Castellated Beams with Fiber-Reinforced Lightweight Concrete Deck Slab as a Modified Choice for Composite Steel-Concrete Beams Affected by Harmonic Load

Zahraa Hussien Dakhel
Department of Civil Engineering
University of Baghdad
Baghdad, Iraq
zahraa.hussein1701@coeng.uobaghdad.edu.iq,

Shatha Dheyaa Mohammed
Department of Civil Engineering
University of Baghdad
Baghdad, Iraq
shatha.dh@coeng.uobaghdad.edu.iq

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Abstract-The behavior investigation of castellated beams with fiber-reinforced lightweight concrete deck slab as a modified choice for composite steel-concrete beams affected by harmonic load is presented in this study. The experimental program involved six fixed-supported castellated beams of 2140mm size. Three types of concrete were included: Normal Weight Concrete (NWC), Lightweight Aggregate Concrete (LWAC), and Lightweight Fiber-Reinforced Aggregate Concrete (LWACF). The specimens were divided into two groups: the first comprised three specimens tested under harmonic load effect of 30Hz operation frequency for 3 days, then the residual strength was determined through static load application. The second group included three specimens identical to those of group I, tested under static load only. The results show that LWAC was more influential than LWACF under harmonic load. The reduction in the residual strength of LWACF and NWC deck corresponding to the harmonic load was 0.94 and 0.7% respectively. The outcome proved that using LWACF as a deck for the castellated steel beams affected by harmonic load presents a significant choice with weight reduction of 16% compared to NWC. Steel fiber's tensile strength 1700MPa enhanced the absorbed energy and the ductility factor by 0.4 and 0.5% respectively.

Keywords-harmonic load application system; operation frequency; steel fiber; castellated beam

I. INTRODUCTION

A dynamic load usually changes with time in magnitude, direction, and position. Structures are often subjected to at least one type of dynamic load during their service life [1]. Structural dynamics is a form of structural analysis that investigates the way a structure behaves when subjected to dynamic (high-acceleration) loads. People, wind, waves, traffic, earthquakes, and explosions are all examples of dynamic loads. Dynamic loading can occur to any structure. To figure out how dynamic displacements move over time, things like dynamic analysis and modal analysis are being used, among other things [2]. Harmonic loading occurs when an applied load changes as a sine or cosine function. Harmonic motion is seen in the vibrations produced by an unbalanced rotating machine, the vertical motion of an automobile on a road surface, and the oscillations of a tall chimney induced by vortex shedding in a constant breeze. Structural engineers have been seeking a way to convey the structure's ability to withstand imposed loads and usage for a long time, not only with aiming at lightness and economy but also with the goal of becoming aesthetic landmarks and meeting the current sustainability demands [3]. Some of these ways used open web expanded steel beams. Recent structures are developed using classic design principles, with components such as beams, columns, and other structural elements designed to transmit loads quickly, but at a high cost. Because of the above disadvantages, a new form of beams known as castellated beams was developed. By modifying just the pattern, these beams become cost-effective and have a high load-bearing capability. When an I-beam is cut longitudinally along the web of the beam and then rebuilt with a deeper web using a particular pattern, it separates the web and reassembles the beam with the deeper web [4]. In steel design, castellated beams unite beauty, adaptability, and economy. They've long been recognized as advantageous structural members for many reasons, including lighter sections, higher strength-to-weight ratios, on-site utility line adoption, lower foundation costs, lower painting and maintenance costs, and better aesthetics and appearances [5]. The term "lightweight concrete" refers to concrete that has a low density of 1120-1920kg/m^3 and compressive strength of at least 17MPa [6]. Adding fibers to lightweight concrete enhances the density to reach 2000kg/m^3 [7].

II. LITERATURE REVIEW

Regarding the castellated structures, there are many studies that investigate the effect on these structures by various types of static loads. Authors in [8] studied composite concrete-open web expanded steel beams under combined flexure and torsion.

