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BEHAVIORS OF REINFORCED CONCRETE PANELS UNDER IMPACT LOADS (FALLING MASS)

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Abstract: The use of GFRP in concrete structures under harsh environment leads to extended service life and lower life cycle cost. This paper discusses the progress made in experimental studies designed to verify the response of (1000 * 1000) mm of reinforced concrete slabs subjected to shock loads. Four tiles were tested for failure under repeated weight drop in the middle of the board. Methods for measurements included a load cell and stress in the reinforcement and a laser sensor to measure the center deviation of the plates (LVDT). The experimental variables included in this study mainly focused on the number of fabric layers and the thickness of the slab (80 and 60) mm.

The results showed that covering the face of the slab reinforced with bars (GFRP) with three layers of glass cloth under the effect of repeated weight dropping is more effective in increasing the slab's tolerance to the number of strikes by (75.86%) than placing two layers of glass in the slab. And more effective than its counterpart with a thickness of (60) mm, and since these layers prevent the appearance of cracks in the pressure area, the increase in the thickness of the plate also affects the slab's resistance to more strokes by (50.34%). This increase in texture layers and thickness in the slab increases pre-cracking hardness, post-cracking toughness, and ultimately the ability to withstand more impact. The use of GFRP rods with glass textiles is more sustainable and cost-effective.

Introduction and Background

Structural design applications are subject to continuous improvement in accordance with the changes and requirements of mankind. With the development of reinforced concrete technology, reinforced concrete structures became the majority among new structures, but despite the huge number of such slabs that were designed and built, and the characteristics of their behavior under the impact, the shock loads in general were not properly evaluated or taken into account. Local phenomena of influence may be difficult to evaluate analytically because the dynamic contact between two objects and corresponding physical behaviors under loading stresses are not easy to model. Experiments are therefore required to support the development of an understanding of the behavior of reinforced

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concrete slabs under loads. Impact loads are any forces of magnitude applied over a short period, such as may be caused by falling rocks, collisions with vehicles, ice or flying objects in hurricanes, volcanic eruptions, or fragments from accidental explosions, military action, dropping objects, or any other impact.

The analysis and design of reinforced structures exposed to impact loads have attracted a great deal of research interest; for example, Chen and May (2009) [1] gathered data from experimental tests on structural elements such as RC slabs and beams under impact loading with the aim of building a numerical model. They adopted 14 beam specimens with 2.7 m spans and four with 1.5 m spans that were then tested under impact loads from a freely dropped mass. The four slabs with dimensions of 800 mm square had 76 mm thickness and the two slabs of 2,300 mm square had 150 mm thickness. The main parameters measured in their tests were acceleration, velocity, and displacement and they focused on local failure. The test results showed that the beams and slab supports were less affected by impact force than the span.

Batar-lar (2013) [2] presented the results of an experimental programmer designed to investigate the behavior of RC slabs under low-velocity impact loads. The programmer involved making comparisons between the static and dynamic behaviors of three pairs of simply supported slabs. The results obtained from these tests showed that the impact behavior of slabs differed significantly from their static behaviors. Ali and Al-Khafaji 2014 [3] offered an experimental study of reinforced concrete slabs subjected to impact loads that included examining the effects of dimensions of slabs as well as reinforcement ratio and support conditions. They found that the central deflections of slabs under impact were reduced as the tensile reinforcing steel ratio increased, but that the ratio of the decreases in the deflection was lower in high steel reinforcement ratios. Those deflections were also found to be oscillatory in nature, being out-of-phase with the applied load. However, clamping the edges of the slabs caused larger oscillation frequencies as compared to the case of simple supports. The current study researched the behavior of RC slabs tested under various impact loads and compared the results with the behaviors of identical specimens tested under static loads to facilitate a comparison of static and impact tests. For the impact loads, the dropped objects had low impact velocities, and damage arising at the impact zone was expected to be dependent on the relative masses of the colliding bodies and the resulting impact energy.

Experimental Program

The experimental program aims to study the effectiveness of GFRP and glass-fabric-reinforced concrete in the externally bonded stress zone in increasing the tolerance of bi-directional panels to repeated impact. Four plates of the same geometry were cast and tested, as shown in Figure (1). The length of the plate is (1000 * 1000) mm and its height is (80 and 60) mm. All panels were reinforced with glass rods (GFRP) of 6 mm in diameter and 310 mm c/c spacing.

The role of different parameters in the number of layers and thickness variation was examined.

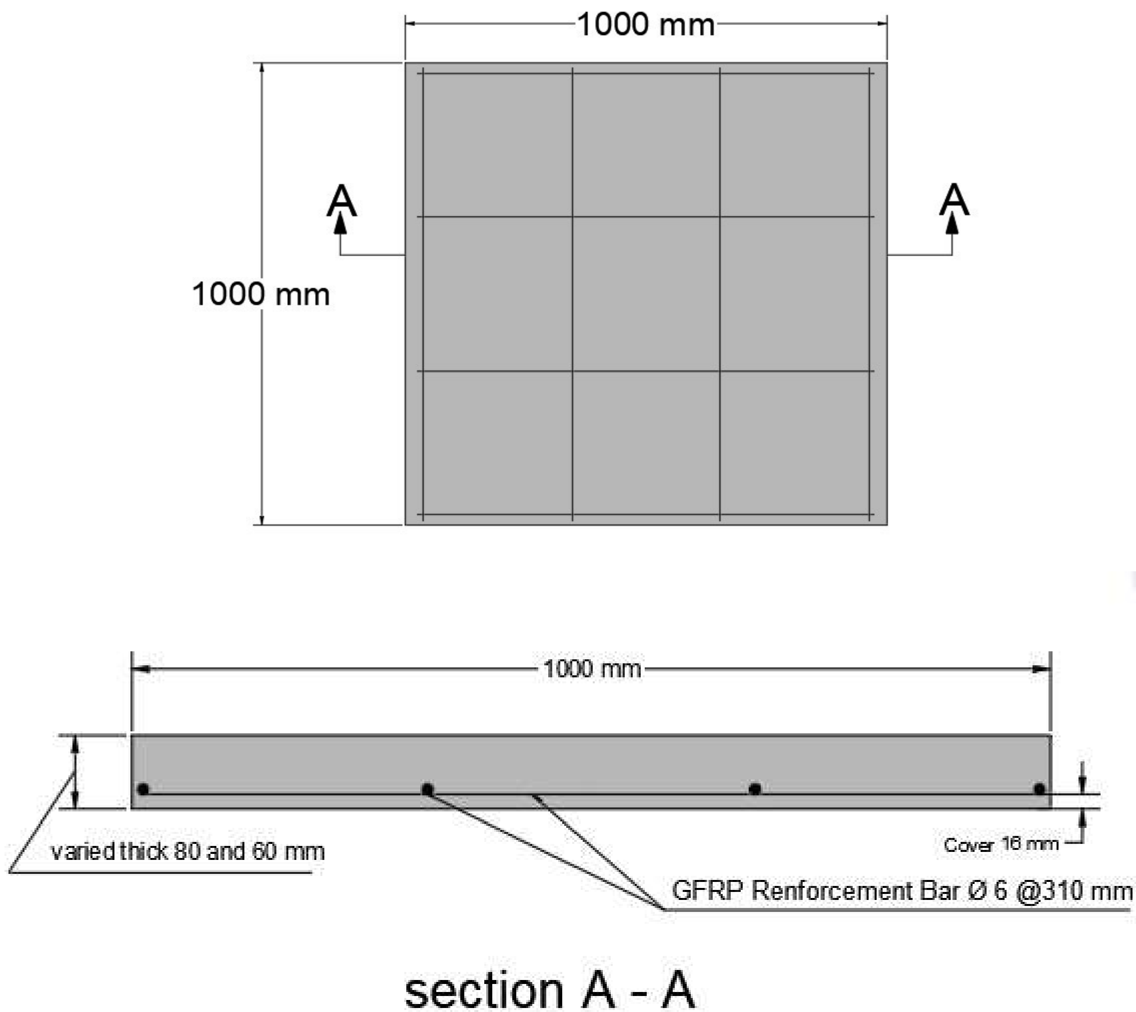


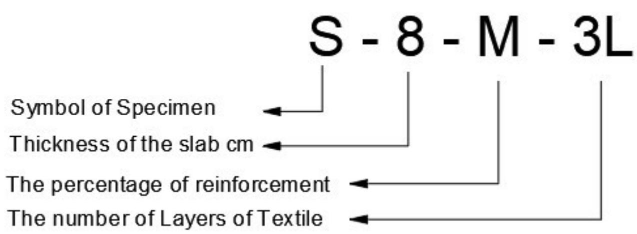
Figure (1) Sample dimensions and reinforcement

