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# Impact Resistance of GFRP Reinforced Concrete One-Way Slabs

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**Abstract:** Concrete structures are usually subjected to short-term dynamic loads besides long-term static loads. Tensile strength and energy dissipation characteristics are reduced as a result of these loads as long as the concrete is weak in resisting impact loads. This paper studies the behavior of one-way concrete slabs reinforced with glass fiber reinforced polymer (GFRP) under an impact load. A comparison one-way concrete slabs reinforced with GFRP and normal steel has been done. Six slabs with dimensions of (4000*1000*180) mm are cast. Three specimens for each type of slab have been constructed and tested under impact load. A simple device has been made mainly to subject an impact load by applying a load of a weight 7 Kg that falls in the center of the slab from two different heights,1000 mm and 2000 mm. The concrete strain at different locations is measured during a specific time.

Results have been taken as an average of three specimens for each type of slab. The results showed that the slabs reinforced with GFRP bars has a better behavior than the ones reinforced with normal steel. The strain of the slabs with GFRP is 25% less than the slab with steel bars, also the time interval was 37.5% less. The value of strains is greater in the short direction than the other directions.

**Keywords:** GFRP, Impact loads, One-way slabs, Strain and Time intervals.

## 1 Introduction

Concrete is the most important and widespread building material due to its acceptable properties such as flexibility in formation, production, and durability. However, concrete has lots of disadvantages including heavyweight, low tensile strength which does not exceed 10% of the compressive strength, brittle behavior and unable to bear impact loads. (Salih et al. 2021).

In the past few years, many researchers worked on using different types of fiber reinforced polymers (FRP) in concrete especially GFRP due to its low cost, having high yield stress and its lightweight, unlike steel. Adding GFRP in concrete improves some of the concrete properties including an increase in tensile strength, toughness, ductility, impact resistance, and reduce the cracks (Salih et al. 2019).

Sawan and Abdul-Rohman (1986) examined simply supported square reinforced concrete slabs with dimensions (750 x 750 x 50 mm) under impact loading by dropping a (7 kg) steel ball on the center of the slabs from varying heights up to (1200 mm). The dynamic deflection of the slab was then tracked over time using dependable equipment. The study examined the relationship between the rigid missile's velocity at impact and the resulting deflection, as well as the relationship between slab reinforcement and dynamic deflection. The test findings indicate that the total dynamic deflections for various heights decrease in general when the steel ratio increases.

Al-Azawi and Hussein (1988) tested two-way spanning simply supported model slabs with dimensions (560 x 560 x 20 mm) to impact loads from a falling mass as well as static loading. The primary factors in the impact experiments were the mass of the falling mass, the dropping height, and the hammerhead form. Maximum transient and residual central deflections, fracture patterns, maximum residual crack width, and residual penetration depth at the impact zone were all measured for each test. The kinetic energy of the falling mass on the slab was determined to be between (2–3) times the specimen's static energy. The mode of collapse was punching shear, which was linked with concrete scabbing on the slab's bottom face.

Baar and Swamy (1989) evaluated the impact resistance of a slab that had been strengthened by fiber insertion in conjunction with the final deformation energy of an impact load applied in flexure shear and torsion. Additionally, they examined Polypropylene fibers using impact tests on small concrete beams. The addition of polypropylene fibers increases the impact resistance of the beam by 29%.

Ong et al. (1999) examined the resistance of fiber concrete slabs to low-velocity missile impact. The major factors in this investigation were the fiber type and volume percent of

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fiber.

Khalloo and Afshari (2005) conducted an experiment to determine the flexural behavior of steel fiber reinforced concrete (SFRC) slabs. To evaluate and analyze the findings, fourteen concrete mixes with four different fiber concentrations, two different fiber lengths, and two different concrete strengths were constructed. The concrete had a strength of 30 to 45 N/mm2 and a fiber volumetric percentage of 0, 0.5, 1, and 1.5. The experiments revealed that ordinary slabs broke suddenly under cracking loads without any discernible deflection warning, but SFRC slabs containing fibers failed progressively after the concrete slabs cracked.

Zineddin and Krauthammer (2007) investigated the dynamic response and behavior of reinforced concrete slabs using several forms of slab reinforcements, including steel bars and welded steel wires, and applied impact loads. The layout and quantity of reinforcement had an effect on the slab failure modes and response. Additionally, when the drop height was increased, the slabs' behavior was dominated by the local response.

Madheswaran et al. (2014) investigated the behavior of reinforced Geo-Polymer Concrete (GPC) slabs subjected to repetitive impact loads. The purpose of this study was to evaluate the impact behavior of reinforced GPC slabs with and without steel fibers to that of plain Portland concrete cement OPCC slabs. The study stressed the need of using GPCC in place of OPCC for structural components subjected to low velocity impact.

