow wide beams under impact actions ،International Journal of Scientific & Engineering Research, 4 (4), 2013, 464-472.

[10] LOTFY, E. M. - ELKAMASH, W.: Numerical study of R.C. beams strengthening by external steel plates. American Journal of Engineering research, 6(3), 2017, 48-56.

[11] MOSHER, K. A. - HASSON, A. H. H.: Strengthening of reinforced concrete beam in shear zone by compensation the stirrups with equivalent external steel plates ،Journal of Babylon University, 24(3), 2016, 604-617.

[12] IOWA St S. A. BHAGAT - BHUSARI, J. P.: Improving shear capacity of R.C. beams using epoxy bonded continuous steel plates" International Journal of Advanced technology in Civil Engineering, 2 (1), 2013, 39-44.

[13] SEVIM, B.: Structural strengthening behavior of beam using steel plates ،International Journal of scientific research and management, 5(2), 2017, 7789-7796.

[14] SWETHA, K. S. - JAMES, R. M.: "Strengthening of R.C. beam with web bonded steel plates" ، International Journal of Engineering and Techniques, 4(3), 2018, 71-81.

[15] EBERLINE, D. K. - KLAIBER, F. W. - DUNKER, K.: Bridge strengthening with Epoxy bonded steel plates" Transportation Research Record 1180, Bridge Engineering Center ate university, 7-11.
[16] ABD, SUHAD, M. – JASSAM, D. G.: Improving the Mechanical Properties of Lightweight Foamed Concrete Using Silica Fume and Steel Fibers. *Al-Nahrain Journal for Engineering Sciences* 21.2 (2018): 300-307. 2018 https://doi.org/10.29194/NJES21020300.
[17] KONOPLIANYK, OLEKSANDRI, NIKOLAY KOTOV - LLLIALLIEV.: "Specific Design Features of Prefabricated Fire-Resistant Floor Slabs Made from Lightweight Concrete." *Civil and Enviromental Engineering* (2022): 1-7. https://doi.org/10.2478/sjce-2022-0001.
[18] XIAOWEN, L. et al.: Experimental and numerical studies on the shear stability of ship's thin plates. *Civil and Enviromental Engineering*, 28.4 (2021): 133-141. https://doi.org/10.2478/pomr-2021-0055.
[19] DYWANY, HAIDAR R. Hashim Al.: Behaviour of wide reinforced concrete beam in shear. Diss. Universiti Teknologi Malaysia, 2010.
[20] AHMED B. SHURAIM. MARCH: Transverse Stirrup Configurations In RC Wide Shallow Beams Supported On Narrow Columns, journal of structural engineering © ASCE, (2012).
[21] ALI, SUHAIB JAMAL - AGARWAL, V. C.: Shear strength capacity of wide reinforced concrete beam with shear steel plates. International Journal of Civil, Structural, Environmental and Infrastructure Engineering Research, 2013.
[22] MANSOOR, AHMED; A.: Strength and behaviour of bubbled wide reinforced concrete beams with shear steel plates. Diss. PhD thesis, University of Technology-Iraq, 2016.
[23] IMAN M. ABDUL AMEER.: Behavior of reinforced SCC beams with steel plates as shear reinforcement. M.Sc. Thesis, Al-Nahrain University Iraq 2016.
[24] KUANG, J. S. - HAMDOLAH BEHNAM - QUNXIAN HUANG: Effective beam width of reinforced-concrete wide beam–column connections. Proceedings of the Institution of Civil Engineers-Structures and Buildings 170.5 (2017) 336-353.
[25] BEHNAM, HAMDOLAH, - KUANG, J. S. - BIJAN SAMALI.: Parametric finite element analysis of RC wide beam-column connections. Computers & Structures 205 (2018) 28-44.
[26] Mohamed, Yasser Tosson, et al. Shear behavior of shallow-wide beams strengthened by external SHCC jacket. HBRC Journal 16.1 (2020) 351-363.
[27] MAWLOOD, BARAZAN OMAR, et al.: Shear strength of reinforced high-performance concrete wide beams. Zanco Journal of Pure and Applied Sciences 33.2 (2021) 117-127.
[28] ACI Committee 318.: Building Code Requirements for Reinforced Concrete and Commentary (ACI 318-14); American Concrete Institute: Farmington Hills, MI, USA, 2014; p. 520.
[29] ABDULJABAR, HASAN T.: SHEAR BEHAVIOR OF FIBROUS REINFORCED CONCRETE WIDE BEAMS. Journal of Engineering and Sustainable Development 26.2 (2022) 77-93.
[30] Building code requirements for structural concrete (ACI 318-19) and commentary. American Concrete Institute, ACI 318M-2019.
[31] IRAQI Standard Specification I.Q.S. No.5,2019: Portland cement. Central Organization for Standardization and Control Quality.
[32] IRAQI Standard Specification (I.Q.S NO.45, 2021) Aggregate from Natural Sources for Concrete and Construction. Central Organization for Standardization and Control Quality.
[33] Standard Specification for Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement ASTM A615/A615M-16b. ASTM A615 2016, ASTM A615 2016. American Society for Testing and Materials West Conshohocken.
[34] 496M-07, A. A. ASTM A496M-07 Standard Specification for Steel Wire.544, A. C. Design considerations for steel fiber reinforced concrete. 2009. American Concrete Institute.
[35] ASTM International [ASTM] (2017). Standard specification for lightweight aggregates for structural concrete (ASTM C330/C330M-17A). West Conshohocken, PA: ASTM International.
[36] FEMA, A. J. A. T. C., Redwood City, CA 2007. 461/Interim Testing Protocols for Determining the Seismic Performance Characteristics of Structural and Nonstructural Components. 113.
[37] DAUD, R. A. 2015. Behaviour of reinforced concrete slabs strengthened externally with two-way FRP sheets subjected to cyclic loads, The University of Manchester (United Kingdom).
[38] ASTM C496/C496M-11.: Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens. American Society of Testing and Materials, 2011.
[39] NOORA H. A. Al-Khafaji - Ibrahim S. I. Harba."Shear and Flexural Behavior of Lightweight Concrete Beams Containing Hybrid Fibers", Civil and Environmental Engineering, 2023.