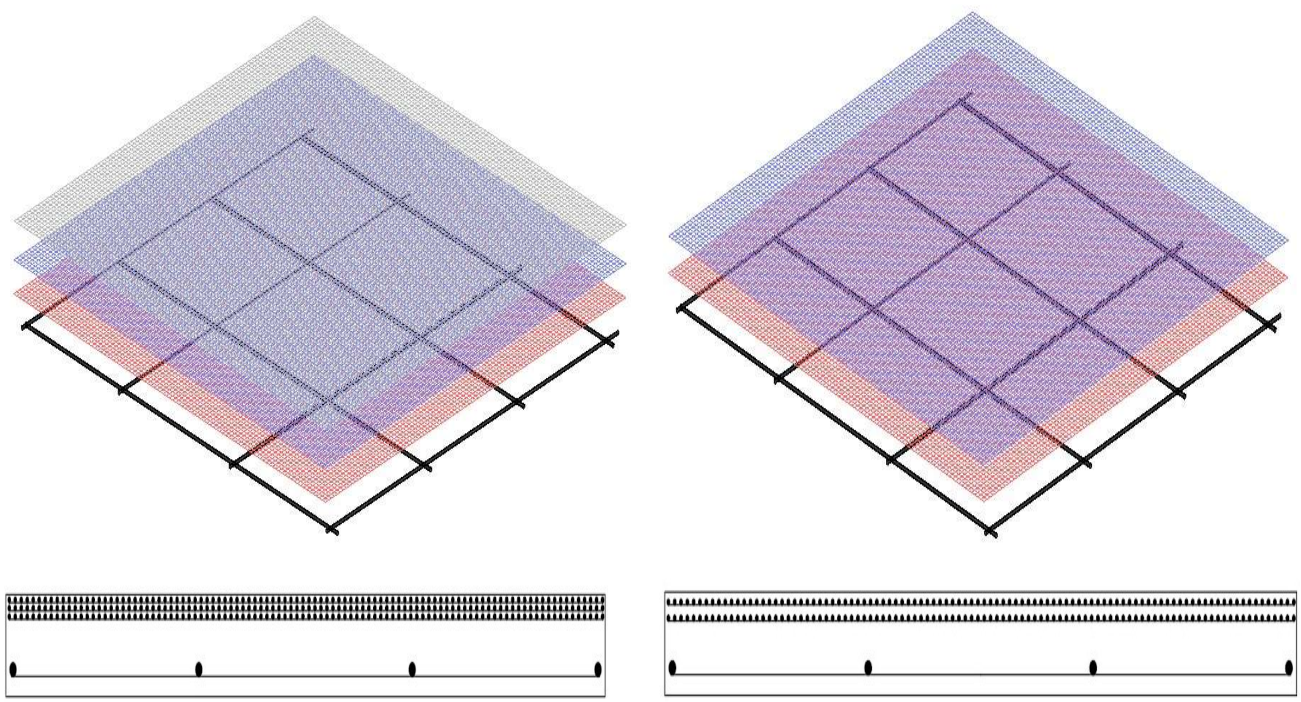
The test samples were described in detail in terms of thickness, number of layers of tissue used in one sample and the percentage of reinforcement (ACI 440.1R-15) as mentioned in Table No. (1) and Figure (2).

Table 1: Details of the test program

Slab no.	R.C. Slab thick (mm)	Slab Symbol	Drop Weight (Kg)	The number of layers of textile	Spacing (mm)	Reinforce-ment ratio ρ %	Drop Height (m)
1	80	S-8-M	4.098	-	Ø6@310 Two layers, top and bottom	0.0014	1
2	80	S-8-M	4.098	2	Ø6@310	0.0014	1

					Two layers, top and bottom		
3	80	S-8-M	4.098	3	Ø6@310 Two layers, top and bottom	0.0014	1
4	60	S-6-M	4.098	3	Ø6@310 Two layers, top and bottom	0.0014	1





Three layers of textile **two layers of textile**

Figure (2) the number of layers of textile used in the samples

Mixes design

Two concrete mixes were used for the slab casting and to produce a compressive strength of 20 MPa. The mixing rates of the raw materials for each mixture are shown in Table 2. The mixtures are designed according to ACI-211.1-91.

Table 2: Mixing rates of raw materials for each mixture

mix no.	mix type	Compressive strength (MPa)	Cement (kg/m3)	Sand (kg/m3)	glass sand (kg/m3)	Gravel (kg/m3)	silica fume (kg/m3)	Superplasticizer Kg /m3)(	Water
1	**normal**	20	400	550		1000	-	-	0.45w/c
2	**especially**	20	480	-	1304	-	144	13	230 mL

Sample pouring steps

- bars (GFRP) with a diameter of 6 mm whose specifications are mentioned in Table (3) are placed at a height of 16 mm from the bottom of the mold in the form of two layers as shown in Figure (3).
- Samples containing fabric layers are cast as follows: -
  - Ordinary concrete consisting of (cement, sand, gravel, water) was poured with a height of 60 mm into the mold with a thickness of 80 mm and a height of 40 mm into the mold with a thickness of 60 mm as shown in Figure (4).
  - The second mixture of special concrete consisting of (cement, glass sand, silica, plasticizers, water) is poured over the remaining height of the mold, which is 20 mm as shown in Figure (5), where layers of fabric are laid, the specifications of which are shown in the table (4) and its image in the figure (6) Within this height, whether it is two or three layers.

Table 3: Properties of GFRP reinforcement (Manufacturer Specifications)

Type no.	Size	Nominal Diameter (mm)	Nominal Area (mm2)	Ultimate Tensile load(KN)	Guaranteed tensile strength (MPa)	Modulus of elasticity (GPa)	Weight (g/m)	Transverse shear strength (MPa)
B100-6	**2**	**6**	**31.67**	**28**	**896**	**46**	**77.4**	**150**

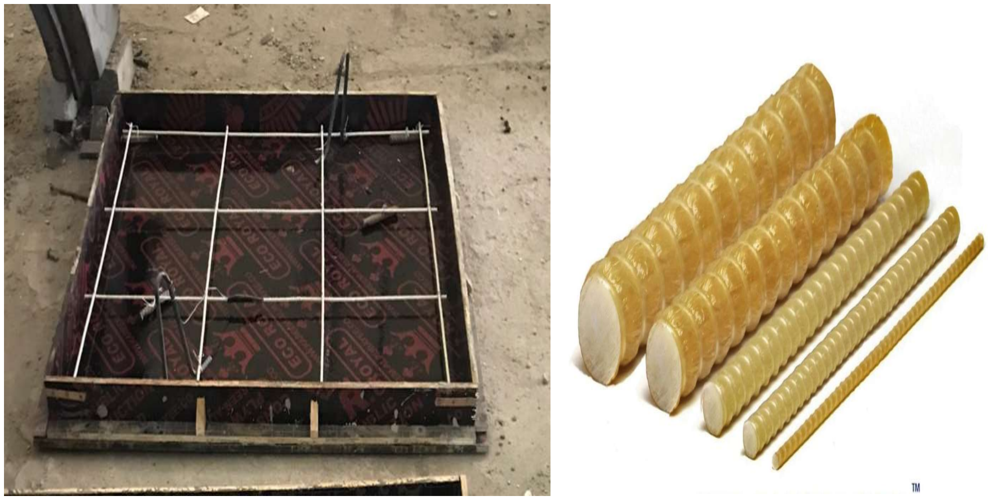


Figure (3) GFRP roads

Figure (4) Indicates the thickness of the two mixtures used to pour the sample

Figure (5) Fixation of textile layers in casting

Table 4: Properties of textile (Manufacturer Specifications)

Weight g/m2	Slot mesh mm x mm	Slot thickness mm	Tensile strength N/mm2
160	4 x4	0.52	2000

