A Review on experimental and numerical studies of Glass Fibre Reinforced Polymer (GFRP) strips strengthened Reinforced Concrete (RC) slab subjected to low velocity impact

S M Mubin¹, A Syamsir² and D Mohamad³

¹Postgraduate Student, Department of Civil Engineering, College of Engineering, Universiti Tenaga Nasional, Malaysia
²Senior Lecturer, Institute of Energy Infrastructure (IEI), College of Engineering, Universiti Tenaga Nasional, Malaysia
³Lecturer, Department of Civil Engineering, College of Engineering, Universiti Tenaga Nasional, Malaysia

Corresponding author: smmubin27@gmail.com

Abstract. This paper reviewed the previous research on experimental and numerical studies on the impact behaviour of fibre reinforced polymer (FRP) strips reinforced concrete (RC) slab with various (FRP) strips arrangement. This review focusses on the effect of thicknesses, arrangements of FRP strips and type of support layouts. Initially, a throughout investigation was made on the FRP and its properties. Experiments associated to impact resistance of RC slabs was also performed. Furthermore, numerous finite element model (FEM) of RC slabs externally strengthened with different arrangement FRP strips were developed with ABAQUS and ANSYS. The numerical simulations on impact resistance of RC slab models externally strengthened with different arrangement FRP strips were performed. Generally, the experimental results displayed the diagonal two-way arrangement FRP strips externally bonded on bottom surface of RC slabs and four hinge supports applied had improved the impact strength significantly. The experimental and numerical impact results obtained for RC slabs externally strengthened with FRP strips were better as compared to the control RC slabs without FRP strengthening. Afterwards, the results gained from numerical was validated with experimental results. Finally, the methods and results of experimental and numerical reviewed was reliable as a reference for the study of RC slab externally strengthened with GFRP strips subjected to low velocity impact.

1. Introduction
Most of civilized and modern occupations can be search in Malaysia as it is one of the modern countries in the Southeast Asia. High-rise buildings were constructed in major modern futuristic countries for important works like industrial, business and economics [1]. Furthermore, accommodation in the form of large condominiums and apartments were made to organize and maintained the populations and migrations of citizens in the country as years progressed. Most countries that had wide residential zones in cities such as United States of America, Japan, Ireland and South Korea consisted of high-quality high-rise apartments. The population increase of humans led to
greater demand in necessities, productivity and residential zones related to high-rise building such as apartments, homestays and hotels [2-4]. Besides that, uncontrolled pollutions surrounding the nature occurred as result from construction works and development of numerous buildings in a modern country. The occurrence of the problem led to eco-friendly awareness and improved the thinking perspective of engineers in a modern country [5]. The Research and Development (R&D) specialized engineers have performed countless researches on product quality improvement, nature friendly and product sustainability.

Reinforced concrete (RC) made from consistent mix as main structural design on buildings were used in most fully or partially developed country. Reinforcement bars embedded in RC has an appropriate stiffness that led to steady compressive strength, flexural strength, indirect tensile and impact strength to somewhat forces loaded. Yet, regular RC does not last in quality and formed some residual defects such as spall, severe long hairy cracks and deflection on structures [6]. The defects happened on structures has high probability to make the buildings collapsed and caused injuries and deaths to the citizens that stayed in the building. Moreover, the cost to maintain and repair the structural defects on buildings were greatly expensive. Expenses for repeatable repairs and maintenance for structures happened usually even after maintenance was performed as possible defect can occurred at different zones of the structure [7].

The Research and Development (R&D) engineers had previously researched various materials on fibres and wastes productions. Fibres were divided into two types which were powdered fibres and grain fibres [8]. Necessarily, fibres enhanced RC in relation to its strength from inside or outside of structures. The researchers stated the RC embedded or strengthened with fibres to be fibre reinforced concrete (FRC) and examples of fibres used for its productions were polypropylene, steel, drink cans and oil palm shells fibres [9]. Other than that, the fibres used to strengthened the structures externally was called fibre reinforced polymers (FRP). FRP conventionally used in civil structure constructions were generally carbon fibre reinforced polymer (CFRP), glass fibre reinforced polymer (GFRP), basalt fibre reinforced polymer (BFRP) and aramid fibre reinforced polymer (AFRP) [10].