Corresponding author: Zahraa Hussien Dakhel

The experimentation required 18 composite specimens with 300mm open web extended section depths made from IPE-200 standard rolled sections, separated into two groups. Each set had 9 composite specimens with hexagonal or circular openings. All beams span 2900mm in basic support with 2 equal concentrated loads. The first strengthening technique enhanced the load capacity of the specimens with castellated holes by 26.08% and circular openings by 21.88% under pure bending, 16.36% and 33.33% under combined flexure and torsion, and 5.6% and 4.44% under pure torsion. The second strengthening technique increased the load capacity of castellated and circular hole specimens by 186.95 and 134.38% respectively, for pure bending, 136.36 and 116.66% for combined flexure and torsion effect, and 6.58 and 4.88% for pure torsion. To study failure modes, authors in [9] tested 6 composite-castellated beams with solid slabs of various lengths. The torsional buckling of web posts in response to a long crack in the concrete slab was found to be the cause of the failure of the tested beams. Shear and flexural behavior of composite concrete-steel castellated beams was investigated in [10]. Different composite castellated beams with different lengths and shear to moment ratios were investigated. Longer flexural beams failed when most of the studs in one half of the span failed, leading to lateral-torsional buckling of the suddenly unrestricted compression flange, whereas shear study beams buckled due to lateral-torsional buckling of the web post.

Most previous studies have focused on dynamic loads caused by quakes and offshore waves. However, not enough research has been conducted regarding the effects of machine vibration on structures. Modern industry has introduced massive machines that significantly affect the performance of structures, causing a new type of vibration load. Machine vibration should be treated as an engineering problem, regardless of size or kind, and should be designed using sound engineering principles. In the last 30 years, there have been many studies on infinite periodic vibration on structures, with an emphasis on free vibration propagation and forced vibration induced by stationary harmonic loads. Authors in [11, 12] presented an experimental and theoretical study on the structural behavior of bubble deck reinforced concrete slabs under the effect of harmonic loads. The results showed that the distribution of bubbles had a significant effect on the structural behavior in the dynamic analysis, and the numerical model used was in good agreement with the experimental data. For the lightweight concrete, in monotonic and cyclic loads, the effect of steel fiber (L=30mm and aspect ratio=60) on the properties of LWAC made of expanded clay was studied in [13]. When LWAC was strengthened by steel fiber of 0.5, 1, and 2 volume fraction, the improvement in compressive strength in monotonic load was near 22, 29, and 38% respectively, and in cyclic load near 23, 28 and 41% respectively. Authors in [14] studied the influence of steel fibers on the compressive strength of a sanded LWAC made with sintered pulverized fuel ash LWA. The specimens had a compressive strength of 90MPa after 28 days and a density of 2015kg/m^3. Many researchers have investigated the behavior of the fiber-reinforced lightweight concrete structure and the results of [15-19] agree with the results in [14].

It is well known that the dynamic response is highly related to the weight and ultimate strength of the structure. In order to improve the structural behavior of the composite beam under harmonic load, a castellated beam was considered in this study instead of a plain steel section to increase the ultimate strength and reduced the self-weight. Moreover, Normal Concrete Weight (NWC) deck slab was replaced by lightweight concrete. Two proposals are being considered regarding the concrete deck slab. These are: lightweight concrete with no fiber reinforced (LWAC) and fiber reinforced concrete (LWACF).

III. EXPERIMENTAL INVESTIGATION

A. Tested Specimens

Six composite castellated steel-concrete specimens with a span of 2140mm were fabricated according to [20] and were tested as fixed-end supported beams. Since the overall height after castellation was set at 400mm, a steel I-beam section (IPE 200) with 100mm concrete deck slab was used. The composite system's components were fully bonded together. Shear connections were placed perpendicularly at 187mm c/c from the upper flange of the steel I-beam, constructed of steel channel section with dimensions of 60mm×30mm×5mm and a total length of 50mm. On both sides of the steel beam, 284mm×47.2mm×6mm steel stiffeners were arranged in the center and at the two ends of the web. Deformed 10mm steel bars spaced at 125mm c/c were used to reinforce the concrete deck in both directions. Figures 1 and 2 show the details of the specimens. Table I shows the mechanical properties of the steel component.

Fig. 1. Fabrication and cast of the composite castellated beams.