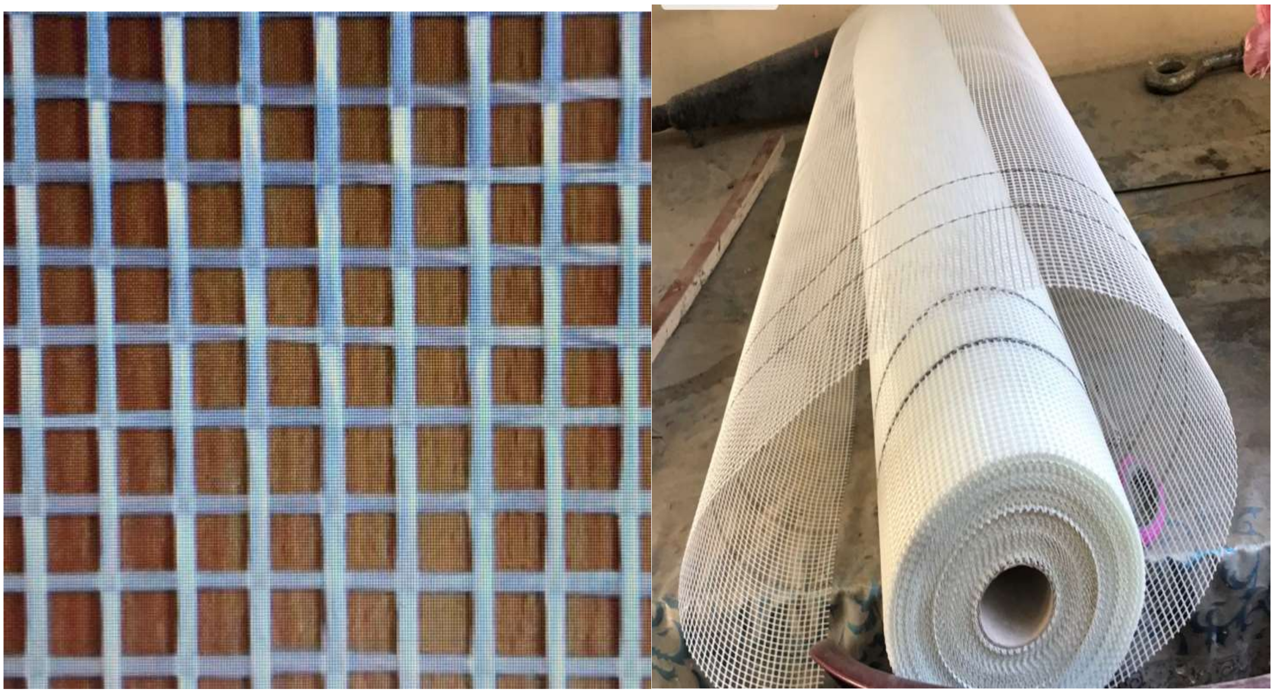


Figure (6) glass textile

Test program:

Testing of reinforced concrete slabs under impact load.

The frame used in the tests, was manufactured locally from iron and installed in the construction lab at the College of Engineering at Mustansiriya University for the purpose of testing the sample on it. It consists of:

- A steel structure with a height of (3) m and it consists of sliding rollers for the purpose of fixing the rope manually. This structure is fixed in the ground
- Square steel table with dimensions (1000 x 1000) mm and a height of 1000 mm
- Aluminum frame with dimensions (500*500) mm square Light weight, a plastic tube is installed on the slab for the purpose of concentrating the weight on it.
- A steel block in the shape of a semicircle with a weight (4.098) kg and a diameter (10) mm
- Using four iron clamps to fix the corners of the slab to prevent it from slipping during the test
- Measurement devices were placed under the sample for the purpose of measuring precipitation and failure of the samples. These devices were linked to a special system for the purpose of data recording.

Figure (7) The structure used for the examination

Measurement tools

The measuring devices were placed in the center of the bottom of the sample for the purpose of measuring sedimentation and sample failure. Table (5) shows the most important devices used in the test. These devices were connected to a special system for the purpose of data recording, as shown in Figure (8).

Table 5: Measurement tools

Parameter	Sensor
Applied load	Load cell
Reinforcing GFRP strain	Embedded strain gauges

Concrete strain	Embedded strain gauges
Specimen deflection	LVDT

Figure (8) Measurement tools

Observation of impact tests

This section presents the visual observation of impact tests including crack patterns and failure patterns resulting from low weight as well as the load and the number of blows leading to the failure of samples. The final states of the panels after the test are also presented as shown below:

1/ Crack pattern and load capacity

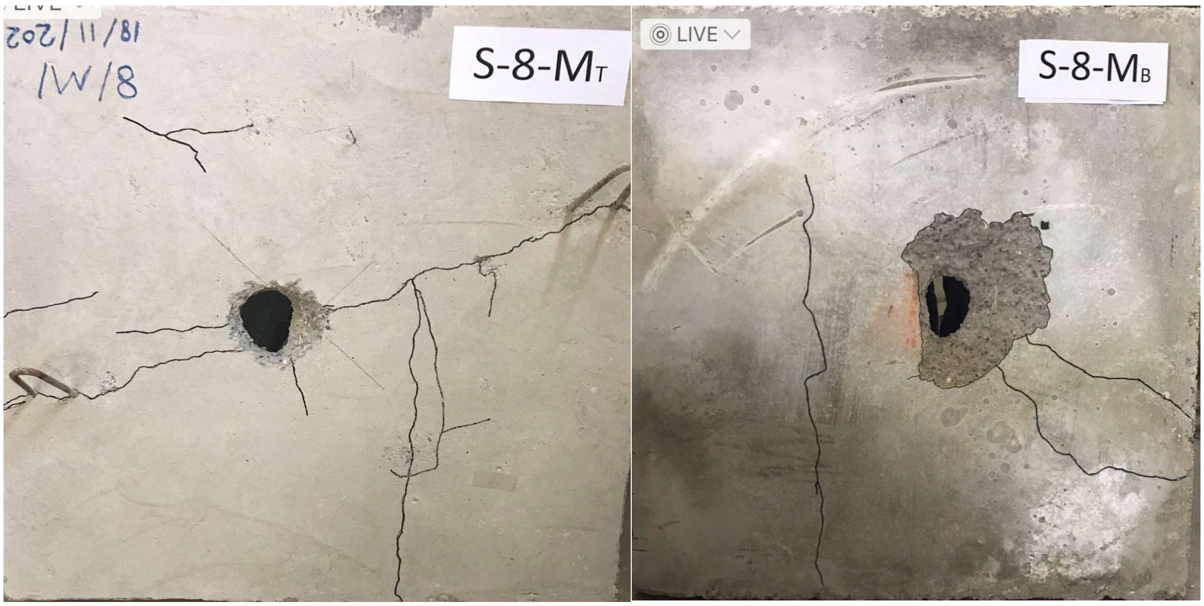
The crack patterns of each slab tested under impact are marked on the slab surfaces (top and bottom) as shown in Figures 9 to 12.

Table (6) shows the loads and number of failure strokes for each slab.

Table 6: load capacity

Specimens	cumulative load	number of blows	first crack load (kN) pcr	Ultimate load (kN) pu	Pcr/Pu %	penetration depth(mm)
S-8-M	800	200	4.8	48	0.1	80
S-8-M-2L	1400	350	20	65	0.30	25
S-8-M-3L	5800	1450	25	120	0.20	45
S-6-M-3L	2880	720	17	77	0.22	20

- Because of the repeated effect by dropping the weight into the center of the upper surface of the slab (S-8-M), the first crack appeared around the sides in the impact area on the face of the pressure area at the strike (40) and at the load (4.8) kN. With the increase in the number of strikes, the fragmentation increased and the weight was penetrated to the entire thickness of the board, and cracks appeared on the surfaces of the upper and lower slab due to the low resistance as shown in Figure (9).



compressive Face(top) **Tension Face (bottom)**

Fig. (9) Patterns of cracks in the slab (S-8-M)

- When repeatedly impacting the slab (S-8-M-2L) reinforced with two layers of glass tissue, the first crack appeared at the impact (120) and at the load (20) kN. With the increase in the number of strikes, new, wider cracks occurred in the middle of the tensile area, scaling, fragmentation, crushing of concrete and then collapse until the sample failed, with no cracks appearing in the slab pressure area as shown in Figure (10).

compressive Face(top) Tension Face (bottom)

Fig. (10) Patterns of cracks in the slab (S-8-M-2L)

- When repeatedly impacting the slab (S-8-M-3L) reinforced with three layers of glass tissue, the first crack appeared at the impact (290) and at the load (25) kN. With the increase in the number of blows, new, wider cracks occurred in the middle of the tensile area, peeling, fragmentation, crushing of concrete and the appearance of bars (GFRP) in the center of the slab's tension area and then collapse until the sample failed, with no cracks appearing in the slab pressure area as shown in Figure (11).

compressive Face(top) Tension Face (bottom)

Fig. (11) Patterns of cracks in the slab (S-8-M-3L)

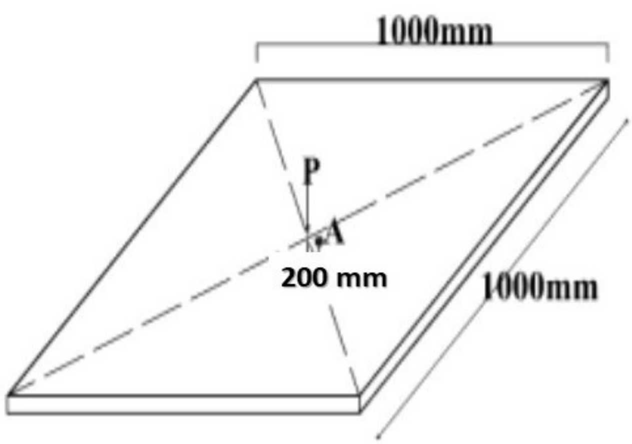
- When repeatedly impacting the slab (S-6 -M-3L) reinforced with three layers of glass textile, the first crack appeared at the impact (190) and at the load (17) kN. With the increase in the number of blows, cracks occurred in the middle of the tension area, scaling, fragmentation, crushing of concrete and then collapse until the sample failed, with no cracks appearing in the pressure area of the slab as shown in Figure (12).