2. Types of Fibre Reinforced Polymer (FRP) and Finite Element Model (FEM) software
Fibre reinforced polymers (FRP) are composite materials made from polymers mixed with fibres [11–14]. It was produced abundantly at composite factories for widespread usages in automotive and structure enhancement. Furthermore, it was produced in different size, geometry and arrangement. The configuration types of FRP strips usually made for external surface application were unidirectional laminate (UL), woven laminate (WL) and random oriented (RO) laminate [15]. FRP such as CFRP, GFRP, BFRP and AFRP were reviewed. Carbon fibre has a density of 1.8g/cm³ and its tensile strength and elastic modulus were 4950MPa and 235MPa, correspondingly. The density for glass fibre was 1.19g/cm³. The tensile strength and elastic modulus of glass fibre were 2300MPa and 90MPa, respectively. In the study, the epoxy adhesive used on GFRP and CFRP sheets was a thixotropic two-component Sikadur 330 epoxy resin. Furthermore, the basalt fibre has a density of 2.60g/cm³ while its tensile strength and elastic modulus in strips form were 1417MPa and 59.2GPa, respectively. Finally, the density, tensile strength and modulus of elasticity of aramid fibre was 1.43g/cm³, 3000MPa and 240MPa, respectively. Each layer of BFRP and AFRP fibre was applied with epoxy resin mixed with Lapox K-6 diamine hardener.

Collections of data and results achievement in investigation project are obtainable through the finite element (FE) analysis or numerical models as an alternative way besides performing experimental test in the laboratory. The actions happened on specimens in experimental tests were accurately simulated by numerical model in its respective analysis software [16]. Researchers regularly used FE analysis software such as ANSYS, SOLIDWORKS, ABAQUS and ANOVA to perform numerical investigations [17-22]. The two main processes need to be carried out to conduct simulation in FE analysis software were preparations of geometrical model and selection of condition or boundaries on the model [23]. The results obtained from the numerical models were mostly equivalent to the original results.
3. Experimental reviews

In this review, numerous experimental studies related to impact resistance of RC slabs and FRP strips by the previous researchers were assessed and proved as valuable reference for the upcoming projects associated with waste GFRP strips externally strengthened RC slab. A lot of researches regarding impact resistance on RC slab with FRP have been made in the past years especially that of carbon fibre reinforced polymer (CFRP) strips and fabric fibre reinforced polymer (FFRP) strips. It has confirmed that the use of FRP enhanced the mechanical properties and impact resistance of RC slabs. Nevertheless, there were likely no published articles that discussed the outcomes on the use of glass fibre reinforced polymer (GFRP) strips to externally strengthened RC slabs. In 2014, J. Radnic et. Al. [23] have made research on impact testing of RC slab specimens strengthened with CFRP strips. They conducted an experiment on RC slab specimens with the existence of CFRP strips bonded to it. Firstly, they performed specimen mixture with ordinary Portland cement (OPC), fine aggregates and coarse aggregates with satisfactory amount of water [24]. The specimens prepared were left in the curing tank for 7 days and 28 days. Next, the specimen was bonded with CFRP strips perpendicularly on the flat bottom surface [25]. The setup of CFRP strips on RC slab specimens were as shown in Figure 1.

![Figure 1. RC slab strengthened with FRP strips.](image)

A successful portion of the RC slab specimens were loaded until it received failure. The mid-span of the slab specimens was tested until failure happened and the results on static forces was gained. Furthermore, non-linear and dynamic analysis of reinforced and pre-stressed concrete slabs and shells were performed in finite element model (FEM) software. The current numerical model results were validated with the experimental specimen results.

