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DYNAMIC BEHAVIOR OF SLAB REINFORCED WITH FRP BARS AND STRENGTH WITH CARBON SHEET

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ABSTRACT

Reinforced concrete slabs are common structural parts that may subjected to impact loads plus static loads. Reinforced concrete structures subjected to harsh environments in some time and because of the high corrosion resistance of Fiber Reinforced Polymer (FRP) bars; can used as a substitute for traditional steel. Up to failure, FRP bars behave in a linear-elastic manner without yielding (brittle behavior), which necessitates a solution. Recently, there has been a proposed external bonding of Carbon Fiber Reinforced Polymer (CFRP) sheet on the tension side of the slab to strengthen it. In this study, the number of CFRP sheet layers (one or two) and their configuration (covering the entire surface or only a portion of it) explored. Five (1550×1550×150) mm concrete slabs support all four corners of each one with simple support and reinforced with Glass Fiber Reinforce Polymer (GFRP) bars casted. Four of them externally bonded with CFRP sheets. All slabs tested under impact loads by dropping a 150kg mass from a height of 5m until cracks appeared. Displacement-time, strain-time, reaction force-time, and acceleration-time explored and compared between slabs with various configurations. The results show that increasing the layer number of CFRP on the tension side of the slab develops impact resistance by delaying the appearance of cracks until third blow. In general, slabs with totally bottom CFRP layers provide better performance than other configurations.

KEYWORDS: Glass Fiber Reinforces Polymer Bar; Carbon Fiber Reinforces Polymer Sheet; Impact Load.

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1. INTRODUCTION

Recently, it has been a growing trend to design some structures to resist both static and dynamic loads. Low-velocity high mass impact loading conditions was the common impact scenarios for civil engineering and a type of dynamic loads. Typical low-velocity impact scenarios include transportation structures subjected to vehicle collisions, airport runways platforms during aircraft landing, rock falls, military actions, terrorist attacks and offshore structures subjected to ship impact. The behavior of a concrete structure subjected to impact loads very different from that of a statically loaded structure. Because the structure vibrated during the impact and some parts of the structure may subjected to tensile or compressive stresses/strains. Particularly slabs, which directly sensitive to collapse under sudden loads, and this performance may because of reinforcement Concrete slabs slender members and that means when subjected to impact loads susceptible to flexural failure, shear failure, or both Tahmasebinia, F.et al. (2008). The effects of dynamic loads on the structures evaluated in terms of local damage (penetration, perforation and scabbing) and structural response in the form of flexural and shear deformations, and the structure dynamically analyzed under the applied force-time history. Fiber reinforced polymer (FRP) bar a revolutionary used as alternative of traditional steel reinforcement in civil engineering structures. The FRP bar composed of continuous fibers made of polymeric resin embedded in a matrix. The fibers had a load carrying function; the resin had the function of linking the fibers together and move them.FRP bars had low weight-to-strength ratios (0.2 to 0.25 of the steel density), their longitudinal tensile strength extremely high, and non-magnetic. Although steel reinforcement had a lower initial cost than FRP reinforcement, high resistance of corrosion, FRP-reinforced frameworks or structural components had lower average life cycle cost. Significantly, lower maintenance expenses wanted for FRP-reinforced structural components (Reinforced Polymer Fiber).

The use of FRP sheets, plates, or other materials for beams Attari et.al. (2012) and slabs Smith et.al. (2011) on the exterior surface has been widely used to strengthen structural elements. Columns that damaged also repaired by using FRP sheets Li et al. (2003) Concrete beams and slabs could also reinforced with FRP bars Alsayed,. (1997) and Noel, (2014). Some important studies related to structural behavior of RC slabs with steel bars under drop weight impact loading addressed.

Batarlar (2013) Six-test slab created and examined under static and impact load. The slabs' reinforcements had mesh shape with an equal reinforcement ratio for all pairs of specimens.

All specimens had a 50.3 mm^2 cross-sectional area and an 8 mm diameter with tension reinforcement ratios of (0.4, 0.3, 0.2) percent in both directions. The impact load resulting from a free-falling drop-weight (210 and 320) kg on the mid-point of the specimen. The outcome data that calculated from the examinations indicated that ductility and static load capacity of structure effect by longitudinal reinforcement ratio. Furthermore, the specimen with the greatest amount of reinforcement ratio able to withstand the greatest load while failing brittle. Bhatti, (2011) studies the impact resistance of concrete slabs, which strengthen with FRP sheet on the tension face. 300 kg weight of steel drop with a 60 mm diameter released to apply the impact load in the middle of the slab. Twelve RC slabs (1650 x 1650 x 150) mm used for the test. The number of layers employed in this investigation as well as the strengthening technique and substances characteristic of the FRP sheet varied. All results show that when fixing FRP sheet to tension face of slab the impact resistance of RC slabs improved and the load bearing mechanism of RC slabs depending on the kind of load and the magnitude of reinforcement in the FRP sheet. Abadel et al. (2017) investigated the local damage behavior of CFRP strengthened RC slab against projectile. RC slab (600 × 600 × 90) mm and reinforced with Ø8@100mm c/c rebar (0.71%steel) with compressive strength (63) Mpa and strength with CRFP sheet. The velocity of projectile varied within sub ordinance range (till there performation) and the projectile weight (0.8) kg and strike slab by using gas gun. The test result show that CRFP strengthen is effective in lessen local damage and increased plastic limit velocity and effective in lessen flying of concrete fragment. Sadraie et al. (2019) Investigate, dynamic, response of slabs reinforced with steel, and GFRP bar, and applied to impact load with low velocity by using the consequences of experimental work and numerical modeling. Fifteen specimens used plain and reinforced concrete slabs (1000 ×1000) mm involving two specimens without reinforcement and with thickness (75) mm five slabs with steel bar and thickness of (75)mm and six slabs with GFRP bar and thickness (75)mm and two slabs with steel bar and thickness (100)mm poured and examine under falling mass. All tested slabs applied falling mass of 105 kg from 2.5 m high at the middle. Bar type (steel or GFRP), reinforcement ratio, single or double mesh, compressive strength, and depth of slab used as parameter.