In another study, (Othman and Marzouk,2016) evaluated the dynamic performance of steel RC slabs under low velocity impact loading by altering the steel reinforcement ratio from 1% to 3% and the steel reinforcement configuration (single or double mesh layer). The results indicated that altering the reinforcement ratio and/or arrangement had no discernible influence on the impulse and absorbed energy values while the impact loading condition remained constant. On the other hand, it was discovered that the crack pattern and mechanism of failure are more reliant on the reinforcing arrangement than on the reinforcement ratio.

Another experimental and numerical investigation conducted by (Xiao et al. 2017) on steel RC slabs subjected to low velocity impact loading evealed that increasing the concrete strength, the diameter of the impacted area, or the slab thickness can significantly increase the energy capacity of a lightly reinforced concrete slab, whereas the effect of steel reinforcement ratio was limited.

Sadraie et al. (2019) used laboratory tests and numerical simulations to evaluate the influence of rebar material, reinforcing quantity and arrangement, concrete strength, and slab thickness on the dynamic behavior of reinforced concrete slabs. The performance of fifteen 1000x1000mm concrete slabs was investigated experimentally. These slabs included two 75mm thick plain slabs, five 75mm thick steel reinforced concrete slabs, six 75mm thick reinforced concrete slabs with Glass Fiber Reinforced Polymer (GFRP) bars, and two 100mm thick steel reinforced concrete slabs. The failure mechanism, fracture formation, displacement-time, strain-time, and acceleration-time responses of several slabs were investigated and compared. LS-DYNA explicit software was used to conduct finite element studies and simulations of specimens. The experimental and numerical results are consistent, indicating that raising the reinforcement ratio or slab thickness improves the behavior of RC slabs under impact loads. By modifying the amount and arrangement of GFRP, it is possible to obtain superior performance in GFRP slabs than in steel reinforced slabs, which, given the material's corrosion resistance, makes it an excellent choice of reinforcing material.

GFRP bars are used in this work to reinforce the one-way concrete slabs in accordance with the American Concrete Institute (ACI 440. 1R-15) and compare these samples with one-way concrete slabs reinforced with normal steel bars. An impact load has been applied for the two types of slabs in order to study their behavior under this type of load by measuring strain and time interval and damping time so that the sample recovers after unloading.

## *1.1 Fiber-reinforcement polymer (FRP) bars*

FRP is a composite material formed along with slender fibers bounded and shaped together by a rigid polymer resin material. There are many kinds depending on the composite material such as glass fiber reinforced polymer (GFRP), aramid fiber reinforced polymer (AFRP), carbon fiber reinforced polymer (CFRP). FRP has numerous properties that make it more particular than the normal steel bars. Tensile strength for FRP bars is much higher than for the normal steel bars and its weight is (20-25) % lighter than the normal steel weight. FRP is stainless, non-corrosive material and it has high resistance to chlorides and chemical attacks. Also, it does not need for admixtures for keeping it in corrosive environments. Further, its service life considerably more than the normal steel. In the case of degradation, the degradation mechanism does not have a negative effect on the concrete, unlike the normal steel which expands causing a failure to the structural member (ACI 440.1R-15).

## *1.2 Impact loading*

Impact loading can be defined as the load induced by the impact of two bodies during a very short time. The magnitude of the impact loading depends on the striker's velocity of the load plus the mass and properties of the material of the structure. Deformations are produced by the power of impact for the two materials (Al-Rousan et al. 2017). There are several examples of this type of loads in civil engineering some of them are the loadings generated as a result of vehicles and trains passing over bridges, loadings resulting from the impact of explosions on the structures, loadings resulting from the collision of ships, loadings resulting by operating the machines inside the structures and impact loadings resulting of driven piles.

In general, impact loadings produce enormous, dangerous stresses and strains, when compared with the ones produced by static loads.

The effect of impact loading for the structures can be classified as two types of impacts, the local impact response and overall impact response. The impact of the first type is by concrete spalling, penetration, and scabbing, The overall (structural) response consists of flexural and shears deformations. A potential flexural or shear failure will occur if the strain energy capacity of the concrete and supports is smaller than the part of kinetic energy transmitted from the zone of penetration or perforation into the concrete. The structural dynamic response of structures subjected to impact can be determined if the applied force – time history is known. (Elavenil and Samuel 2012).

When a hard projectile is moving then collides with high velocity, the power of the impact is absorbed locally, thus the concrete damage will be concentrated in the vicinity of the impact area (May et al. 2006). Large numbers of empirical formulas have been developed to estimate the penetration depth and the minimum thickness required for the concrete to prevent scabbing and perforation. All of these formulas are controlled by impact velocity, properties of the projectile, properties of the penetrated target, mass, and shape of the projectile.