In 2018, T. Yilmaz et. Al. [35] made a research on low velocity impact behaviour of RC slab externally strengthened by diagonal two-way CFRP strips. They stated that various studies in literature regarded the focus on static and dynamic loading of RC were originated [27]. However, the researches about impact load of CFRP strengthened RC slabs are rarely published. Theoretically, the customs or methods of RC slabs strengthened with CFRP strips can be implemented on the study on RC slab strengthened with waste GFRP strips resulted to impact force as the FRP’s thickness, width and length were set into constant variables. So, initiative was made by the researchers to perform the research on the topic. They made arrangement and varied the width of CFRP strips in the experiment. The Figure 2 and Figure 3 showed the RC slab specimen surface bonded with different width of CFRP strips.
Figure 2. Slab specimens strengthened with 50mm CFRP strips.

Figure 3. Slab specimens strengthened with 100mm CFRP strips.

The moveable drop weight machine designed by the researchers was used to apply the impact load on RC slab specimens. A total of nine RC slab specimens with dimension 1000 x 1000 x 80 mm were produced. The CFRP strips were used orthogonally and diagonally on RC slab to strengthen its surfaces. The machine records the data on impact, acceleration and condition of the specimens. The crack distributions of RC slab specimens were showed in Figure 4.
Figure 4. Crack distributions of all slab specimens after tests.

As a whole, published researches related to experimental study on impact behaviour of RC slabs and FRP strips by other earlier researchers were summarized. A. Syamsir et. Al. [8], [11] reviewed the properties glass fiber reinforced polymer (GFRP) and its applications as outdoor structure. A review was made on the current tendencies on GFRP usage and numerous properties of GFRP were observed. After exposure to outdoor environment, the author stated that the durability of GFRP was reduced as well as its mechanical performance and behaviour been degraded. Nevertheless, modifications performed on GFRP composites were able to benefit GFRP to withstand extreme environmental condition [28]. Precisely, the strength, corrosion resistance, sustain capability in harsh nature and long-life serviceability of GFRP composite material was very tough and served as a good insulator in lightning impulse strength. A. Syamsir et. al. [9] examined the torsional load and environment effect on glass fiber reinforced polymer (GFRP) crossarm in transmission line tower crossarm. The crossarm in transmission line towers were created from GFRP in the research. The mechanical strength of GFRP crossarms due to the torsional loading and torsional behaviour based on the past researches were reviewed by the authors before test was performed. Additionally, the GFRP itself was advantageous in terms of high strength and stiffness-to-weight ratio, corrosion resistance and chemical stability compared to other standard materials on strength [29].

A. Syamsir et. Al. [7], [9] reviewed the glass fiber reinforced polymer (GFRP) durability effected by ultraviolet (UV) radiation. GFRP used as external layer frequently led to whole UV exposure and issued to radiation of UV. The issue led to GFRP quality and function degradation. The authors reviewed several past literatures on transmission line tower with GFRP effected by radiation of UV. As a cause from polymerization of the adhesives in steel laminates coupled with GFRP pultruded, increment of load carried capacity of its joint was displayed in the study subjected to UV radiation [30]. Besides that, GFRP age process from the study of UV radiation presented plasticization signs. After 6 months exposed, substantial decrement pattern was observed in the GFRP tensile strength and the modulus of tensile became less influenced compared to tensile strength. The authors detailed that GFRP rose as a probably good material to resist radiation of UV.

M. Jarrah et. Al. [31] agreed that FRP was very delicate after subjected to elevated temperature. The temperature of FRP composite improved in fire conditions consistently until glass transition temperature ($T_g$) was reached. Due to glass $T_g$ reaction, the resin matrix of FRP became soft and changed from a glossy to a rubbery resembled feature. Numerous tensile tests on GFRP and CFRP
sheets with and without intumescent paint at different elevated temperatures were directed. Additionally, the tensile strength, elastic modulus and glass $T_g$ of the epoxy adhesive after cured for 7 days were 30MPa, 4.5GPa and 58℃, individually. The results between painted specimens and unpainted specimens were validated. Total of 108 specimens were made for tensile test. T. M. Pham et. Al. [32] reviewed the concrete structures strengthened with fibre reinforced polymer (FRP) subjected to impact loads. The slab specimens attached with FRP materials were tested by drop the weight to study impact resistance. The drop weight hit the centre of the slab specimens repeatedly until first crack and final crack were observed.