There were two concrete mixes, the first was normal weight concrete that was prepared using ordinary Portland cement type CEM I 32.5 R according to [21] andcrushed stone of maximum size of 10mm, and zone 2 fine aggregates, conferring to [22]. The aggregate: sand: cement designed proportions by weight were 1.6:1.33:1 with a water-cement ratio equal to 0.29 according to [23]. The second one was lightweight concrete, with mix proportions shown in Table II. The ratios of all the constituent materials were compatible with the standard of the

Regular Practice for Structural Lightweight Concrete Collection Proportion according to [24]. Light Expanded Clay Aggregate (LECA) as shown in Figure 3 was adopted to cast the lightweight concrete as ASTM C330 [25] coarse aggregate. The coarse aggregate's grain size was 10mm [26]. One type of fiber was adopted in this work as hooked steel fibers of 30mm length with a volume fraction of 1.5%. The steel fiber properties are illustrated in Table III. The compressive strength of each specimen was determined by testing three standard 150×300mm concrete cylinders according to [27], with a target value of 40MPa.

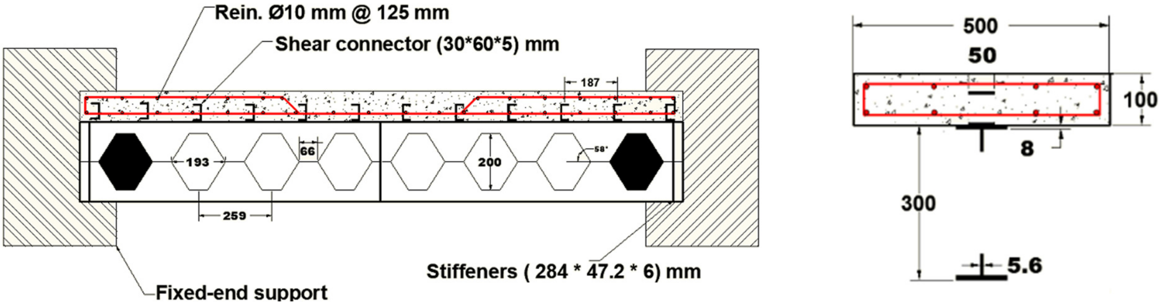

Fig. 2. Castellated beam details. All dimensions are in mm.

TABLE I. MECHANICAL PROPERTIES OF STEEL COMPONENT

Sample	Thickness (mm)	Yield stress (MPa)	Ultimate stress (MPa)	Elongation %
Web plate	5.6	420	518.9	26.6
Plate for top and bottom flange	8	415	515.88	27.15
Stiffener's plate	6	400	520.5	26.36
Shear connecters plate	5	250.14	332.29	29.26
Welding wire	6	456.6	615.7	20.12
Reinforcement	10	410	520	23.4

TABLE II. THE ADOPTED LIGHTWEIGHT CONCRETE MIX

Material	Proportion
Cement	677 kg/m^3
Water	237 kg/m^3
Coarse aggregates (LECA)	210 kg/m^3
Fine aggregates	884 kg/m^3
Silica fume	170 kg/m^3
Superplasticizer	7 litter/m^3

Fig. 3. Light Expanded Clay Aggregate (LECA).

TABLE III. STEEL FIBER PROPERTIES

Fiber type	Diameter (mm)	Length (mm)	Aspect ratio	Tensile strength (MPa)	*E* (GPa)	Density (kg/m^3)
Hook	0.5	30	60	1700	200	7800

B. Groups of the Tested Specimens

Six composite castellated beams were cast and evaluated. All specimens were 2140×500×400mm in length, width, and total depth respectively. They were categorized into 2 groups: The first group consisted of 1 NWC deck slab and 2 specimens with lightweight concrete deck slabs, one of plain LWAC and the other with reinforced LWACF with hooked steel fibers of 1.5% volume fraction. The specimens of group I were subjected to a harmonic load of 30Hz vibration frequency before being subjected to concentrated load up to failure. The harmonic load was applied continuously for 3 working days, each lasting 6hr. The second group comprised of 3 specimens identical to those of group I, but they were only exposed to static concentrated load until failure.

IV. TESTING PROCEDURE

For the first group, there were two loading stages. In the first stage, the adopted harmonic load was applied and an advanced digital data logger was connected to a computer device given a specific program to record and save the data in an spreadsheet. This instrument has a rate of 1000 records/s and contains 24 channels divided into 4 groups that can record strain values, vibration amplitude, and the applied load as shown in Figure 4.

Fig. 4. Digital data logger.