### *1.3 Phases of failure for the impact loading*

Many researchers studied the effect of impact loading on the reinforced concrete using Charpy's method. However, few among them have defined the stages of failure for concrete subjected to an impact loading produced by falling load from a specific height. Some of these definitions are: initial failure, secondary failure, and final failure. Final failure stage occurs when the concrete is crushed in the compression area or when the cracks meet together inside the sample or when concrete scabbing occurs in the tensile area. Nevertheless, this does not mean that papers and studies dealing with the effect of impact loading on buildings and constructions require applying load continuously until the failure, but it can stop applying as soon as the produced strains are measured plus the required time interval for the recovery of the sample after unloading.

In the last two decades, lots of studies have been done for the purpose of knowing and understanding the behavior of concrete members under the effect of an impact load for the beams and columns after strengthening them with fiber polymer. However, none of the researchers could study the behavior of the one-way concrete slabs reinforced with GFRP bars under the effect of impact loading. Therefore, this paper shows the importance of this study.

## 2 Research significance

The dynamic analysis of reinforced concrete structures such as slabs has risen in importance over the last several decades and has been the topic of numerous studies. This widespread attention has been directed toward determining the structure's true behavior under dynamic stresses such as collision, explosion, or earthquake.
The importance of this paper lies in the fact that this study is concerned with studying the behavior of the one-way concrete slabs reinforced with GFRP bars under an impact load, then comparing this behavior with the one-way concrete slabs reinforced with normal steel bars. It is distinguished to be an innovative study since the application of an impact load to the concrete structure have not been covered yet according to the best knowledge of the authors.

## 3 Experimental works

### *3.1 Test specimens*

In this paper two full scale samples of one-way concrete slabs (4000*1000*180) mm were cast, the first sample is reinforced with GFRP bars, the second is reinforced with normal steel bars, reinforcement details are shown in Figure 1. Each sample has three specimens. These slabs were supported parallel to the short member of the slab on two walls of concrete blocks with 1800mm height in which they were constructed for this purpose. Figure 1 illustrates all the details of the supporting walls, reinforcement, and slabs after casting.
The study parameters are first type of reinforcement (Slab reinforced with normal steel and reinforced with GFRP), second height of impact load, the drop height of the impact loading (1000 and 2000 mm), the places where the strain gauges are placed Figure 2.

### *3.2 Concrete mixture*

Table 1 represents the mix design for the reinforced concrete slabs, consisting of cement, coarse aggregate, fine aggregate, and the weight of water used for the concrete mixture. The aggregate is taken from a local quarry in the city while the cement is the ordinary portland cement, all of the required tests for these materials were conducted in the civil engineering laboratory in Tikrit University. The designed compressive strength for the concrete is chosen to be 30 MPa for 28 days. The compressive strength of the concrete has been obtained according to British standard (B.S116:1989) by testing concrete cubes with side dimension of 150mm.

### *3.3 Machine impact test*

The slabs were supported on two parallel concrete block walls with a height of 1800 mm, thickness of the wall is 200 mm the clear spacing between two supports 3600 mm so that the total length for the slab is 4000 mm and its width is 1000 mm. A simple device was made up in order to conduct the impact test straight to the slabs. This device consists of a metal structure 1500mm in length, 750 mm in width, and 250 mm in height and it's supported on the two slabs that are near to the slab which it desired to test. It carries a tube from the middle with 100 mm in diameter tied to the angles of the