V. Kumar et. Al. [33] investigated the impact resistance behaviour of prestressed and reinforced concrete slabs performed through drop test. The drop test was performed with steel impactor. Furthermore, reinforced and prestressed concrete slab specimens with dimensions of 800 x 800 x 100-mm were casted in the experimental study. The compressive strength of reinforced and prestressed concrete cubes with dimensions of 150 x 150 x 150-mm made from same type of slab specimen batches were gained after tested with Compression Testing Machine (CTM). The drop test equipment was able to drop 300kg weighted steel impactor from a maximum drop height of 1750mm. Additionally, the impact force, reaction, acceleration and deflection outcomes were measured by the authors for both prestressed and reinforced concrete slab specimens via a data logger. A. Abadel et. Al. [15] researched the local impact behaviour of reinforced concrete slabs strengthened with carbon fibre reinforced polymer (CFRP). The authors innovated the RC structures by application of FRP on bottom surface. The RC slab specimens were tested with projectile impacts experimentally at varied hit velocities. RC slab specimens with dimensions of 600 x 600 x 90-mm were casted with 8mm in diameter of 0.71% steel reinforcement bars. The CFRP sheets were attached on the surface of RC slab specimens by the use of epoxy resin after it hardened [34]. The test was conducted by projectile with diameter of 40mm hemispherical muzzle hit the CFRP strengthened RC slab specimens. Then, the quasi-static tests were performed on CFRP strengthened RC slab specimens. It was performed to established results on punching shear resistance of CFRP strengthened RC slab specimens.

To finish, V. Kumar et. Al. [35] researched capacity of energy absorption in multiple impacted prestressed and reinforced concrete slabs. The previous drop test research done in past literatures helped the authors to study the increase of impact resistance with relation to concrete material structures [36-42]. Additionally, the prestressed and reinforced concrete slab specimens were casted with equivalent dimensions of 800 x 800 x 100-mm. After cured, steel clamp equipment was used on all four edges of both types of concrete slab specimens. The steel ball with weight of 243kg was hit on centre of the span for all slab specimens freely and vertically from a height of 500mm. Therefore, the impact force and deflection results were gained for both prestressed and reinforced concrete slab specimens by the authors. Reduction on maximum impact force magnitude and increment of maximum displacement magnitude at centre and quarter span was observed for all concrete slab specimens subjected to residual impact. X. Zheng et. Al. [43] examined the method of reinforced concrete (RC) slabs strengthened with carbon fibre reinforced polymer (CFRP) laminates and steel plates hybrid. Two common materials such as steel and FRP were used mostly to toughen RC structures. Hence, strengthen method innovations was produced via combination of FRP and steel materials in varied ways to detect the most effective strengthened arrangement. Nineteen RC slabs specimens strengthened with different arrangements of CFRP and steel plates were prepared. The form created by authors for the RC slab specimens were 120 x 600 x 2500-mm. In addition, a diameter of 8mm smooth reinforcement steel bars was implanted inside each RC slab specimens. Then, four-point bending test were performed. The failure modes, deflection effected via load, internal strains of reinforcement bars and stiffness of the specimens were inspected. Precisely, the average flexural maximum capacity rose for 204.2% while the stiffness reached were 91% over the control slab specimens.
4. Numerical reviews

In this review, numerous numerical studies related to impact resistance of RC slabs and FRP strips by the previous researchers were assessed and proved as valuable reference for the upcoming projects associated with waste GFRP strips externally strengthened RC slab. The researchers, O. Anil et. Al. [44] completed both studies in numerical and experimental titled “Reinforced Concrete (RC) slabs with different types of support subjected to low velocity impact behaviour” in 2015. Based from the former literature, previous engineers focused the behaviour of RC slabs specimens exposed to static and dynamic loads under varied support conditions [45]–[47]. None study related to the effect of support conditions variation on the RC slabs behaviour subjected to impact loads was initiated in previous years. Therefore, the authors performed an experimental study to demonstrate that the support condition were proficient for positive RC slabs improvement.