Calibrated piezo (vibration type) was considered to measure the harmonic applied force and the vibration wave at the specimen center-line as shown in Figure 5. The application system of the harmonic load consists of a vibration motor of 3HP, combined with a steel mass of 278kg. The specimen was set to the test frame so that it behaved as a fixed-end supported beam. The fixed system comprised two steel plates 600mm×100mm×400mm connected by a steel thread rod with a diameter of 25mm, in such a way that they prevented the specimen from any movement (Figure 5). The application system of the harmonic load and the Piezo sensors were set in the adopted position shown in Figure 6. The time duration of the applied harmonic load was 6hr/day for 3 days. To achieve the main goal of this study (i.e. checking the amplitude variation), the data were recorded at an interval of 2hr for a period of 120s for all the testing days. Table IV shows the details of the tested specimens. For the second stage of Group I and Group II, by using a load control test at a rate of 250N/step, all specimens were exposed to a static load up to failure. The measurements included mid-span deflections and strain across the section depth.

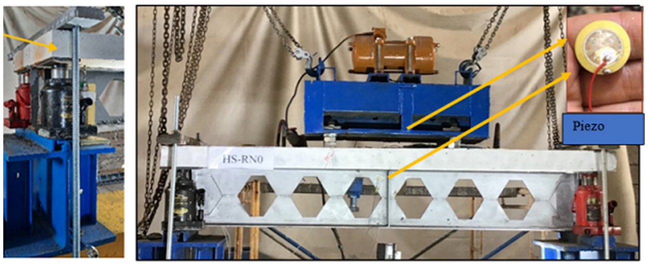

Fig. 5. Specimen set up for Group I (first stage).

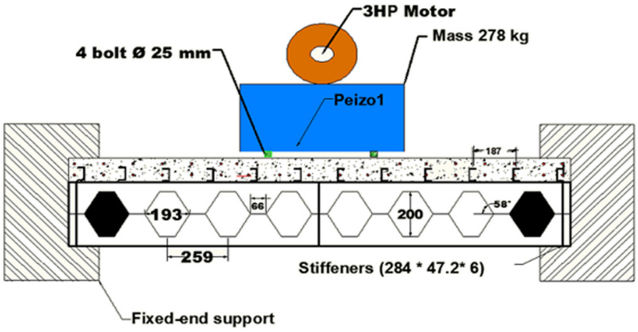

Fig. 6. The application system of the harmonic load.

TABLE IV. DETAILS OF THE TESTED SPECIMENS

Specimen	Deck slab type	Group	f'_c (MPa)	Density kg/m^3	f_t^* (MPa)	E_c (MPa)	Load type
HS-RL0	LWAC	Group I	37	1640	3.0	20407	Harmonic +static
HS-RN0	NWC		40	2400	3.4	28333	
HS-RL1.5	LWACF		40	2000	3.5	23584	
S-RL0	LWAC	Group II	38	1600	3.2	20407	Static
S-RN0	NWC		42	2400	3.54	28333	
S-RL1.5	LWACF		40	2000	3.7	23584	

* According to ASTM C496/C496M-17[28].

V. RESULTS AND DISCUSSION

A. *Results of the Dynamic Part for Group 1 (First Stage)*

This group consists of 3 composite castellated steel beams of NWC, LWAC, and LWACF concrete deck slab types. The specimens were exposed to a harmonic load of 30Hz. The vertical vibration magnitude and vibration sine wave for the applied harmonic load at the selected frequency were evaluated using the outcome of the piezo sensors. Figure 7 shows the noise-removing process with computer software that modified the piezo recordings by removing the noise.

1) *Load -Time History*

The harmonic load is considered dynamic in this study. In general, the mathematical formula for this load comprises two components. The first is the harmonic load's amplitude ($2me\omega_0^2$), while the second is the sine wave ($\sin(\omega t)$) term, [29].

$$p_d = 2me\omega_0^2 \sin(\omega t) \quad (1)$$

where p_d is the dynamic load (N), m the eccentric rotating mass (3kg), e the eccentric distance (0.08m), and ω_0 the operating frequency of the machine (rad/s). The recorded load time histories for the adopted load frequency are shown in Figure 8 and Table V.