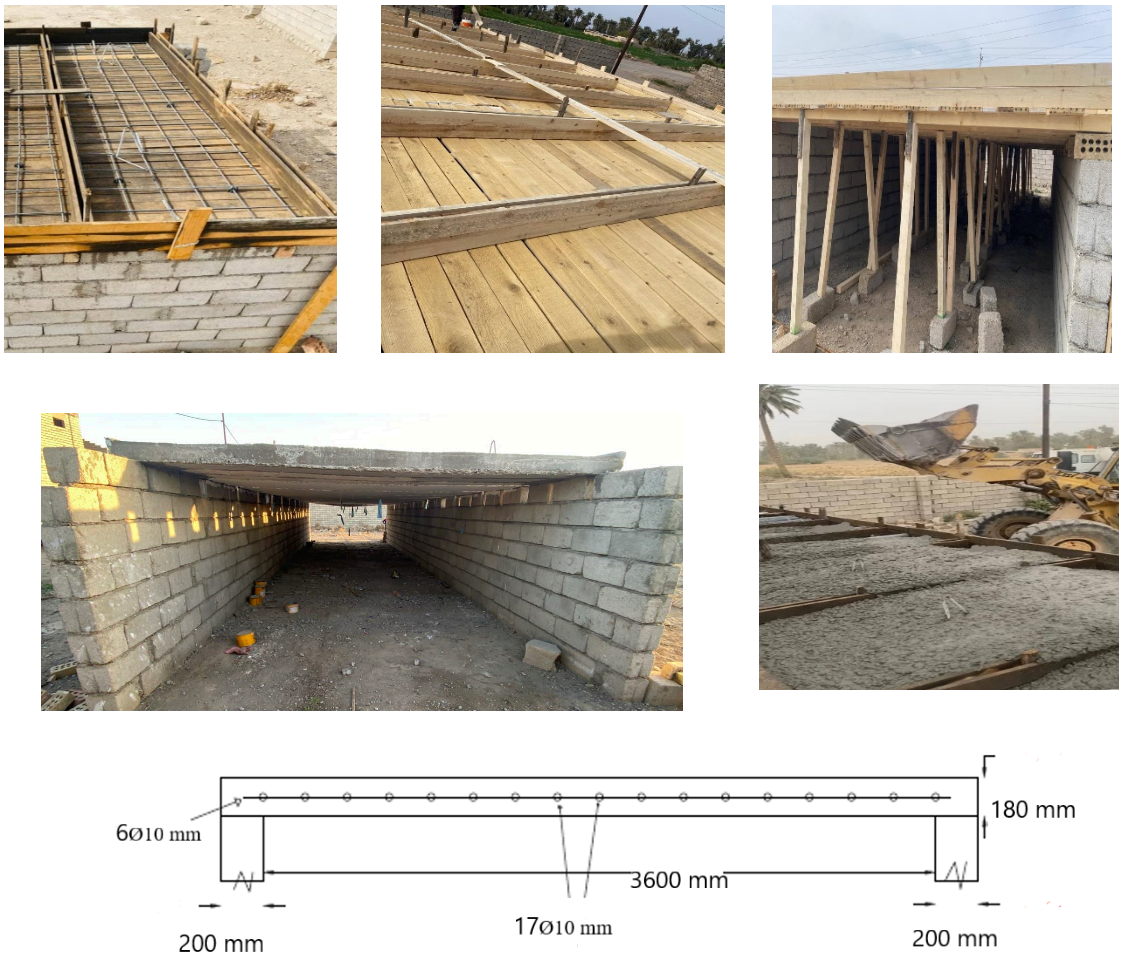



**Fig. 1:** Details of the supporting walls, reinforcement and slabs after casting

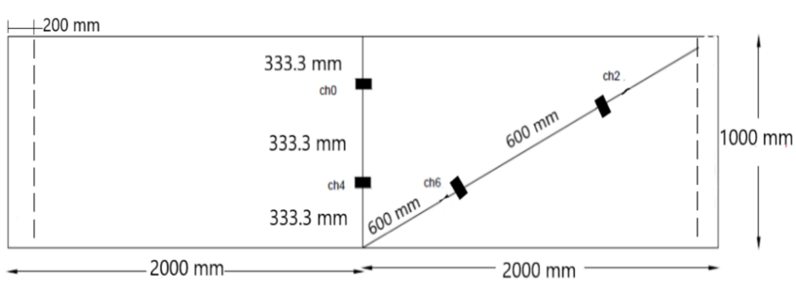



**Fig. 2:** Places of the strain gauges.

**Table 1** Mixture details.

| Ingredient | Quantity (kg/m$^3$) |
|---|---|
| Cement | 380 kg/m$^3$ |
| Coarse aggregate | 925 kg/m$^3$ |
| Fine aggregate | 710 kg/m$^3$ |
| Water | 170 |

metal structure from four sides, A steel cylindrical hammer moves inside it in different heights having a 75mm diameter and 7 Kg weight and it is centered on the top of the slab The clear spacing between the bottom of the hammer and the sample is 1000 mm and 2000 mm as stated by this study, this represents the falling height. The hammer is raised up by a wire until reaching the selected height then left to free-fall upon the sample as shown in Figure 3.

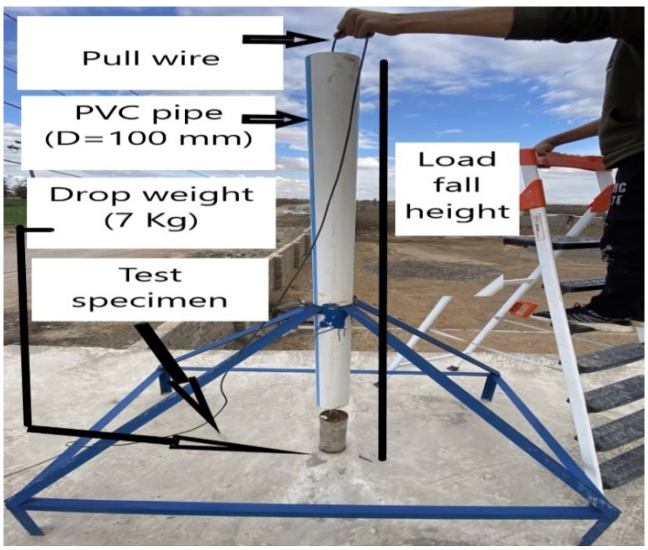



**Fig. 3:** Impact loading device.

### *3.4 Electrical strain gauges*

Uniaxial electrical resistance is used in this paper as a foil to measure the strain of the concrete caused by the impact load, the size of these wire gauges is 25 mm, the parameter value is 2, it has a resistance value of (120 Ω). These gauges are placed on the bottom of the sample using adhesive of type (CN-E and CN-Y), they are linked with a quarter bridge circuit, details are shown in Figure 4.