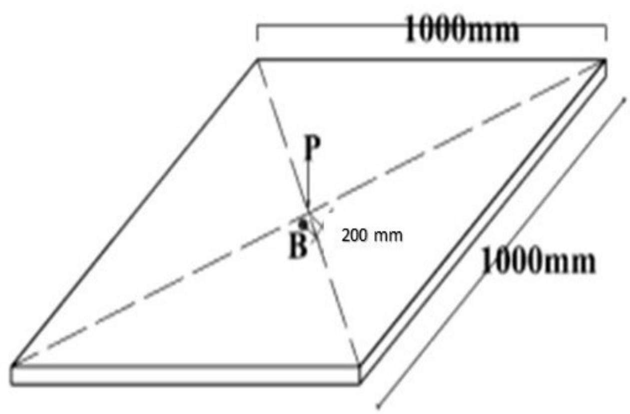
compressive Face(top) Tension Face (bottom)

Fig. (12) Patterns of cracks in the slab (S-6-M-3L)

2/ measuring deviation

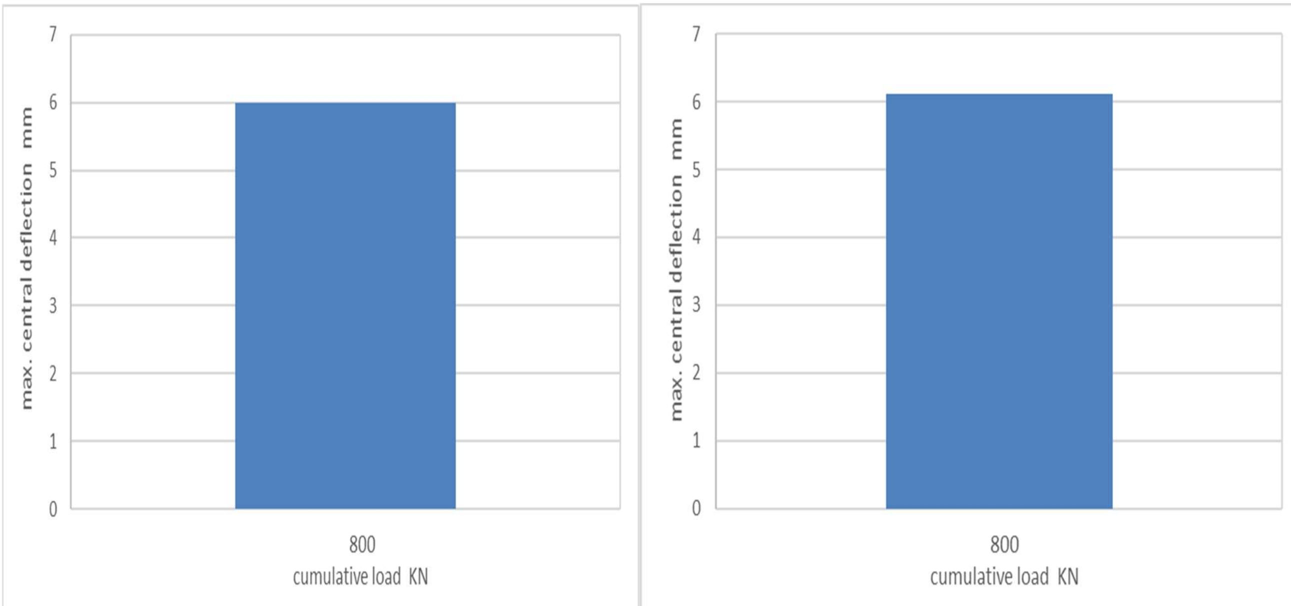
The vertical deflection under load was recorded at each load as a response to the load and the deflection of each plate as shown in the figures below. Where the deviations were measured at a distance (200 mm) from the center of the lower surface in two locations (A, B).





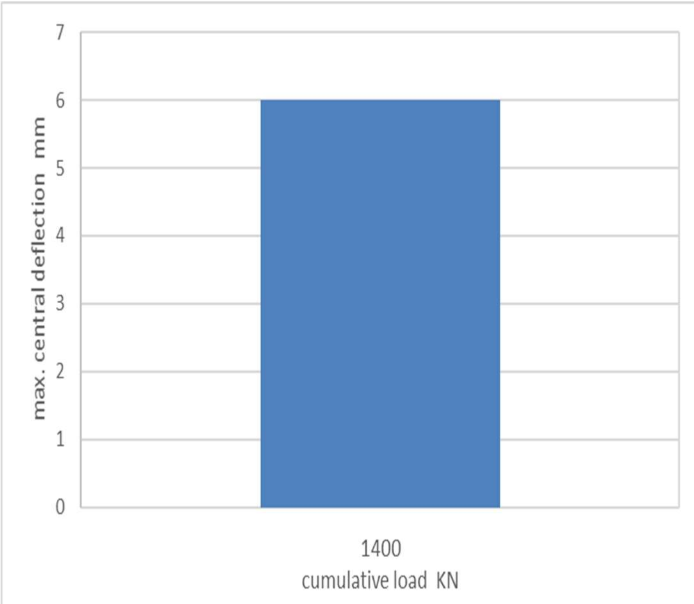
The point (A) represents the first(LVDT) position, Which is located 200 mm from the center of the bottom of the slab

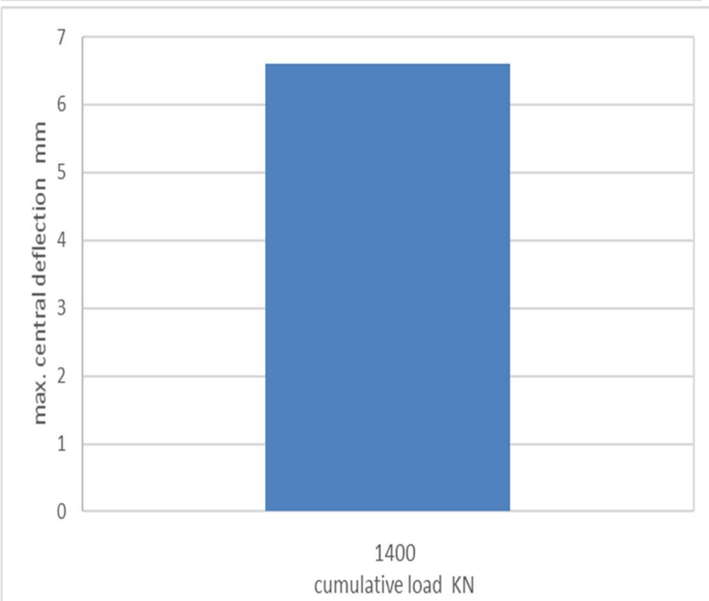
The point (B) represents the second (LVDT), position which is located 200 mm from the center of the bottom of the slab.



Point (A) Point (B)

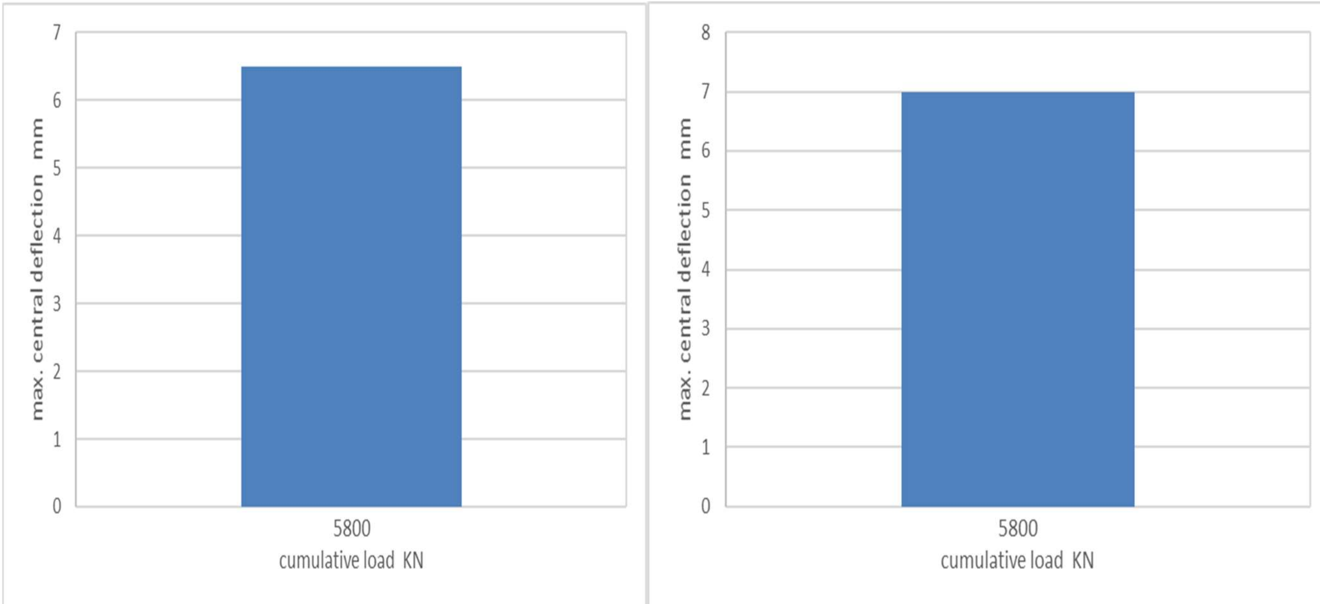
Fig. (13) Deflection- cumulative load chart for Slab (S-8-M) Thickness=80mm, without textile, at 200 blows