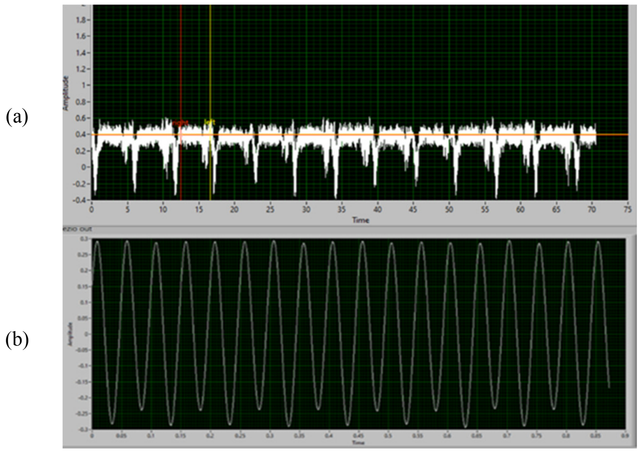

Fig. 7. Noise removal process: (a) Before and (b) after noise removing.

TABLE V. AMPLITUTE OF THE HARMONIC LOAD ($2me\omega_0^2$)

Frequency (cyc/s)	Frequency (rad/s)	Amplitude force (N)
30	188.5	17055

Note: The magnitudes of m and e are measured experimentally

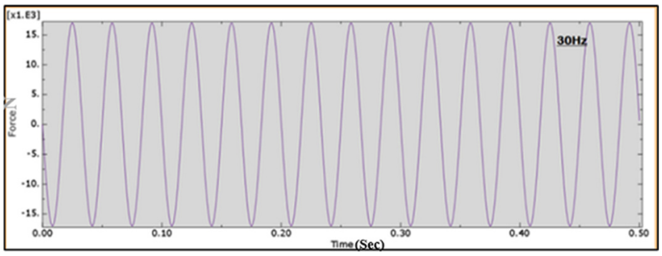

Fig. 8. Recorded load time history for the adopted load frequency.

2) *Vibration-Time History (First Stage).*

Table VI and Figure 9 show that the LWCA had significantly the highest response when subjected to the 30Hz harmonic load for 3 days. Cracks appeared in the tension face of the specimen HS-RL0 during the first day of the vibration test. As seen in Table VI, the data of the vibration wave were collected every 2hr of the loading period. Figure 10 shows that as the load time increases, new cracks continue to form and propagate in the center zone of the slab. The variation in amplitude between the specimens HS-RL0 and HS-RN0 also increased day by day as shown in Table V. As for the fiber-reinforced concrete specimen HS-RL1.5, when compared with HS-RN0, it showed a slight difference in the amplitude on the first day of operation by about 18%, while during the last two days of operation, the amplitude values began to remain stable at 0.33mm. On the last day, the variation became less. The fiber-reinforced lightweight concrete behaves slightly similar to NWC under harmonic load. This behavior may be attributed to the fiber presence, which enhanced the mechanical properties of lightweight concrete [19] so that it became an alternative to normal weight concrete (Table IV). Regarding the generation of the crack in the fiber-reinforced specimen, no cracks appeared during loading.

Figure 9 and Table VI show that the amplitude values of the vibration were mostly determined by the percentage of compatibility between the natural frequency of the specimen and the operating frequency of the vibrating motor. They indicate that the value of vibration amplitude was slightly constant for the HS-RL1.5 specimen during the operation time since the natural frequency was far from the operating frequency by about 77%. Moreover, the steel-fiber presence advanced the specimen's strength. Regarding the lightweight concrete, the values of the peaks differ from one reading to another due to the crack generation that decreased stiffness.

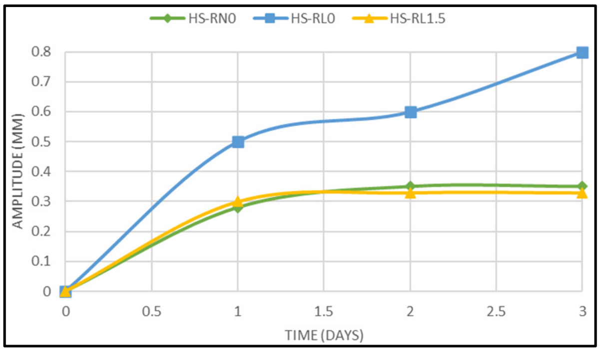

Fig. 9. Vibration-time history under harmonic load.