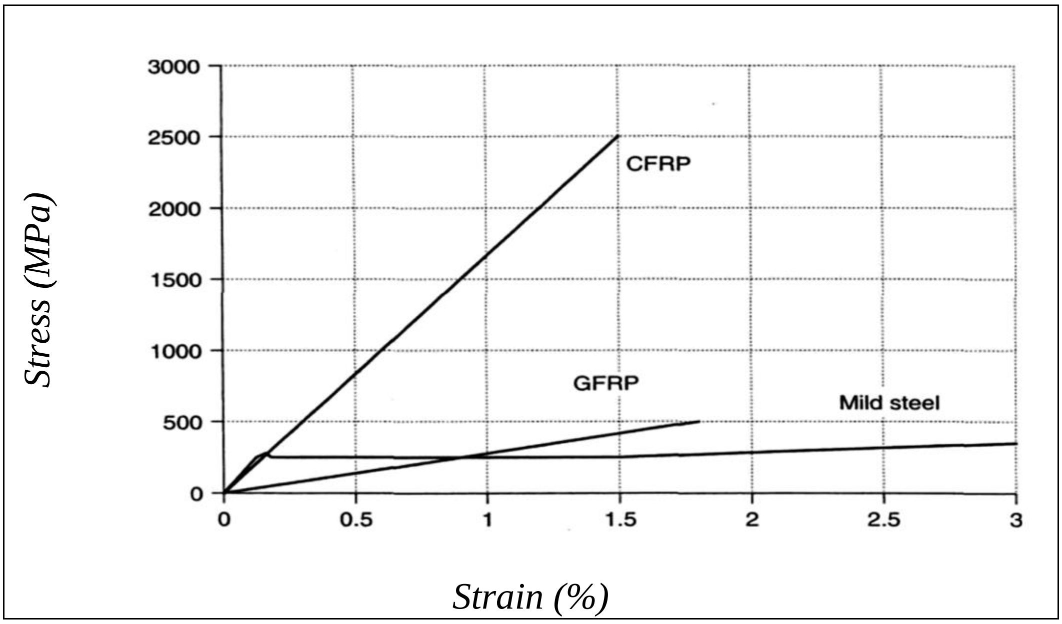


Fig. 1. Stress strain relationship of FRP Teng et al., (2011).

The results proved concord between them and shown that rising of the reinforcement ratio with used two layers reduced displacement and that adjusted the quantity and the rearrangement of GFRP bar resulted in bestead execution in slabs reinforce with GFRP bar than steel reinforced slabs and Increased in bottom reinforcement ratio had better influence than addition of top reinforcement layer. From the all above review, found that many researches that took on account behavior of slabs reinforced of steel rebar under impact load with or without strengthen of FPR(sheet or textile or plate) with a few number of researches that studied the behavior of slabs reinforced with FPR rebar under impact load. However, no researches investigate the execution of slabs reinforced with GFRP bar instead of steel bar to treat the corrosion, which subjected to some structure and externally strengthen with CFPR sheet to withstand of brittle behavior of FRP bar and to give warning before failed when subjected to impact load.

2. TEST SPECIMENS

Five slab specimens with dimensions of (1550 x 1550 x 150) mm and a 25 mm concrete cover casted and tested to evaluate the behavior of impact load on concrete slabs reinforced with GFRP bar. Single layer (bottom) of glass-reinforced bar with reinforcement ratio of (0.96%) used in all spacemen .Externally bonded Carbon Fiber sheets used to strength four of the RC slabs, with serving one as a control specimen (CFRP). Based on the preliminary design according to ACI 440.1R-15, the reinforcement for the tested slabs estimated.

3. CONSTRUCTION MATERIAL

In this investigation, ordinary Portland cement (type I) made in Iraq (Al Mass Company) employed. Al-Ekhaider natural sand with a maximum size of 4.75mm employed as fine aggregate. Crushed gravel from AL-Nibaey region used for the concrete specimens with a maximum size of (10) mm. use a super-plasticizer known commercially as "Hyperplast PC175," used in high-strength concrete to improve the performance and, durability of concert mixes, and also retaining the workability of fresh concrete mixtures. Glass fiber reinforced polymer (GFRP) bar used as reinforcement for all slabs Table 1 show their properties and Table 2 show the property of Sika Wrap -300C (carbon sheet) that used as strength. Sikadur-330 a structural epoxy paste with a high modulus and high strength that is used for external attaching carbon fiber reinforced polymers (CFRP) sheets to the bottom surface of RC slabs. Table3. Show the property.

Table 1. Properties of GFRP reinforcement.

Type No.	Size	Nominal Diameter (mm)	Nominal Area (mm^2)	Ultimate Tensile Load (kN)	Guaranteed Tensile Strength (MPa)	Modulus of Elasticity (GPa)
B100-13	4	13	126.7	96	**758**	46

Table 2. Properties of CFRP sika wrap 300-C.

Thickness (mm)	0.167
Tensile strength (MPa)	4000
Elastic modulus (MPa)	230000
Ultimate tensile strain (%)	1.7
Density (g/cm3)	1.82

Table 3. Resin Remarks of Resin Characteristics.

Adhesive type	Impregnating epoxy resin
Mixing ratio	Part A (resin) : part B (hardener)= 4 : 1 by weight
Tensile strength (MPa)	30
Elastic modulus (MPa)	3800
Density (kg/lt)	1.31

4. CONCRETE MIXES

The mix proportion to produce concrete (cement, sand, crush coarse aggregate) was (1: 2.175: 2.625), and the W/C (0.225). Table 4 and Table 5 Show the mixture for (1) m^3 and the control test Cylinders / Cubes Compressive Strengths and Splitting tensile Strengths for Concrete Mix use**.**

Table 4. Mixture characteristics (1 m^3).