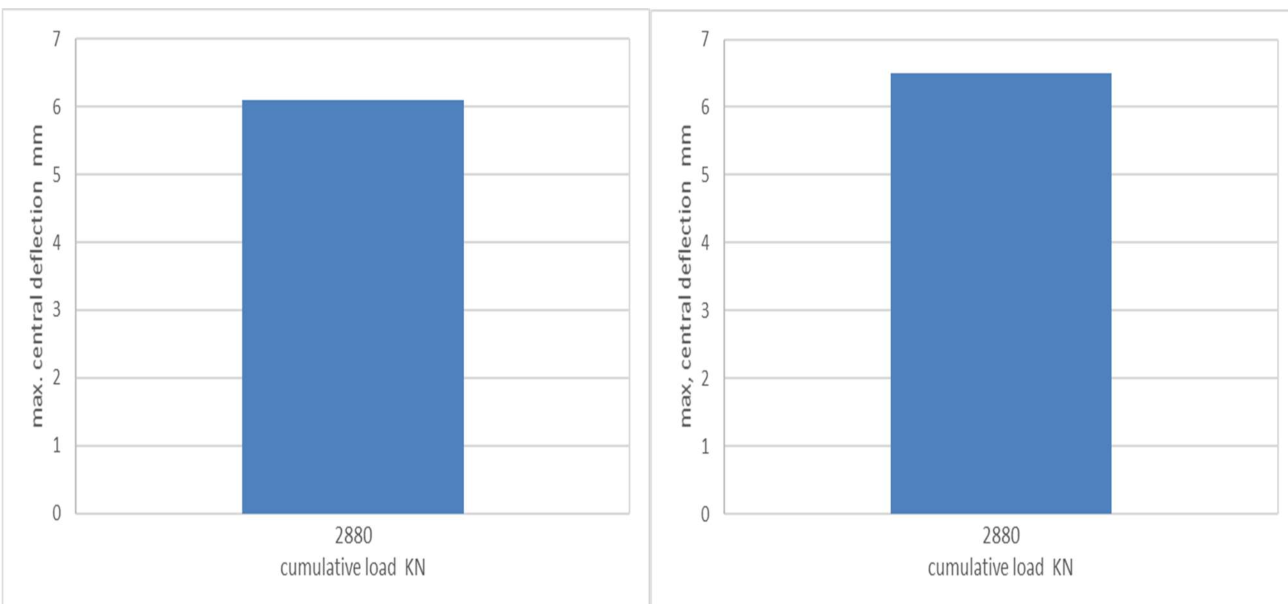
Point (A) Point (B)

Fig. (14) Deflection- cumulative load chart for Slab (S-8-M-2L)
Thickness=80mm, with two layer of textile, 350 blows



Point (A) Point (B)

Fig. (15) Deflection- cumulative load chart for Slab (S-8-M-3L)
Thickness=80mm, with three layer of textile, 1450 blows



Point (A) Point (B)

Fig. (16) Deflection- cumulative load chart for Slab (S-6-M-3L)
Thickness=60mm, with three layer of textile, 720 blows

- It was observed from the load-with-precipitation diagram that tiles (**S-8-M-2L**) reinforced with two layers of fabric increased their flexural capacity by (7.42%) than tiles (**S-8-M**) not reinforced with textile.
- The bending strength of a slab (S-8-M-3L) reinforced with three layers of fabric was slightly increased (5.71%) than that of a slab (S-8-M-2L) reinforced with two layers of fabric.
- The bending capacity of slab (S-6-M-3L) reinforced with three layers of fabric with a thickness of 60 mm is less than that of slab (S-8-M-3L) reinforced with three layers of fabric with thickness of 80 mm by (7.14%)

3/ Number of textile Layers

Comparing the results of the samples (S-8-M, S-8-M-2L, and S-8-M-3L) shows the effectiveness of the tissue layers in increasing the number of strikes inflicted on them, as the number of strikes to the slab (S-8-M-3L) increased. Reinforced with three layers with (1450) strokes more than the sample (S-8-M-2L) Reinforced with two layers with (350) strokes, which in turn is more than the sample (S-8-M) without fabric with (200) strokes with the same thickness of 80 mm, as shown in Figure (17).

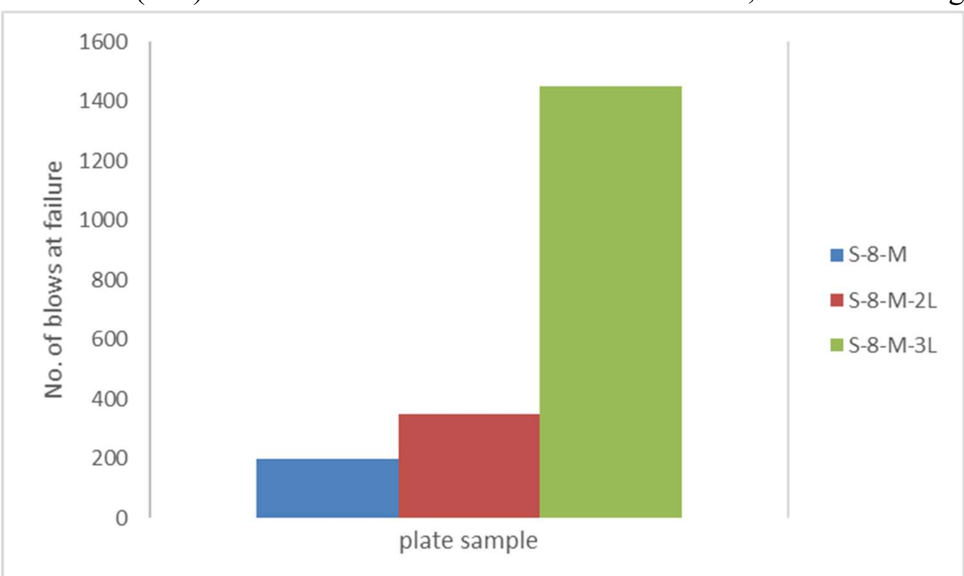


Fig. (17) Number of blows Required for Reaching Failure in slab (S-8-M, S-8-M-2L, and S-8-M-3L) Thickness=80mm, ρ = 0.0014

4/ change in thickness of slabs

When comparing the number of blows on the 80 mm three-layer reinforced slab (S-8-M-3L) with that of the 60 mm three-layer reinforced slab (S-6-M-3L), the difference is (50.34 %) between the two tiles as shown in Figure (18).