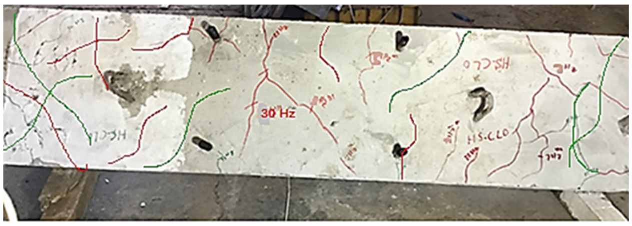

Fig. 10. Crack pattern of the specimen HS-RL0 due to harmonic load.

B. *Results of the Static Part for Group I and Group II*

After removing the continuous harmonic load, a concentrated load was applied to the specimens of group I (stage two) and group II to evaluate the dissipated energy caused by the harmonic load. As illustrated in Tables VII and VIII, the failure loads for all the tested specimens in the first group were less than those of the corresponding specimens in the second group by about 0.7, 24, and 0.9% for NWC, LWAC, and LWACF specimens respectively.

TABLE VI. MAXIMUM AMPLITUDE OF THE SPECIMENS UNDER HARMONIC LOAD

Days	Specimens	HS-RN0	HS-RL0	Variation% (HS-RN0)	HS-RL1.5	Variation% (HS-RN0)
	Natural frequency Hz	**128.24**	**130.75**	**1.96**	**125.93**	**-1.8**
	Time (hr)	**Amplitude (mm)**	**Amplitude (mm)**	**Variation% (HS-RN0)**	**Amplitude (mm)**	**Variation% (HS-RN0)**
1	2	0.27	0.49	81.48	0.32	18.51
	4	0.28	0.50	78.57	0.327	16.78
	6	0.28	0.57	103.57	0.327	16.78
2	2	0.35	0.57	62.86	0.327	-6.57
	4	0.35	0.60	71.43	0.33	-5.71
	6	0.35	0.60	71.43	0.33	-5.71
3	2	0.35	0.64	82.86	0.33	-5.714
	4	0.35	0.77	120	0.33	-5.714
	6	0.35	0.77	120	0.33	-5.714

1) *Crack Pattern, Load Capacity, Ultimate Deflection, and Failure Mechanisms*

The cracks started and spread along the fixed support path in group II, which changed the structure from a static indeterminate structure to a static determinate one. According to the collected data, the percentage of load required to produce such cracks varied from 38.5% to 70.8% of the corresponding ultimate load as shown in Table VII. The outcome presented a significant enhancement in cracking load and the ultimate load for the lightweight aggregate concrete when the fiber was added to the mix compared with the specimen without fiber as shown in Table VII. Figure 11 shows the crack pattern for the specimen S-RL1.5.

Fig. 11. Crack pattern of specimen S-RL1.5.

TABLE VII. CRACKING AND ULTIMATE LOAD OF GROUPS I AND II

Specimen	Group	P_{cr} (ton)	P_{ul} (ton)	Variation in P_{ul} %	P_{cr}/ P_{ul} (%)	Failure modes
HS-RN0	I	----	42.5	---	---	Web post-buckling, Saint-Venant, and concrete crush
HS-RL0		----	29	-32	---	Concrete crush .
HS-RL1.5		----	42.1	-0.95	---	Web post-buckling, Saint-Venant, and concrete crush
S-RN0	II	25	42.8	---	58.4	Web post-buckling, Saint-Venant, and concrete crush.
S-RL0		15	38	-12.6	39.5	Web post-buckling and concrete crush .
S-RL1.5		30	42.5	-0.71	70.6	Web post-buckling, Saint-Venant, and concrete crush.

TABLE VIII. LOAD CAPACITY REDUCTION

Group II			
Specimen	S-RN0	S-RL0	S-RL1.5
P_{ul} (ton)	42.8	38	42.5
Group I			
Specimen	HS-RN0	HS-RL0	HS-RL1.5
P_{ul} (ton)	42.5	29	42.1
Reduction %	0.7	23.7	0.94

Table VIII shows that the rate of reduction in the failure load varied from 0.7% to 24%, indicating that the lightweight concrete deck slab specimen is more influenced by the harmonic load than the other specimens. This reduction belongs to the harmonic load effect, which caused damage presented by crack generation as shown in Figure 10. The reduction percentage of carrying load capacity between the two groups regarding the fiber-reinforced lightweight aggregate concrete (specimen HS-RL1.5) was slightly similar to the specimen HS-RN0. This reflected the steel-fiber contribution in enhancing the lightweight concrete characteristics (LWAC). It improved the overall structural behavior and decreased the ultimate load variation compared to the normal weight concrete by no more than -0.95 % and -0.71 % as shown in Table VII. In summary, the specimen HS-RL1.5 was not significantly affected by the harmonic load, just like the NWC specimen. Figures 12-17 show the failure type in the tested specimens at the end of the tests.