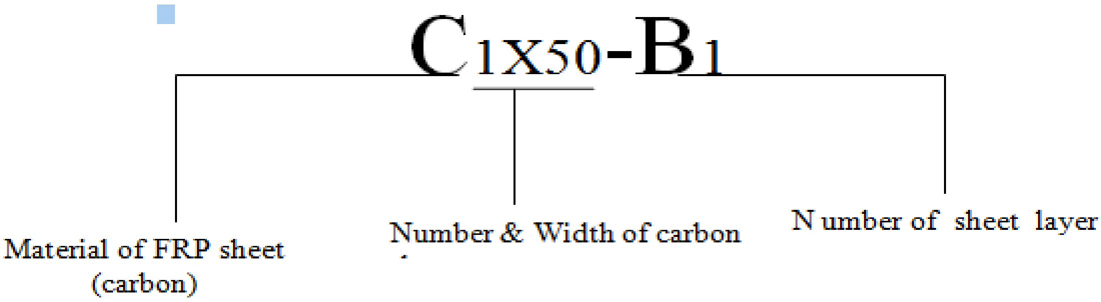
Cement (kg/m^3)	Sand (kg/m^3)	Gravel (kg/m^3)	Admixture (ml/m^3)	Water/Cement Ratio	Water (kg/m^3)
400	870	1050	3500	0.225	90

Table 5. Cylinders / Cubes Compressive Strengths and Splitting tensile Strengths for Concrete Mix use

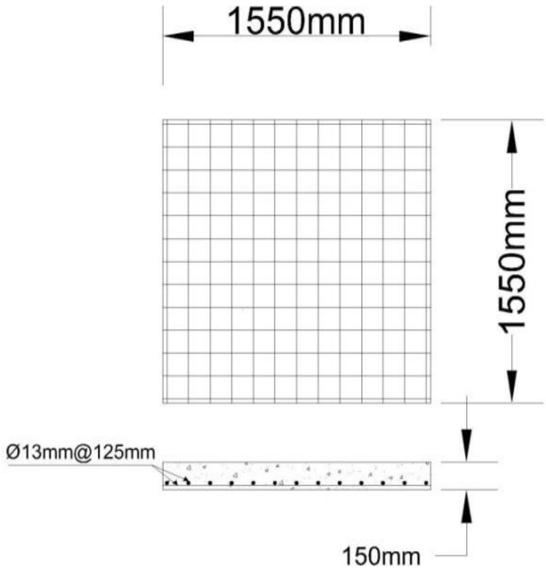
Slab name	f_{cu} (Mpa)	f_c' (Mpa)	f_t (Mpa)	f_r (Mpa)	Ec (Mpa)
S, C_{1x50}-B_1, C_{1x100}-B_1	41.32	31.4	4.57	6.32	26336.78
C_{1x100}-B_2,C_{2x50}-B_2	40.21	30.96	4.34	6.12	26151.6

5. PREPARING OF SLABS AND FIX CARBON SHEET

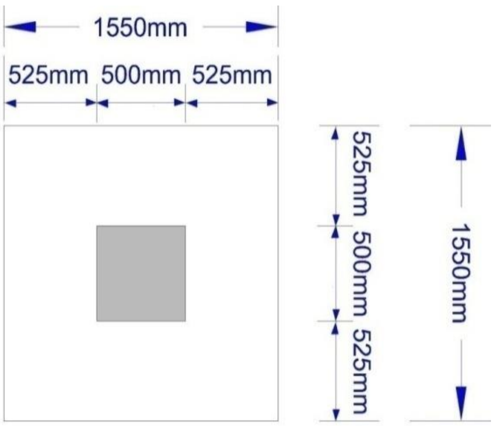
The amount of CFRP sheet layers (one or two) and the configurations of CFRP sheets (taking 2/3 or 1/3 of the surface area) changed among the specimens to discover how RC slabs strengthened with CFRP sheets. The Slabs identification and arrangement of CFRP sheets show in Figs. 2 and 3.



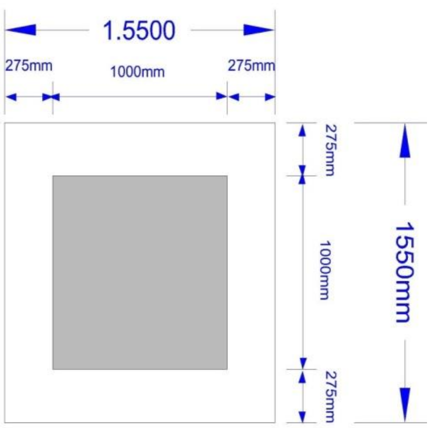
Slab designation



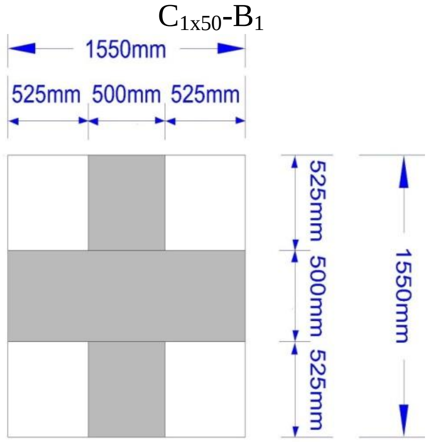
Slabs reinfocement



C_{1x50}-B_1



C_{1x100}-B_1& C_{1x100}-B_2



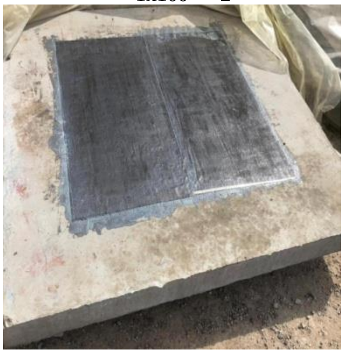
SGC_{2x50}-B_2

Fig. 2. Dimensions of layout and reinforcement details of specimens.

C_{1x50}-B_1

C_{1x100}-B_2

SGC_{2x50}-B_2



C_{1x100}-B_1

Fig. 3. CFRP strengthened slabs.

6. TEST SETUP

The drop-mass low velocity impact setup specifically designed for such investigations, as shown in Figs. 4 and 5 Under the same loading and supporting circumstances, all specimens examined. Specimens subjected to hard impact in the middle and simply supported on all four corners to reduce the measurement of reaction forces. The slab bolted to underlying support on all four corners with four 16mm bolts to avoid any rebounding due to impact load, and then the stand that carried the specimen was bolted to the earth with a 20mm bolt to avoid any movement during the test. Two impact drops of 150 kg applied to each specimen from a 5 meter height, resulting in a theoretical impact velocity of 9.9 m/s. The drop-mass lifted to the necessary height by using a crane. The crane carried a magnetic box type pML-10 with a capacity of 1000 kg and box, which contained man who caught the handle of the magnetic box to release the drop-mass and hit the concrete slabs with a capacity of 7.35 kJ. No damping substances used in the contact area during the tests, since damping materials diminish the strain rate accidentally.