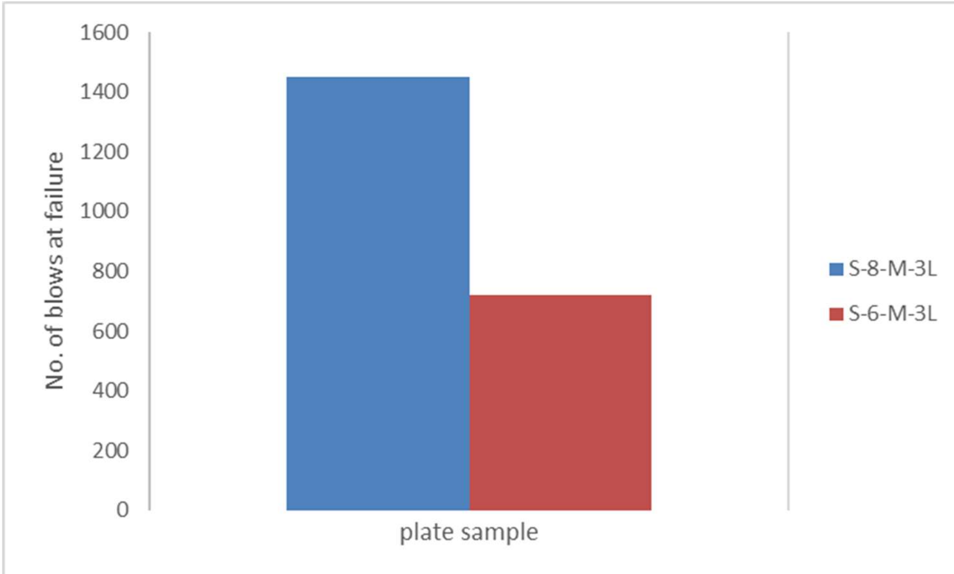
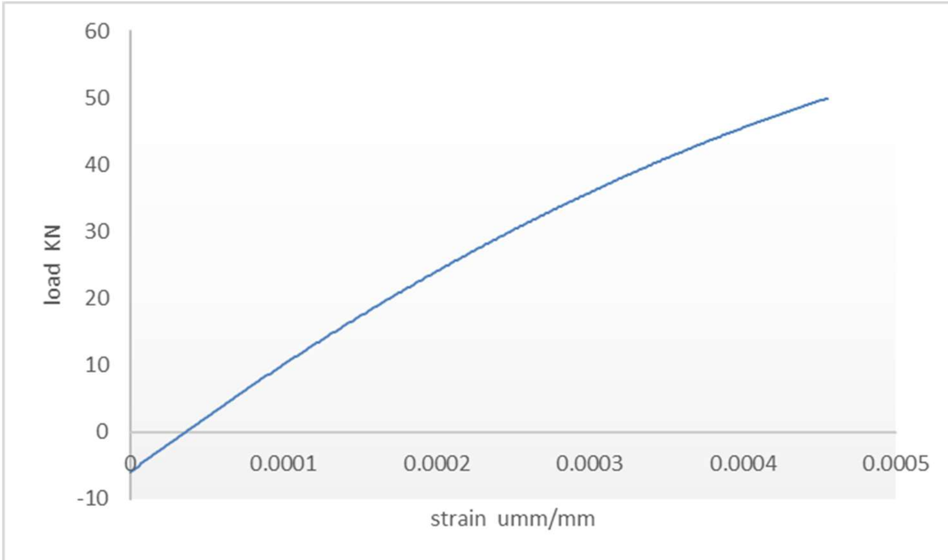


Fig. (18) Number of blows Required for Reaching Failure in slab (S-8-M-3L and S-6-M-3L) ρ = 0.0014

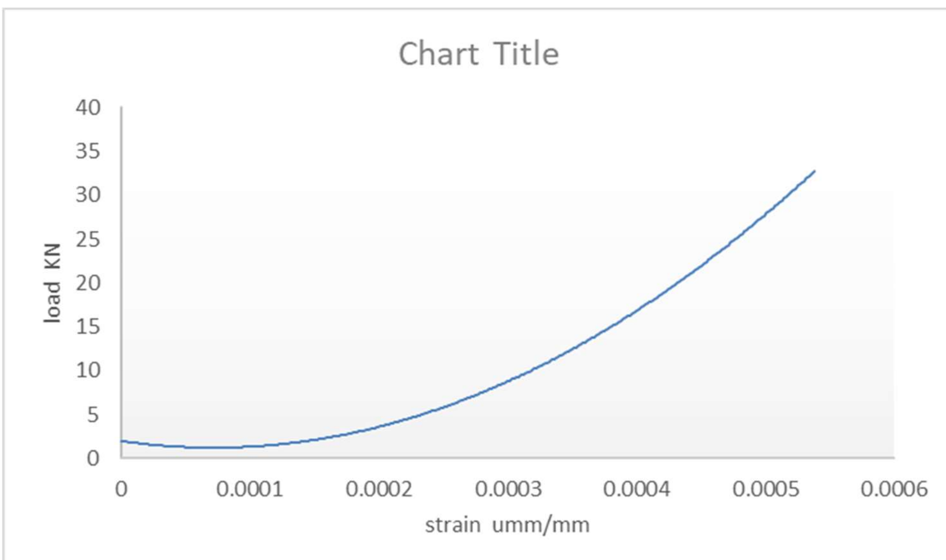
5/ Load-Strain Relationships (GFRP)

Stress gauges are installed at the bottom of the longitudinal tensile reinforcement bars (GFRP) for the plates as shown in Figure (19) to measure their stress during loading (A, B, C, D) in Figure (20).

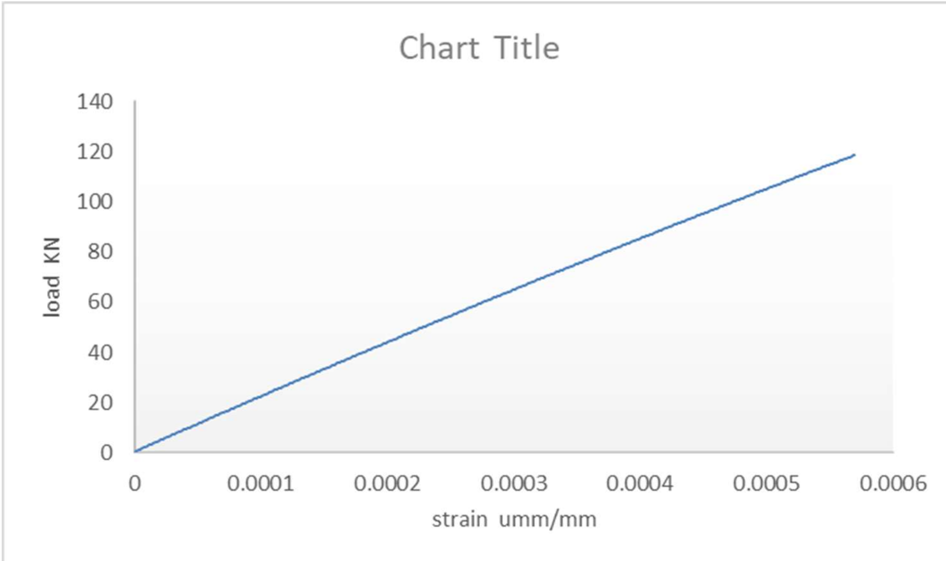
Figure (19) Citrine strain gauge



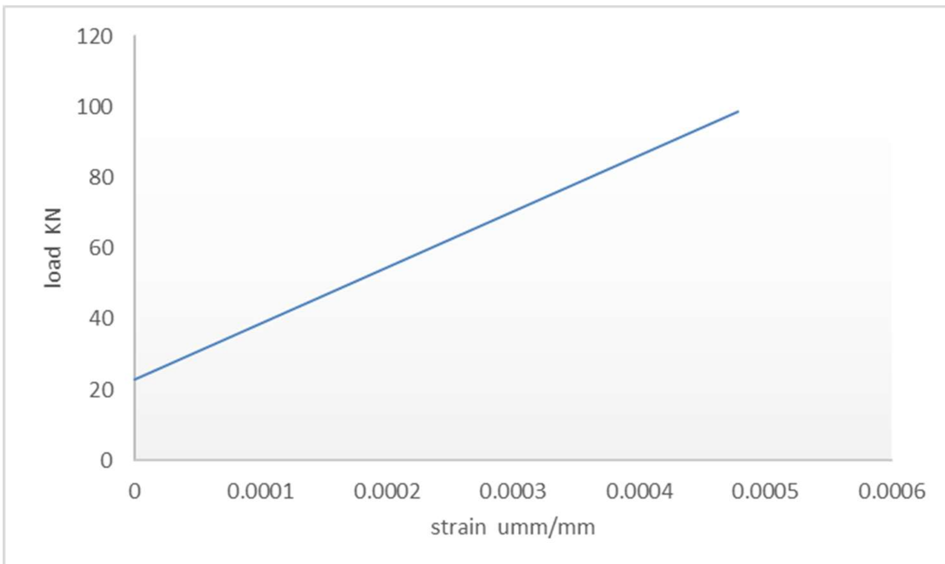
(A) Load-Strain Curve for Slab (S-8-M)



(B) Load-Strain Curve for Slab (S-8-M-2L)



(C) Load-Strain Curve for Slab (S-8-M-3L)



(C) Load-Strain Curve for Slab (S-6-M-3L)

Figure (20) Load-Strain Curve

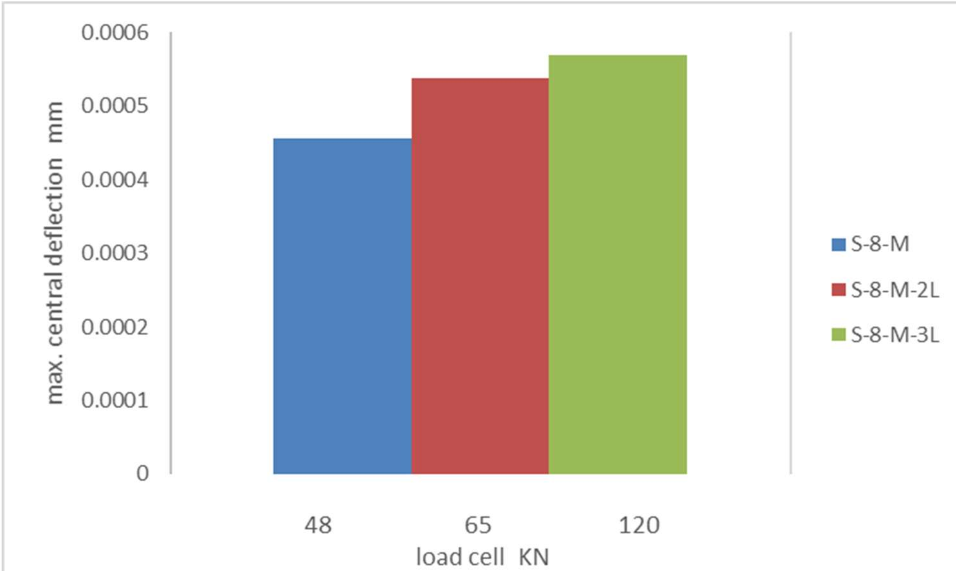


Fig. (21) Load - Strain chart for Slab (S-8-M, S-8-M-2L, and S-8-M-3L) Thickness=80mm, ρ = 0.0014