## 4 Results and discussions

### *4.1 Max. Slabs strain*

The maximum strain of the slabs occurred by applying the impact loading is measured by the strain gauges which are placed at the bottom of the slab as shown previously in Figure 2, it includes 4 different gauges named h0, h2, h4, h6, this called the positive strain. The strain gauges h4 and h0 are placed on the vertical axis, h4 is nearer to the center of the sample than the other gauge. h6 and h2 are located at 45 $^0$on the inclined axis, h6 is the nearest to the center of the sample throughout this axis.

**Table 2** summarizes the maximum strain values for the slabs with GFRP and steel bars by using four gauges in each slab and for the two heights of falling impact load. The first slab reinforced with GFRP bars record less strain values in each gauge and for both heights compared with the strain values recorded for the slab reinforced with steel bars. It can be noticed that in the case where the height for falling impact load is 1000 mm, the strain of the slab with GFRP are 24%, 20%, 20%, 20.3% less than the other slab in the following gauges h0, h2, h4, h6 respectively. Also, in the case where the height of falling impact load is 2000 mm, the strain of the slab with GFRP bars are 25.5%, 21%, 25.5%, 20% less than the other slab in the following gauges h0, h2, h4, h6 respectively.

Slabs reinforced with GFRP bars do not respond to these strains because it has high yield stress compared with the normal steel bars, it might be the reason why the slabs reinforced with GFRP are better than the ones reinforced with normal the first and second slab was cast with the same concrete mixture so the type of reinforcement is the reason. It can also be noted that the gauges for h4 and h0, recorded higher values of the strain than the other gauges h2 and h6. The difference between the two readings is significant due to the transfer of the stress in the one-way slabs orthogonal direction which transfers in the short direction more than the inclined direction.

**Table 2:** Slabs strains.

| Channel No. | Reinforced Type | Max. strain *($10^{-4}$) Falling height (mm) 1000 | 2000 |
|---|---|---|---|
| h0 | Normal steel | 5.0985 | 524.589 |
| | GFRP | 3.8748 | 390.8188 |
| h2 | Normal steel | 11.8935 | 25.9428 |
| | GFRP | 9.5148 | 20.4948 |
| h4 | Normal steel | 8.532 | 524.318 |
| | GFRP | 6.8256 | 390.7415 |
| h6 | Normal steel | 281.007 | 4.6724 |
| | GFRP | 224.8056 | 3.7379 |


**a)** Adhesive **(b) Strain gauges** **(c) Quarter bridge circuit**

**Fig. 4**: (a) Adhesive, (b) Strain gauges and (c)Quarter bridge circuit.

Furthermore, increase the distance of falling load results in increase the strains obtained, the reason for that is the velocity increase of the body which makes the power of impact increase thus the strains increase. Also, the differences of the strains in the gauges placed on the same line are clearer than the shorter distance of the falling load (1000 mm), it reaches 43% for the first slab (reinforced with steel) and 40.3% for the second one according to the gauges h4 and h0 respectively.

## *4.2 Strain-Time*

The maximum extent for the pulse range transferred in the sample was measured which is caused by applying the impact load using strain gauges these record maximum strain values will be represented as a graph. All of these readings were taken from an impact loading distance of 2000 mm considering this as the worst case.

Figure 5 shows the velocity of pulse transfer through slab with steel bars. The relationship is plotted between strain readings and time interval. When comparing the strain readings for the gauges h4 and h0 (located at the short direction). It noticed that the strain in the first gauge h4 which is the nearest to the location of the impact starts to dissipate starting from the time 2 sec until 14 sec thus recording a very small and different value, then the pulse start to increase steadily and regularly starting from the time 15 sec until this pulse finish at the time 31 sec, while the pulse of strain gauge h0 starts at the time 2 sec and finishes at the time 31 sec recording the highest value of strain 0.052 during the period of time 29 sec.

The experimental results showed that the maximum strain is measured in the gauge h6 at the time 6 sec was 0.00007 but it dissipated at the time 8 sec (i.e., at a time interval of 2 sec), while in gauge h2, the pulse started at the time 4 sec and until the time 21 sec recording the maximum strain value 0.0026.

As long as the strain values are higher in the (parallel to the short way of the slab or the supporting). In a comparison with the other directions, strains are also larger when it's nearer to the impact location and the dissipation velocity of the pulse is higher in the location nearer to the impact load while the far locations need larger time interval to dissipate the pulse.