7. INSTRUMENTATION

Two accelerometers mounted on the slab, specimens used to evaluate the transverse acceleration behavior of the slab specimens (vertical accelerations) and measure accelerations over a wide range of ± 10000 g, ±5000 g shown in Fig. 7. Each slab provide four strain gauges of type (BFLAB-5-5-3LJC-F) attached to the bottom side of the longitudinal reinforcement bar to measure tensile reinforcement's axial strain and location shown in Fig. 6. Four load cells model DYLF-102 with O/P= 2.0 MV/V placed on the four corner of the stand under the specimen with a capacity of 700 kN as shown in Fig. 5. The NI PXI-4472 sound and vibration module part of the National Instruments Dynamic Signal Acquisition/Analysis (DSA) system and developed specifically for dynamic signal acquisition applications used to measure the impact test results. All slab specimens tested using applications. Eight analog input channels available on the NI 4472. These channels had a 102.4 kS/s peak sampling rate, 24-bit resolution, and a set of triggering technique, involving exterior digital triggering. Each input channel had its own 4 m current sources that may switch via software. Data acquired with the help of Lab VIEW Academic Standard Suite software.

Fig. 4. Impact setup.

Fig. 5. Fix load cell on stand and bolted stand with earth.

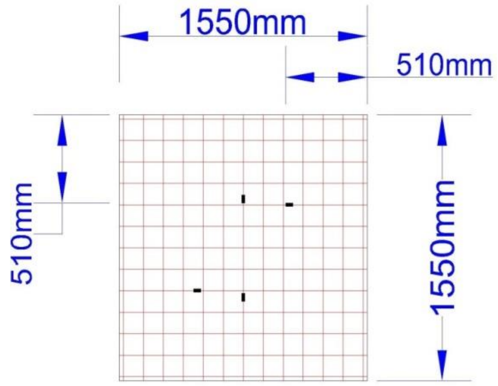


Fig. 6. Location of the strain gauges on reinforcement.

Fig. 7. Accelerometer on the surface of specimen.

8. RESULTS AND DISCUSSION

8.1. Deflection

Figs. 8 and 9 show typical displacement-time histories and comparisons of RC slabs strengthened overall by CFRP sheet to compare the results based on the number and area covered by CFRP sheet. Only the spaceman (S) failed at the first blow, with high scabbing and penetration, while the strength slab failed at the second and third blows. Improvement could attribute to the high strength of the CFRP sheet in the specimen's initial stiffness. However, due to accumulated energy, the second strike caused stress concentration on the backside resulting in high maximum deflections. When compared maximum displacement of slabs C_{1x100}-B_1, C_{1x100}-B_2 at second blow as respect to the number of CFRP layers. show that increasing of CFRP layer in bottom of the slab from one to two layers leads to a peak displacement reduction of 7.7% from (39)mm to (36)mm and when compared with respect to area from (0.25 to 1) m^2 C_{1x50}-B_1 , C_{1x100}-B_1 lead to displacement reduction of 9.3% from(43)mm to (39)mm . C_{2x50}-B2 compare with C1x100-B2 as respect to width of layer found that C1x100-B2 reduce displacement from (43) mm to (41) mm at third blow and from (37) mm to (36) mm at second blow .When compare the strength slabs with non-strength find a large difference between them. Because the displacement of slab which not strength failed at first blow (46) mm and the higher displacement of strength slab at first blow (10.9) mm at slab C_1x50-B_1 .it can be observed that the use of this strengthening method had a significant impact on decreasing the maximum displacements of slabs at first blow .

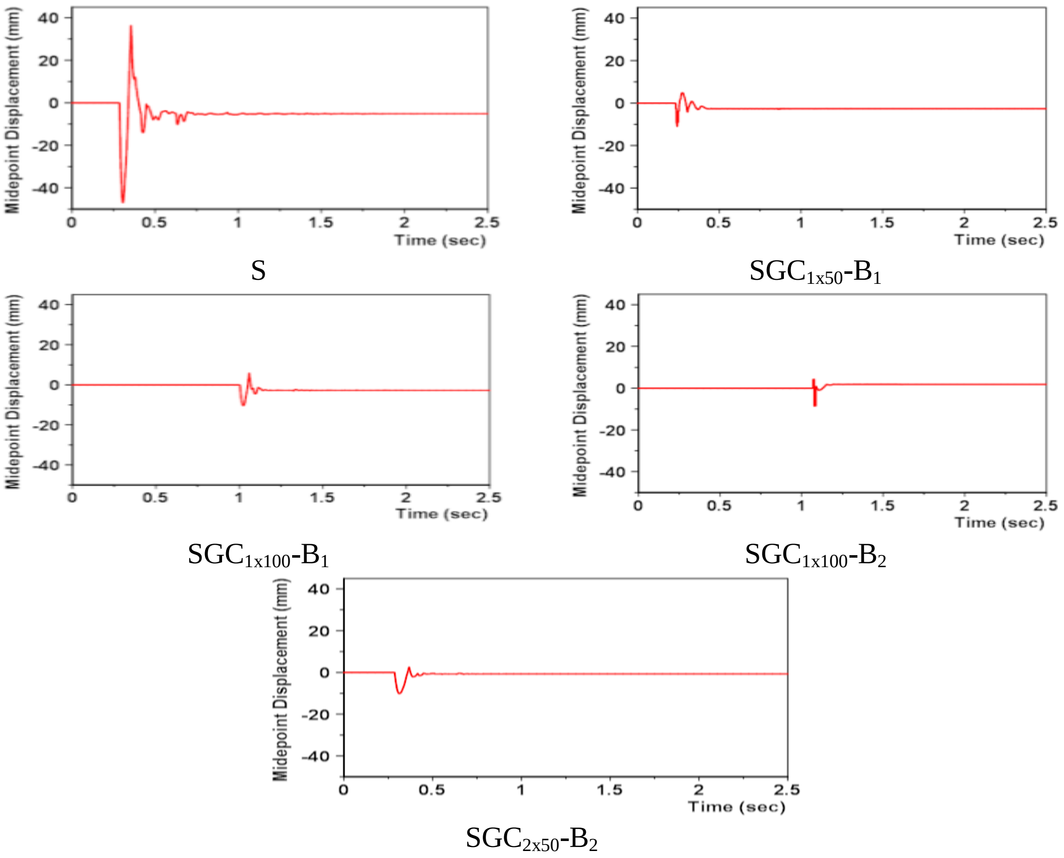


Fig. 8. Mid-span displacement for first blow.