As shown in Table IX, the same influence was noticed regarding the ultimate deflection. The percentage of deflection reduction was 3.1, 16.66, and 2.7% for specimens of NWC, LWAC, and LWACF deck slabs respectively. Concerning the behavior of the castellated steel beams, two behaviors were observed: the first was for the lightweight concrete deck slab (specimen HS-RL0), where the harmonic load had a clear effect on concrete from the first day of the test. This effect reduces the concrete strength so that the local failure of the deck occurred before the yielding state of the castellated steel beam, which indicates that this section is non-economic due to the earlier failure of the deck affected by the harmonic load while the generated stresses in the steel beam were very small. The other behavior was completely opposite to the previous one, especially for the fiber-reinforced specimen: The steel section was affected faster than the concrete deck, due to the concrete strength and the bearing improvement caused by steel fiber adding. Table X shows the reduction in the yielding strength of the specimens. It is clear that the presence of fiber and the use of LECA as an alternative coarse aggregate in the HS-RL1.5 specimen have a significant effect on the behavior of the whole structure. The reduction in yielding strength was close to the specimen with NWC as deck slab by 0.58% and 0.63% for HS-RN0 and HS-RL1.5 respectively.

TABLE IX. REDUCTION IN ULTIMATE REFLECTION

Group II			
Specimen	S-RN0	S-RL0	S-RL1.5
Δ_u (mm)	13.59	11.4	14.6
Group I			
Specimen	HS-RN0	HS-RL0	HS-RL1.5
Δ_u (mm)	14	13.3	15
Reduction %	3.1	16.66	2.7

TABLE X. ULTIMATE LOAD CORRESPONDING TO THE INITIAL STEEL YIELDING

Group II			
Specimen	S-RN0	S-RL0	S-RL1.5
Ultimate load (ton)	35	35	35
Group I			
Specimen	HS-RN0	HS-RL0	HS-RL1.5
Ultimate load (ton)	34.8	----	34.78
Reduction %	0.58	---	0.63

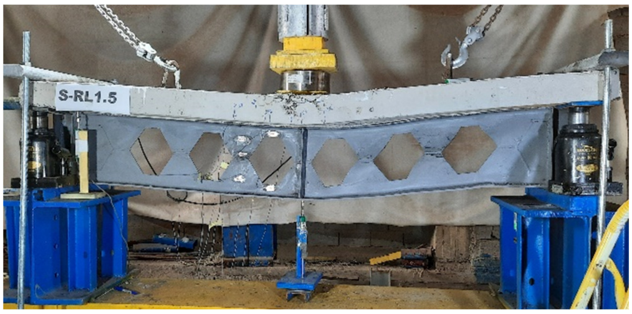

Fig. 12. Failure mode of the specimen S-RL1.5.

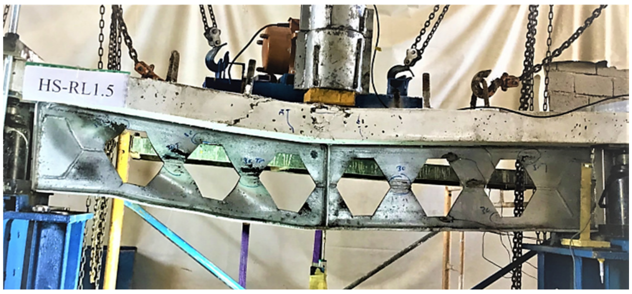

Fig. 13. Failure mode of the specimen HS-RL1.5.