Figure 6 illustrates the transfer velocity of the pulse through the concrete slab reinforced with GFRP bars. The figure shows that h4 and h0, the strain in the first gauge nearest to the impact location, h4 starts to dissipate at the time 8 sec until the time 14 sec recording a small value. After that the pulse progressively starts to increase steadily and regularly starting from the time 15 sec until it finishes at the time 25 sec. The maximum strain recorded was 0.039 during a time interval of 10 sec until this pulse finishes dissipates at the time of 25 sec. In strain gauge h0, the pulse starts at the time of 4 sec and finishes at the time of 25 sec recording a maximum strain value of 0.039 during a time interval of 21 sec.

These results are compared with the concrete slab reinforced with normal steel bars. The concretes slabs reinforced with GFRP bars recorded strains values 25% less for the same locations of the strain gauges, and the time needed to suppress the pulse is 37.5% less than that required for the slab with steel bars.

When comparing between the readings of the gauges located at h6 and h2, the maximum strain value recorded for h6 at the time 4 sec is 0.00037, but it dissipated at the time 5 sec, i.e., at a time interval of 1 sec. While the pulse for h2 starts at the time 3 sec until the time 14 sec recording a maximum strain value of 0.0002 which is a very small value.

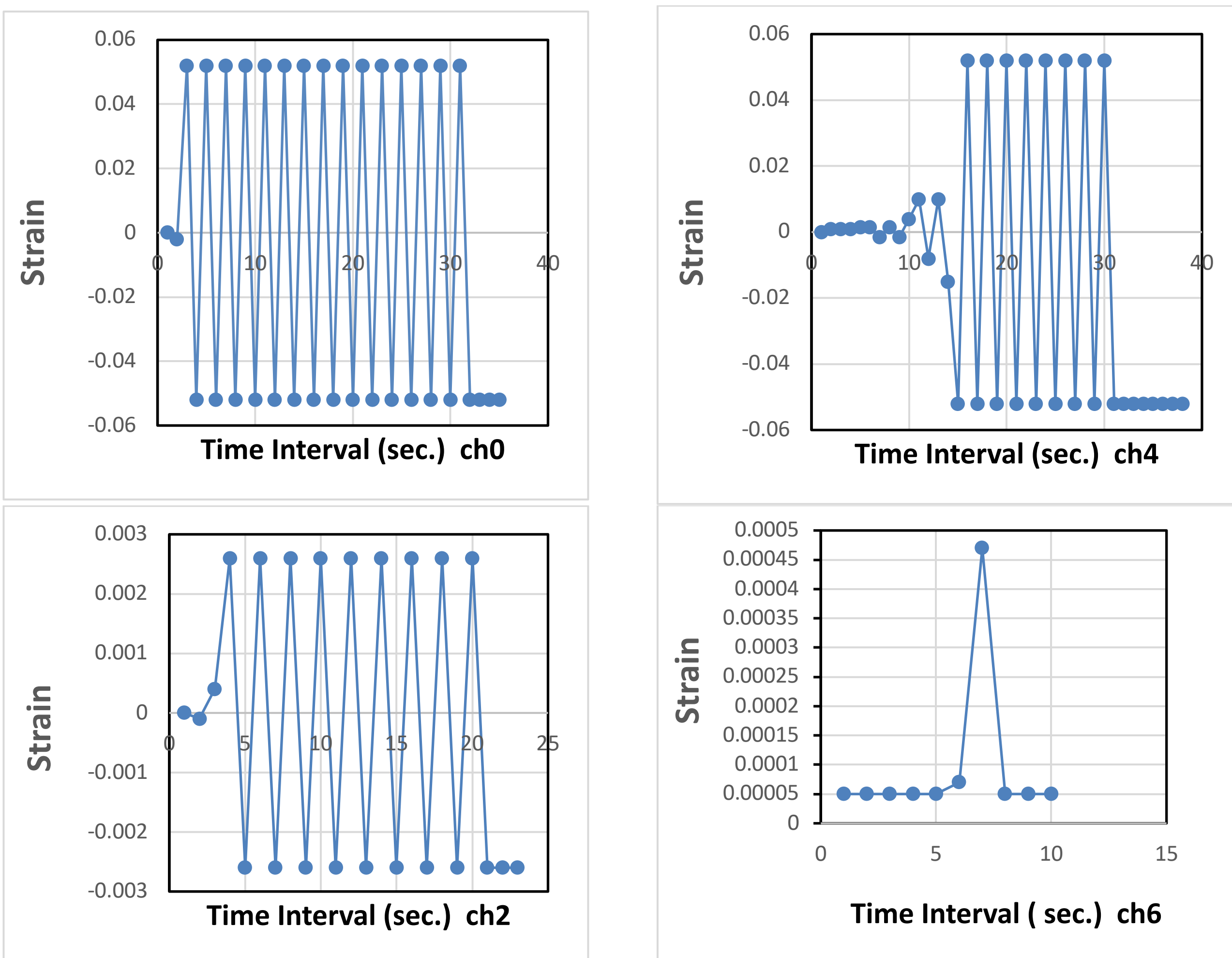
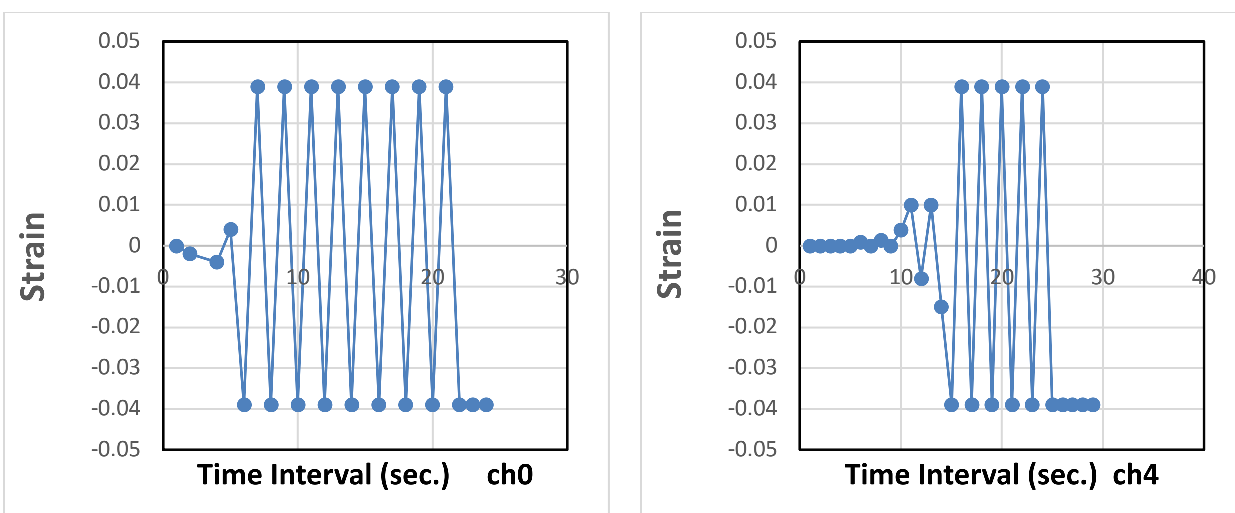