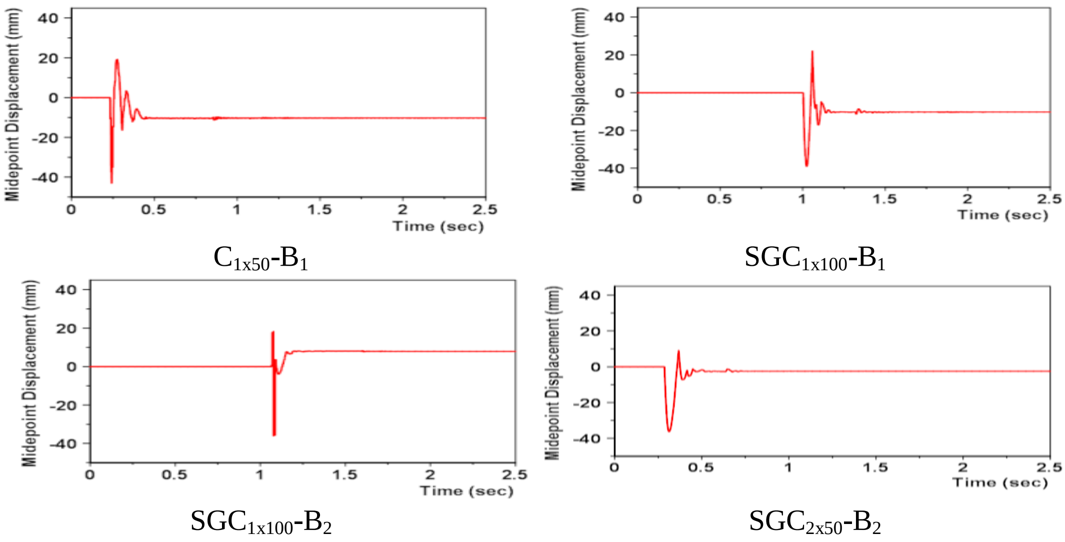


Fig. 9. Mid-span displacement for second blow.

8.2. Acceleration

From Figs. 10 and 11 which demonstrates the acceleration-time histories of selected slabs. Show that using of CFRP sheets to strength slabs generally results in a higher maximum acceleration. Furthermore, there is a clear correlation between the number of CFRP layers and the greatest acceleration recorded. The stiffness and rigidity of concrete slab improve by attaching CFRP sheets to the slabs' bottom. In the other word the more the slab reinforcement, the higher the acceleration of the slabs. This conclusion is in line with the results reported by references Hamid Sadraie et al. (2019). Who have obtained the acceleration-time history of concrete slabs under the impact loading. When compared the results in terms of numbers' layers of CFRP sheet C1x100-B1 and C1x100-B2 show that the maximum acceleration increasing by 5.4 percent from (421)g to (445)g at first blow and 7.5 percent from (366)g to (396)g at second blow when layers increased from one to two. When compare with respect of area of CFRP sheet from (0.25 to 1) m^2 C1x50-B1, C1x100-B1 found that (365)g to (421)g at first blow and (296)g to (366)g at second blow. The effect of the strength more clear because at first blow the slab has its initial stiffness However, due to accumulated energy, the second strike caused stress concentration on the backside, resulting reduced on acceleration.

8.3. Total Support Reactions

Figs. 12 and 13show the total reaction forces measured from load cells located at the four corner supports for the first, second, and third impacts of specimens. In comparison with the strengthening techniques, the response force indicates a load that is not subject to loss, such as the inertial force in an impact load. The maximum reaction force of C_{1x100}-B_2 was approximately (352) kN at first blow, (293) kN at second blow, and (208)kN at third blow, which was greater than the other strength slab. This due to time delay in the impact energy transfer due to the impact load dominated by inertial force in the early stages, and subsequently the impact force diminished, increasing the effect of the reaction force, increasing the influence of the reaction force [43–45]. When the total reactions force of the slabs C_{1x100}-B_1, C_{1x100}-B_2, compare with respect to number of CFRP sheet layers in bottom of slab. Show that increasing of CFRP sheet layer from one layer to two layers increases the total reaction force by 4.8 percent from (336)KN to (352)KN at first blow and 10.66 percent from (270)KN to (293)KN at second blow respectively. When compare with respect to area of test slab C_{1x50}-B_1 and SGC_{1x100}-B_1 found that increase area lead to rise total reaction force by 7.7% from (312)KN to (336)KN at first impact and 13% from (239)KN to (270)KN at second blow. When compare with respect to the width of layer test slab C_{2x50}-B_2 and SGC_{1x100}-B_2 found a little increase from (345) KN to (352) KN at first impact and from (286) KN to (293)KN at second blow. Because of the amount of cracks occurred, all spacemen tended to gradually reduce the reaction force at the second blow. Generally, strengthen slab with carbon sheet increase reaction force (96-136) KN than non-strength slab (216) KN at first slab.