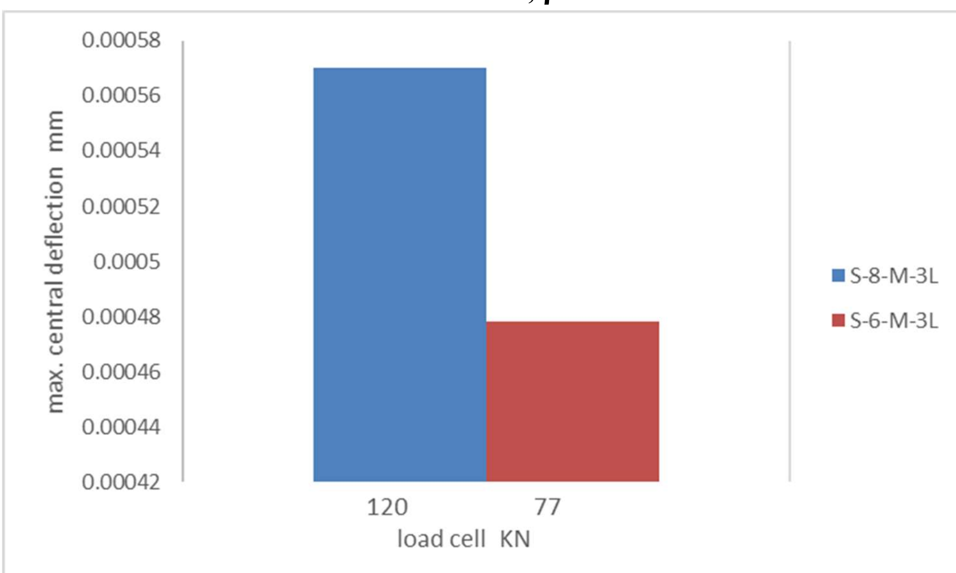


Fig. (22) Load - Strain chart for Slab (S-8-M-3L, and S-6-M-3L) ρ = 0.0014

6/ concrete strains

To measure the concrete strains, a slide was placed on the tension face of the concrete slab. 200 mm from the center of the slab. The strains appear to change linearly until major cracks along the diagonals begin to propagate. As shown in the figures

In general, the stress values are observed to be higher when the panels are reinforced with texture layers than the non-reinforced panels as follows:

- The load stress in the slab (S-8-M-2L) increased by (5%) over the slab (S-8-M) as shown in Figure (23 and 24).
- It was observed that when the number of fabric layers in the tiles increased (S-8-M-2L, and S-8-M-3L), the load stress was increased by (20%) as in Figure (25)
- The load stress was reduced by (12%) when the thickness was reduced from 80 mm to 60 mm when the number of layers was fixed as in the tiles (S-8-M-3L, and S-6-M-3L) as in Figure (26)

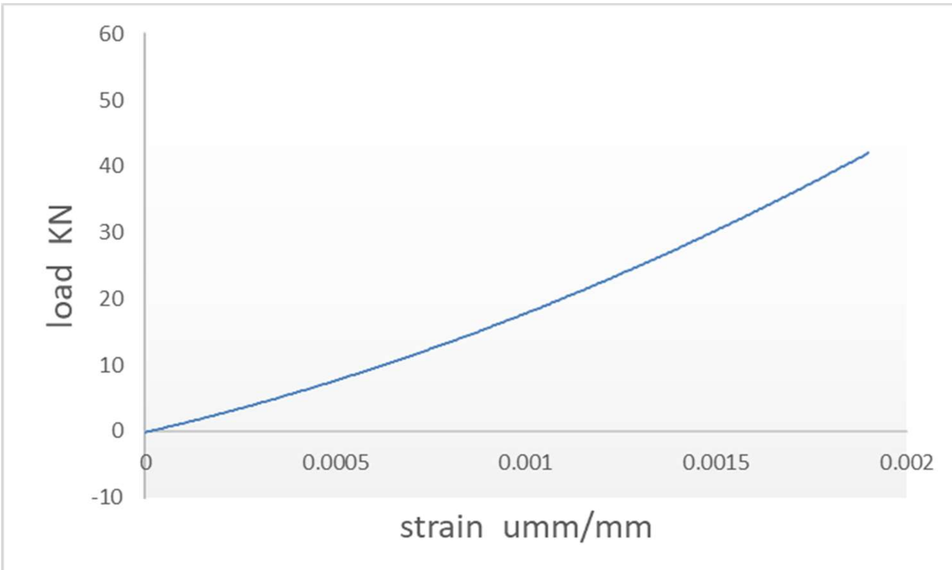


Fig. (23) Load-Strain Curve for Slab (S-8-M)

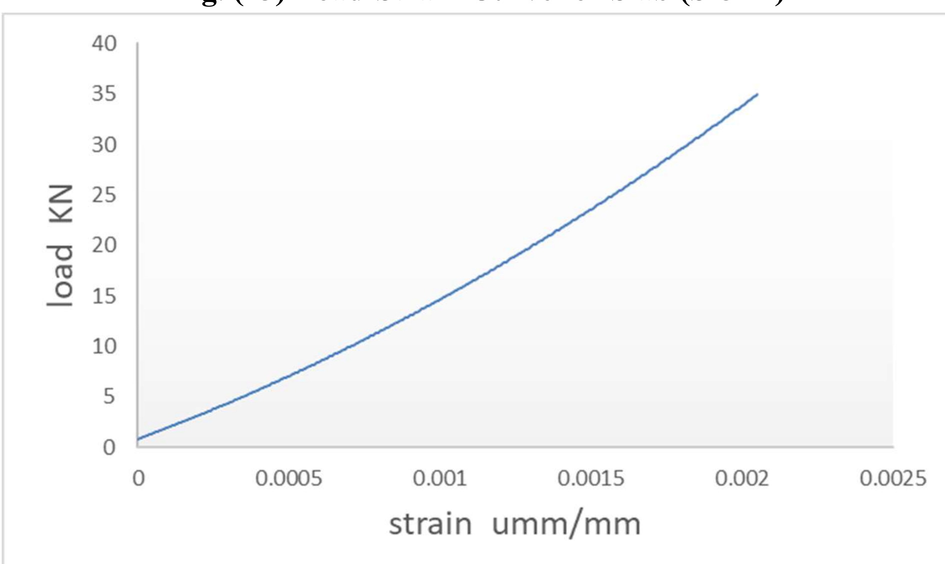


Fig. (24) Load-Strain Curve for Slab (S-8-M-2L)

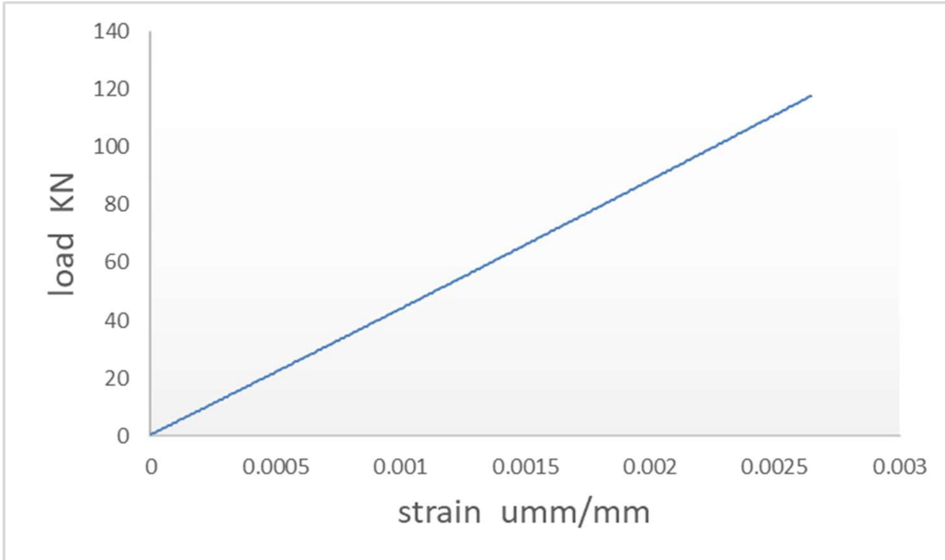


Fig. (25) Load-Strain Curve for Slab (S-8-M-3L)