**Fig. 5**: Strain -Time Interval in Slabs reinforced with steel.



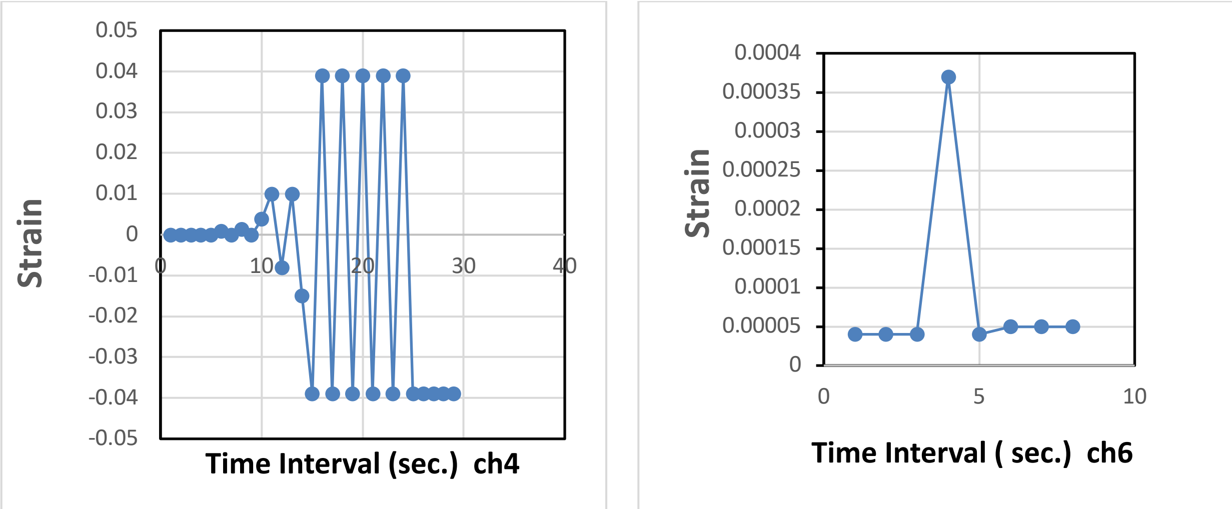



**Fig. 6:** Strain -Time Interval in slabs reinforced with GFS.

## 5 Conclusions

1. For both slabs with GFRP and steel bars, the strains on the short direction are larger than the strains in the long direction. It concluded that the strain gauges located along the short direction of the slabs recorded the same values regardless of their location from the impacting load.
2. The time interval required to suppress the pulse changes depends on the impact location,
3. The strains transfer through slab in the form of interfering waves in time, i.e., one of the strain gauges records the obtained strains at that point even if it has finished in the other locations of the strain gauges.
4. The concrete slabs reinforced with GFRP bars has strains 25% less than the strains obtained of the concrete slabs with steel bars, also the suppress time was 37.5% less.