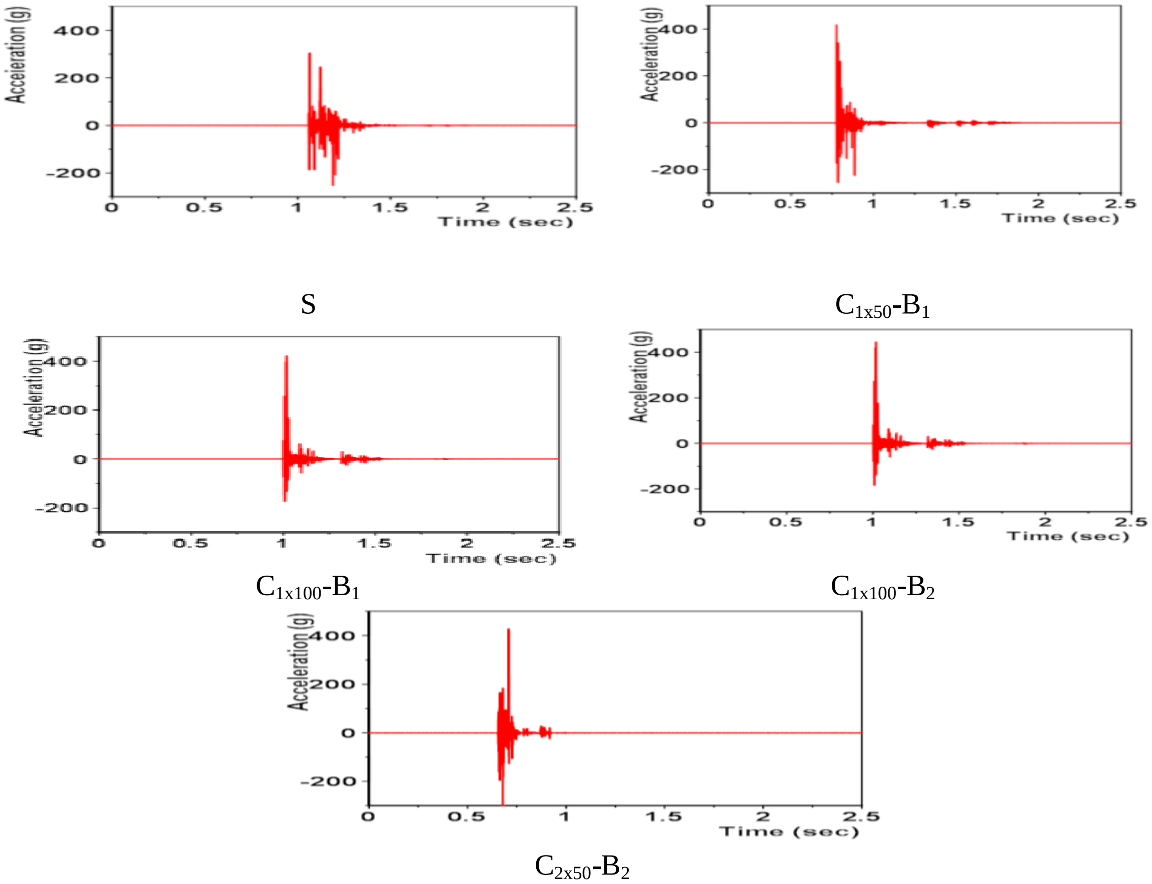


Fig. 10. Acceleration of slab for first blow.

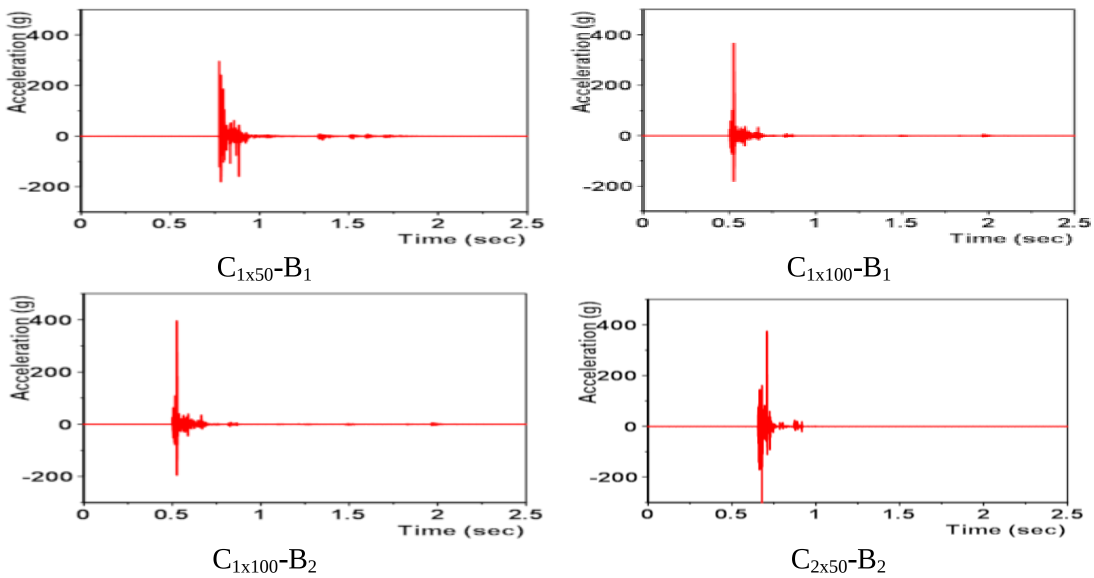


Fig. 11. Acceleration of slab for second blow.

8.4. Strain of Reinforcement

Four strain gauges embedded on the bars of each slab to study of the reinforcements' strain-time history and the maximum energy absorbed by reinforcements, as mentioned in the preceding chapter. Because several of the strain gauges were broken during impact tests due to problems, these measurements are not available. Typical strain-time histories of certain slabs plotted in Figs. 14 and 15.The measured strain-time history of the first drop reveals the same tendency in all specimens regardless of the strength configurations, according to the findings. The strain-time history of a strength specimen, on the other hand, is influenced by strengthens in the second impact event, and this variation in behavior might be return back to the damage and associated loss of stiffness caused by the first impact event. CFRP sheets reduced reinforcing bar strain by 33% for slabs with whole CFRP sheet.