The authors organized eight RC slabs with dimensions of 500 x 500 x 50-mm. A single layered plain mesh reinforcement bars with diameter of 4mm were implanted 10mm above bottom surface of RC slab in tension region and the space amid the reinforcement bars was 50mm. The details of RC slab specimens and reinforcements were showed in figure 5. The changed parameters known as support type and support layout were tested for RC slab specimens produced. Moreover, fixed and hinge supports were applied on four different RC slab specimens support layouts. An impactor of 5.25kg was positioned at a constant height of 500mm for impact resistance test on specimens. The dissimilarities of support layout of RC slab specimens and the impact resistance equipment were showed in Figure 6 and Figure 7.

![Figure 5. The dimensions with reinforcement details of RC slab specimens.](image-url)
Figure 6. The support layout variation and RC slab specimens.

Figure 7. The impact resistance equipment setup.

Specimens tested for impact resistance displayed acceleration against time results as detailed by the authors. The examinations related with the parameters effects on distribution of damage, drops amounts, acceleration against time, velocity against time and displacement against time results were also recorded. Additionally, the measurement accelerations existed in the project recorded the velocities varied and displacements results of all specimens [48]. The Finite Element Analyses (FEA) of the RC slab specimens under fixed and hinge supports was performed by the authors via ANSYS Explicit STR software and the impact resistance results in relation to the von-misses stress distribution, acceleration and displacement were simulated. The RC slab models with variation support types was showed in Figure 8.
The optimum numerical result of impact resistance was displayed at specimen 5 that was subjected to impact behaviour on four hinge supports. The simulations of equivalent von-misses stress occurred at specimen 5 was showed in Figure 9. The maximum acceleration, maximum acceleration ratio, displacement and displacement ratio gained for specimen 5 was resulted at $3201.40 \text{m/s}^2$, $0.83$, $0.471 \text{mm}$ and 0.96, individually. The overall numerical model results demonstrated was closely equal to the overall results received from experimental study.

In 2017, Y. Xiao et Al. [49] finished a research titled “Behaviour of reinforced concrete (RC) slabs subjected to low velocity impact”. All concrete made building and structures were certainly subjected to impacts especially low velocity impacts throughout its service lives. Natural disasters were the common situations that led to impact on structures made of concrete. Examples of natural disasters were tsunami, tornedos and earthquakes. Furthermore, human made actions like vehicle collision and explosions caused damage on structures [33], [50]. In the past, researchers studied the relation among high velocity impact which was classed as impact happened at above 100m/s with RC slab specimens. However, the study of low velocity impact rose in demand at civil engineering to determine the strength of RC slab specimens. Accordingly, the authors planned and directed experiments of low velocity impact to acquired knowledge for RC slab specimens behaviour.

A total of fifteen RC slab specimens with dimensions of $1200 \times 1200 \times 150$-mm were casted for low velocity impact test. The $10$mm diameter reinforcement bars were placed inside RC slab specimens and the concrete cover was resolute at the thickness of $18$mm. Additionally, the RC slab specimens were clamped at four supports and were impacted via impactor with diameters geometrically $10$cm hemispherical, $10$cm flat and $20$cm flat vertical, congruently. The author examined the RC slab specimens damage depended on impact energy, impacted area diameter, and geometries of impactor. The increment of impact energy on the RC slab specimens led by increase on damage due to low velocity impact [35], [51]. Furthermore, the failure modes related to punching shear was spotted for all RC slab specimens. The damage pattern depended on the impactor diameters.
were showed in Figure 10. The shear capacities attained on the casted specimens were in agreement to ACI 318-14 standards.