## References

[1] Salih, Y. Ali., Mohammed, A. A., & I Abdulla, A. The Properties of Short Circular Reinforced-Concrete Columns Strengthened by Treated Natural Jute and Non-Treated Jute Fibres. Information Sciences Letters., **10(3)**, 17( 2021).

[2] Salih, Y. A., Sabeeh, N. N., Yass, M. F., Ahmed, A. S., & Khudhur, E. S. Concrete Beams strengthened with Jute fibers. Civil Engineering Journal., **5(4)**, 767-776(2019).

[3] Sawan J and Abdul-Rohman M. Impact Effect on R. C. Slabs: Experimental Approach, ASCE Journal of Structural Engineering, September. **112(9)**, 2057 –2065 (1986).

[4] Al-Aazawi TK and Hussein AM. Dynamic Behavior of Reinforced Concrete Model Slabs due to Impact Loading, Second Iraqi Conference on Engineering ICE, Baghdad (1988).

[5] Baar,Ben, and R. N. Swamy, eds. Fiber Reinforced Cements and Concretes: Recent Development;[ papers Presented at the International Conference on Recent Developments in Fiber Reinforced Cements and Concrete,Held at the school of Engineering, University of Wales College of Cardiff, UK, **18-20** (1989)]. Elsevier Applied Scince,(1989).

[6] Ong K C G, Basheerkhan M and Paramasivam P. "Resistance of Fibre Concrete Slabs to Low Velocity Projectile Impact", Cement and Concrete Composites., **21**, 391 – 401 (1999).

[7] Khaloo R, Afshari M. "Flexural behavior of small fiber reinforced concrete slabs",cement and concrete composites ., **27(1)**, 141-149 (2005).

[8] Zineddin M, Krauthammer T. Dynamic response and behavior of reinforced concrete slabs under impact loading. Int J Impact Eng., **34(9)**, 1517–34 (2007).

[9] Madheswaran C K, Dattatreya JK, Ambily PS Karansingh PR. "Investigation on behavior of reinforced geopolymer concrete slab under repeated low velocity impact loading", International Journal of Innovative Research in Science, Engineering and Technology, March., **3**, 3 (2014).

[10] Othman H, Marzouk H. An experimental investigation on the effect of steel reinforcement on impact response of reinforced concrete plates. Int J Impact Eng., 88, 12–21 (2016).

[11] Xiao Y, Li B, Fujikake K. Behavior of reinforced concrete slabs under low velocity impact. ACI Struct J ., **114(3)**, 643–50 (2017).

[12] Sadraie, Hamid, Alireza Khaloo, and Hesam Soltani. "Dynamic performance of concrete slabs reinforced with steel and GFRP bars under impact loading." Engineering Structures., **191**, 62-81 (2019).

[13] (American Concrete Institute) ACI 440.1R-15 Guide for the Design and Construction of Structural Concrete Reinforced with Fiber-Reinforced Polymer (FRP) Bars., (2015).

[14] Al-Rousan, Rajai Z., Mohammed A. Alhassan, and Harith Al-Salman. "Impact resistance of polypropylene fiber reinforced concrete two-way slabs." Struct. Eng. Mech., **62(3)**, 373-380 (2017).

[15] Elavenil, S., and GM Samuel Knight. "Impact response of plates under drop weight impact testing." Daffodil International University Journal of Science and Technology., **7.1**, 1-11 (2012).

[16] Khazaal, Ammar Saleem and Aziz I. Abdulla " Bahavior of RC Beam Strengthened by CFRP and Steel Rope under Frequent Impact Load " Journal of Advanced Sciences and Engineering Technologies ., **1.1,** 30 (2018).

[17] Mohammadi, Y., Carkon-Azad, R., Singh, S.P., Kaushik, S.K., "Impact Resistance Steel Fibrous Concrete Containing Fibers of Mixed Aspect Ratio", Construction and Building Materials Journal., **23**, 183-189 (2009).

[18] Abdulla, Aziz I., Ali, Alya'a A. , Ghanee, Ahmed Adnan, " Mechanical Properties and Dynamic Response of Lightweight Reinforced Concrete Beam" Eng. & Tech. Journal, Vol. , No. , 2011, Technology University, Baghdad, Iraq., 202 (2011).