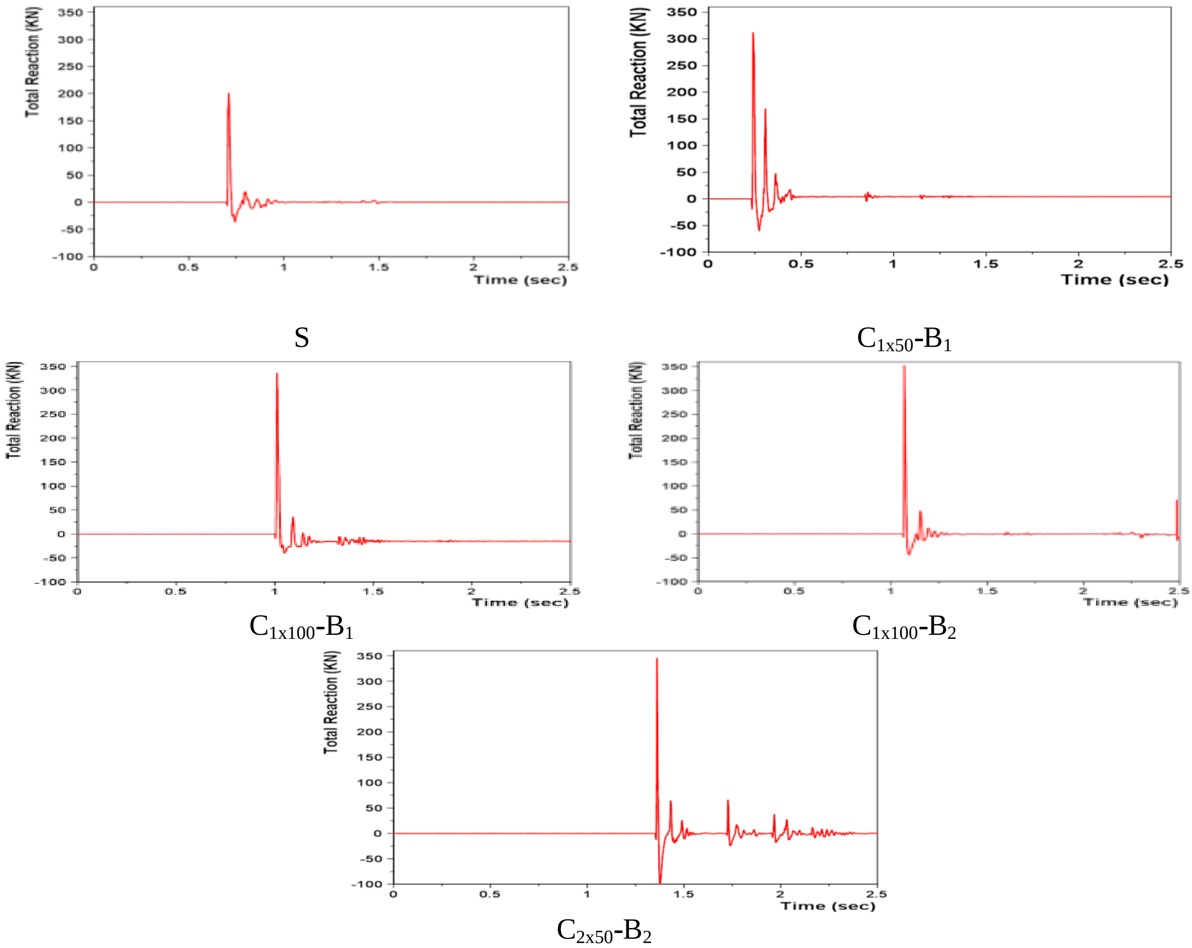
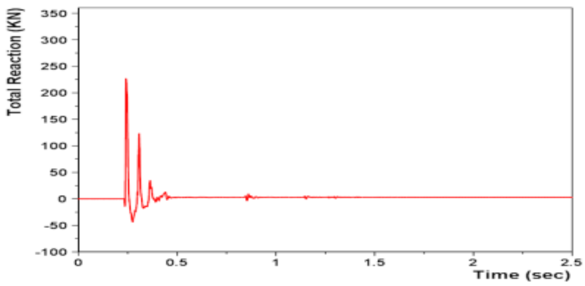
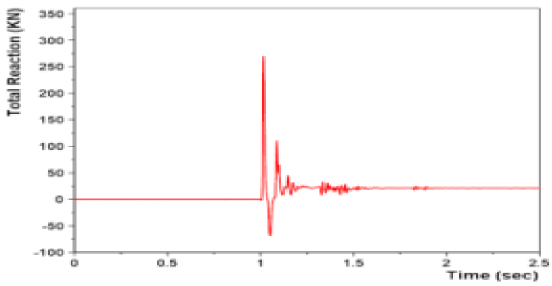


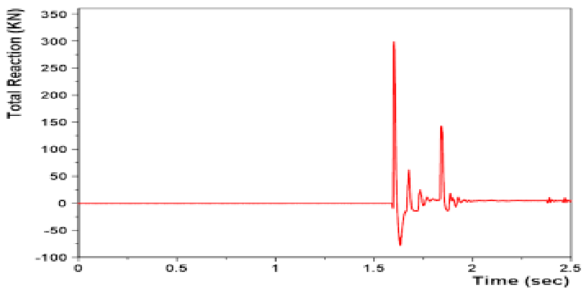
Fig. 12. Total Reaction Force of Slabs for first blow.



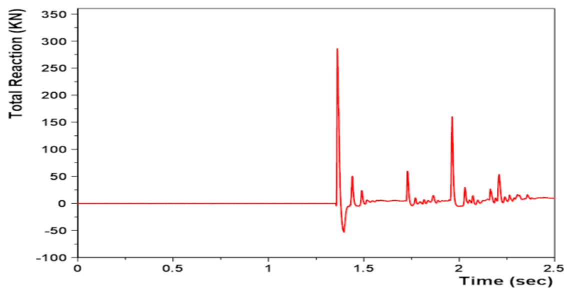
C_{1x50}-B_1



SGC_{1x100}-B_1

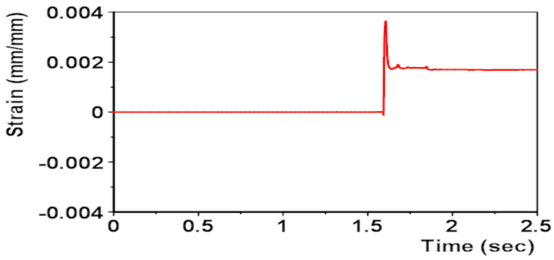


C_{1x100}-B_2



C_{2x50}-B_2

Fig. 13. Total Reaction Force of Slabs for second blow.