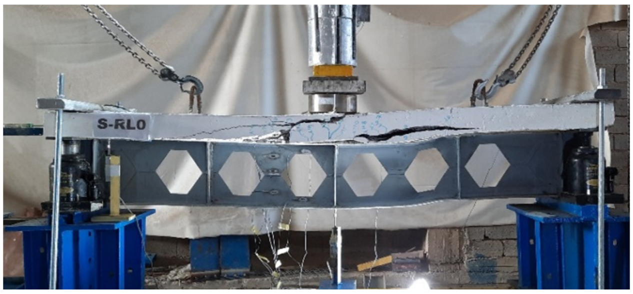

Fig. 14. Failure mode of the specimen S-RL0.

Fig. 15. Failure mode of the specimen HS-RL0.

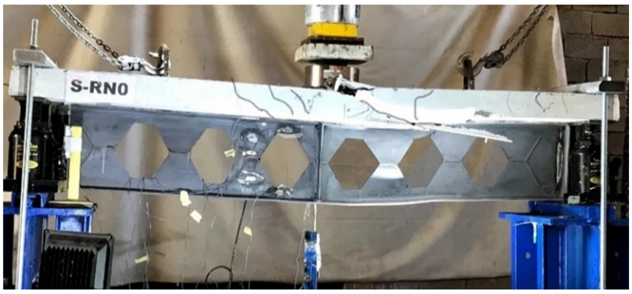

Fig. 16. Failure mode of the specimen S-RN0.

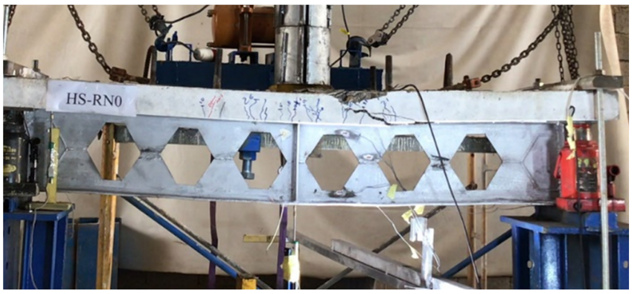

Fig. 17. Failure mode of the specimen HS-RN0.

2) Absorbed Energy and Ductility

Toughness is defined as the ability to absorb energy [30], and it is evaluated from the region below the flexural load-deflection curve. Table XI shows the reduction percentage of the absorbed energy. The HS-RL0 specimen showed strength reduction while no significant effect was detected in the other specimens. It can be concluded that adding fibers to the LWAC induced a considerable enhancement in the concrete toughness index, which is considered good for NWC [31]. The ductility factor reduction for the HS-RL1.5 specimen was the smallest, indicating that this specimen is the most ductile, due to the steel fiber's high tensile strength of 1700MPa (Table XII).

TABLE XI. ABSORBED EBERGY

Group II			
Specimen	S-RN0	S-RL0	S-RL1.5
Absorbed energy (ton. mm)	1206.75	938.60	1213.40
Group I			
Specimen	HS-RN0	HS-RL0	HS-RL1.5
Absorbed energy (ton. mm)	1200.00	657.7	1201.90
Reduction %	0.56	42.70	0.95

TABLE XII. DUCTILITY FACTOR

Group II			
Specimen	**S-RN0**	**S-RL0**	**S-RL1.5**
Ductility factors	1.199	1.06	1.2
Group I			
Specimen	**HS-RN0**	**HS-RL0**	**HS-RL1.5**
Ductility factor	1.19	0.9	1.197
Redaction %	0.75	15.1	0.25

VI. CONCLUSION

The outcome of the tested specimens can be concluded to:

- The concrete deck slab type has a significant effect on the response and structural behavior of the castellated composite beam under harmonic load.
- The fiber-reinforced lightweight concrete behaves similarly to normal weight concrete under harmonic load. When fibers were added to the mix, the outcome showed a significant improvement in cracking load, ultimate load, concrete toughness index, and ductility, so adding fibers is considered a good choice for NWC.
- The fiber-reinforced lightweight concrete is a suitable choice in the deck of the castellated beam under harmonic load. This choice provides a structural part with smaller weight (approximately 16%), which presents an advantage process for castellated beams that is widely used for low-loaded structures.
- The lightweight concrete specimen HS-RL0 exhibited a clear effect from the harmonic load from the first day of the test. This effect was evident through the cracks' appearance and the increase in their number with time.
- Local failure of the deck occurred before the yielding state of the castellated steel beam for the HS-RL0 specimen,

indicating that this section is not economical as a result of the earlier failure of the deck affected by harmonic load while the generated stresses in the steel beam were sufficient.

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