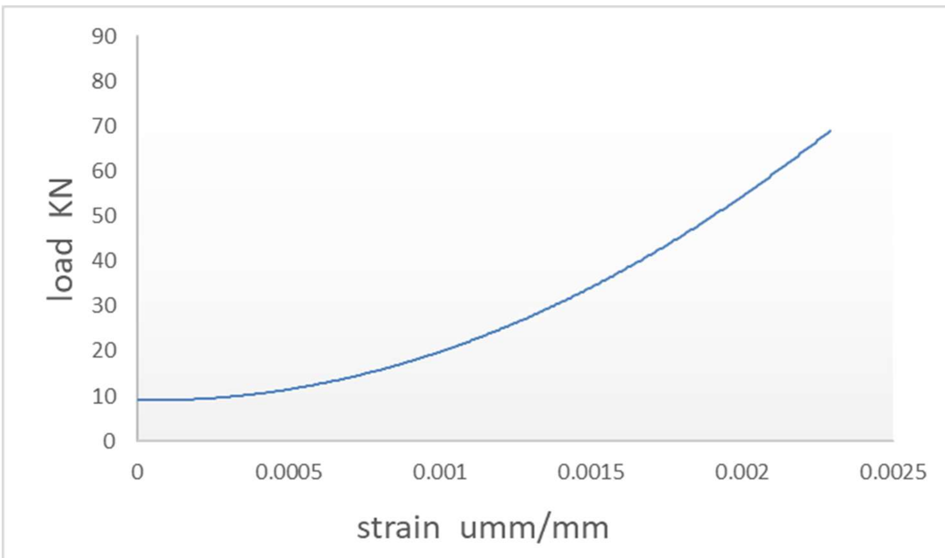


Fig. (26) Load-Strain Curve for Slab (S-6-M-3L)

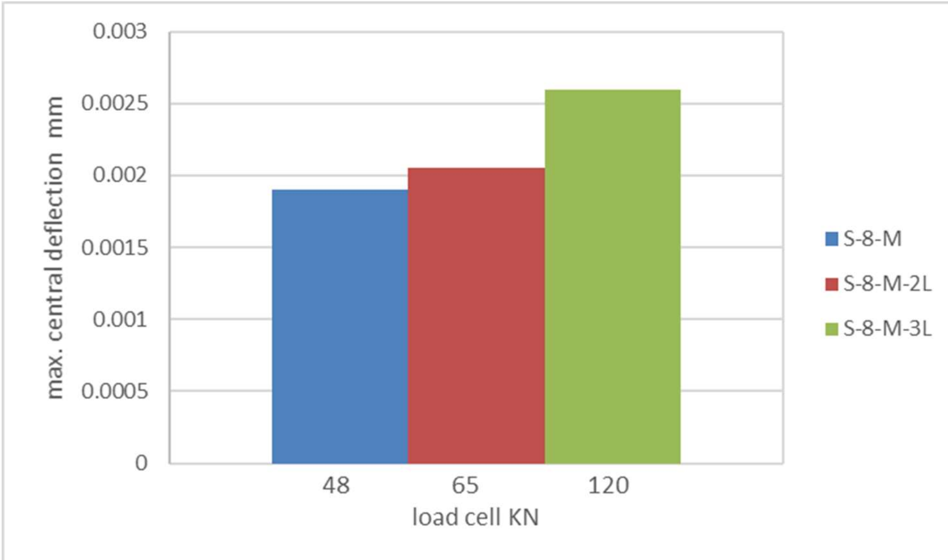


Fig. (27) Load - Strain chart for Slab (S-8-M, S-8-M-2L, and S-8-M-3L) Thickness=80mm, ρ = 0.0014

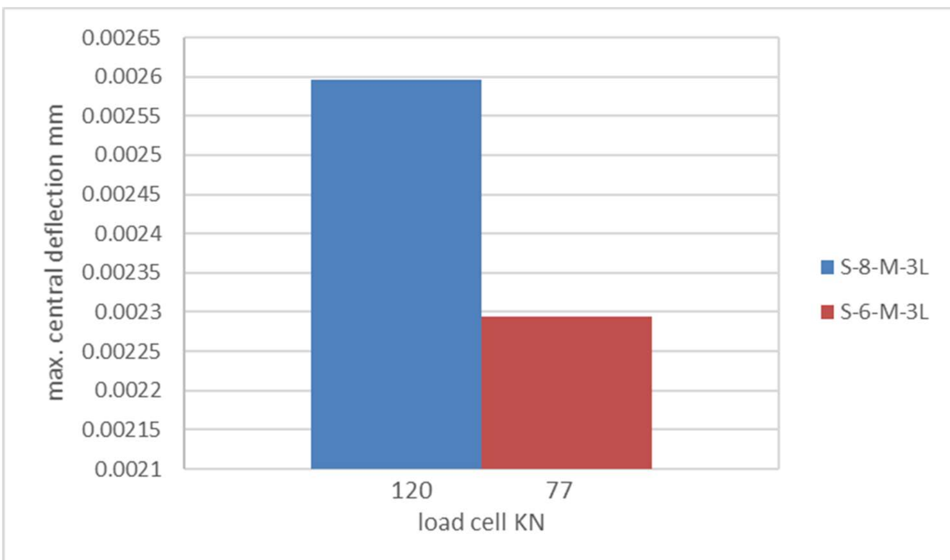


Fig. (28) Load - Strain chart for Slab (S-8-M-3L, and S-6-M-3L) ρ = 0.0014

Discussion of Results

This paper presents an experimental investigation on the efficacy of a new material, vitreous-reinforced concrete as a method of reinforcing slabs reinforced with bidirectional (GFRP) rods. The design of the samples allows investigation of a series of parameters including the number of layers of fabric, thickness of the slab. The main conclusions are summarized in a fairly qualitative manner.

In the following way:

- Due to the repeated dropping of weight, the upper surface of the slabs was splintered with a penetration of 80 mm thickness of slab (S-8-M), thickness 25 mm of slab (S-8-M-2L), thickness 45 mm of slab (S-8-M-3L) and thickness 20 mm of slab (S-6-M-3L).
- The slab (S-8-M) failed carrying 48 kN and number of blows 200 blow, while slab (S-8-M-2L) failed carrying 65 kN, number of blows 350 blow, slab failed (S-8-M-3L) carrying 120 kN number of blows 1450 blow, and slab failed (S-6-M-3L) carrying 77 kN number of blows 720 blow
- When comparing the samples (S-8-M, S-8-M-2L, S-8-M-3L and S-6-M-3L) with the effectiveness of the layers, it was observed that the first crack appeared in the tension area of the slab (S-8-M) at the blow 40, the first crack of the slab (S-8-M-2L) at the blow 120, the first crack of the slab (S-8-M-3L) at the blow 290 and the slab (S-6-M-3L) at the blow 190
- The percentage of the difference in the number of strokes in the slab (S-8-M-3L) with a thickness of 80 mm with the slab (S-6-M-3L) with a thickness of 60 mm was by (50.34%)
- The difference in the bending strength of the two panels (S-8-M and S-8-M-2L) was observed by (7.42%), while the bending strength of the slab (S-8-M-3L) reinforced with three layers was (5.71%) higher than that of the glass fabric. Slab (S-8-M-2L) is reinforced with two layers. The bending resistance of the slab (S-6-M-3L) reinforced with three layers of 60 mm thickness of the corresponding sheet (S-8-M-3L) with a thickness of 80 mm was also observed to decrease by (7.14%).
- The texture layers prevented the cracks from appearing in the pressure area, as they were not observed in the tiles (S-8-M-2L, S-8-M-3L and S-6-M-3L) while these cracks appeared in the tiles (S-8-M)
- In the impact test, the fabric layers did not increase the bending ability of the tiles, as the significant effect was not observed, but it affected very significantly on the tiles' endurance for the number of strikes.

CONCLUSIONS

This paper presents an empirical study on the effectiveness of fabric layers in bi-directional rod reinforced board (GFRP). Where one control sample was poured without a tissue and two samples were poured, one with two layers and the second with three layers of tissues with a thickness of 80 mm, and the fourth sample was poured with three layers of tissues with a thickness of 60 mm applied on it with pressure.

Through the experimental work, the following was concluded: -

- It was concluded that covering the entire face of the slab with three layers of glass cloth is more effective in increasing the slab’s tolerance to the number of repeated weight strikes than placing two layers of cloth in the slab by (75.86%) and also more effective than using three layers in the 60 mm thick slab by (50.34%)
- The layers of the fabric prevent the appearance of cracks in the pressure area

- The study also showed that the glass fabric and polymer-modified mortar are more effective, sustainable and cost-effective.

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