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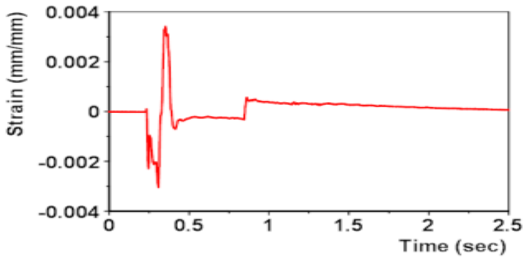
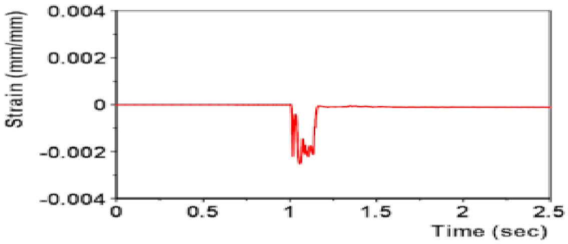
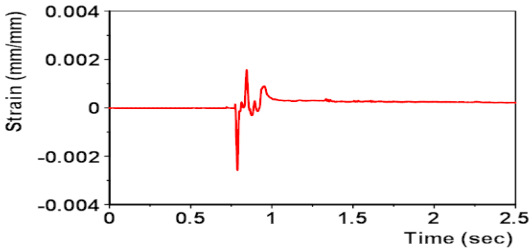


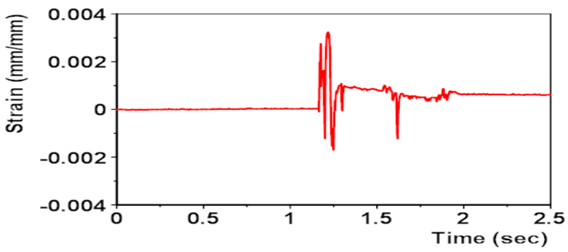
C_{1x50}-B_1



C_{1x100}-B_1

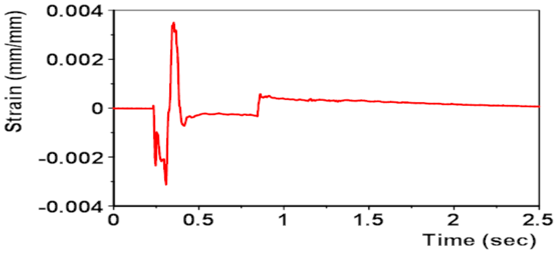


C_{1x100}-B_2

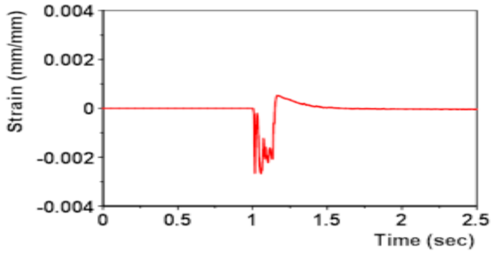


C_{2x50}-B_2

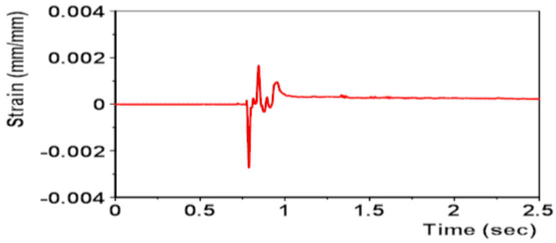
Fig. 14. Strain of Reinforcement bar for first blow.



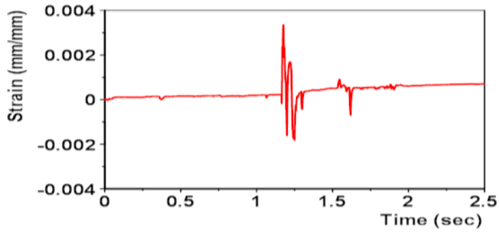
C_{1x50}-B_1



C_{1x100}-B_1



C_{1x100}-B_2



C_{2x50}-B_2

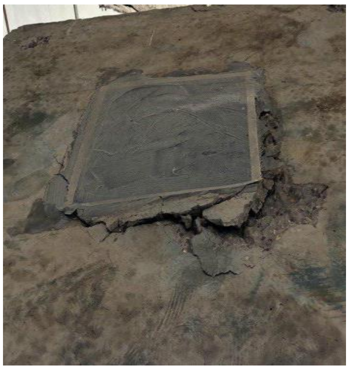
Fig. 15. Strain of Reinforcement bar for second blow.

8.5. Structural behavior

The presence of CFRP sheets prevented scabbing and spalling which caused by impact loads as shown in Fig. 16 which implying that CFRP sheets increase slab stiffness, however crack development due to the GFRP reinforcing bar's low elastic modulus. Failure mostly associated or caused by separation of the CFRP sheet this behavior relate to the higher shear stresses in the contact regions and due to stress concentration developed at the smaller contact area.

S

C_{2x50}-B_2



C_{1x50}-B_1

C_{1x100}-B_1 C_{1x100}-B_2

Fig. 16. Failure of Slabs.

9. CONCLOUSION

- The use of GFRP reinforcement promotes crack growth and scabbing mass, such as slab S(control one), which has a large crack that appears on the first blow, but on strength slab, any crack not appeared on the first blow but appeared on the second or third blow and smaller than slab S.
- In slabs strengthened with CFRP sheets covered the bottom surface of strike point, it has been observed that CFRP sheets prevent the spalling and increasing number of layer from one layer to two layers leads to a peak displacement reduction maximum deflection to 12%.
- Comparing deflection at the first blow the lowest maximum deflection observed in the strength specimen with 82% lower than the control slab. This enhancement credited to the high strength of the CFRP sheet in the initial stiffness of the specimen.
- From experimental work observed direct relationship between the numbers of CFRP layers and recorded maximum acceleration founded. The crack appeared on slab strengthened with two layers at third blow slabs C_{1X100}-B_2 and C_{2x50}-B_2 while on other strengthened slabs appeared on second blow. This increased in acceleration values indicates the increased resistance of test specimens against impact load and increased absorbed energy capacities under impact load effect.
- Increasing CFRP sheet layer in the bottom of the slab from one layer to two layers leads to increase the acceleration by (7.5) percentage from (366g) (396g) at second blow.
- Maximum acceleration of slabs that strengthened by CFRP as respect to area C_{1x50}-B_1, C_{1x100}-B_1 increased from (365) g to (421) g at first blow and (296) g to (366) g at second blow. Because at first blow the slab has initial stiffness However, due to accumulated energy, the second strike caused stress concentration on the backside, resulting reduced on acceleration.

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