![Figure 10. Crack pattern on base surface of RC slab specimen.](image1)

![Figure 11. FE model of RC slab specimen and steel supports.](image2)

Other than experimental, LS-DYNA software was used to create 3D finite element (FE) model and analysis of RC slab specimens by the authors. The analysis process was performed to govern the impact energy that undoubtedly caused punching shear failure at RC slabs specimens [52]. The RC slab models and its fixed supports were showed in Figure 11, where the 3D strain rate sensitive material models were used in concrete and steel reinforcement formations. Furthermore, the supports and impactor invention were made via rigid body [53]–[55]. A success proposal of two dimensionless empirical equations in term of various parameters were attained from FE analysis results to measure the capacity of energy in RC slab models exposed to low velocity impact. Lastly, a confirmed effective boost on RC slab model’s capacity of energy were demonstrated as the strength in concrete material structures, diameter of impacted location and slab thickness increased in the FE analysis results.

Overall, published researches related to numerical study on impact behaviour of RC slabs and FRP strips by other earlier researchers were summarized. A. Syamsir et. Al. [12] reviewed the behaviour of fiber reinforced polymer (FRP) creep. FRP composites were easy to produce, lightweight and high flexibility. Therefore, FRP was widely utilized in transmission line as replacement for the conversational cross arm to increase its mechanical strength. Fundamentally, the authors studied the creep behavior to determine the maximum load it can withstand in a time period. Structural collapse and destruction happened as a result from extreme creep deformation [56]. Then, ANSYS was used to develop a numerical model for flexural creep test measurement. The GFRP creep behaviour after 6 and 14 months led to 20% Young's modulus composites reduction. Temporarily, the shear stiffness presented from the pultruded flexural member of GFRP creep behaviour after 50 years were 22% to 43% with effective instantaneous flexural average decrease. Furthermore, better creepocity was
achieved from deformation of shear instead of counterpart bend. The potential of GFRP in structural industries was confirmed as the study on GFRP girder creep after five months displayed above 40% increment of instantaneous deflection.

O. Anil et. Al. [44] studied the conditions of reinforced concrete (RC) slabs with different types of support subjected to low velocity impact. Finite element analyses (FEA) were finalized in ANSYS Explicit STR software where the von-misses stress distribution, acceleration and displacement were simulated for impact behaviour of specimens clamped with fixed and hinge supports [57]. Y. Xiao et. Al. [49] studied the behaviour of reinforced concrete (RC) slabs subjected to low velocity impact. The relation between high velocity impact which was categorized at more than 100m/s and RC slab specimens were mostly discovered and aimed by previous researchers [58]. The failure modes related to punching shear was spotted for all RC slab specimens. The shear capacities recorded for casted specimens were in agreement to ACI 318-14 standards [59]. Finally, the authors developed 3D finite element (FE) analysis of RC slab via LS-DYNA software to govern the impact energy that probably resulted to punching shear failure [60].

Finally, T. Yilmaz et. Al. [61] researched the low velocity impact behaviour of two-way reinforced concrete (RC) slabs specimens covered with carbon fibre reinforced polymer (CFRP) strips. In the impact related experiment, the authors firstly arranged and varied the width of CFRP strips. The transferrable drop weight machine was designed and used by the authors to hit the impact load on slab specimens [62]. ABAQUS analysis software was used to validate the results obtained from the finite element models of RC slabs bounded with CFRP strips with the results achieved from experimental [63].

5. Conclusion
This review is comprehensible to help increase the knowledge on enhancing the quality of reinforced concrete (RC) slabs externally strengthened with fibre reinforced polymer (FRP) strips especially FRP like waste glass fibre reinforced polymer (GFRP) strips. From the overall review, it can be concluded that the use of FRP primarily GFRP to strengthened RC slabs resulted to:

1. FRP material improved the impact resistance of RC slabs as well as increased the load carried capacities, ductility and energy absorption. Finally, the tensile strength of RC slab specimens rises as the strain rate increased along the force applied to the surface of the specimens. It was confirmed that the developed numerical models were reliable to demonstrated the simulation for specimens.

2. The optimum result of RC slab specimen subjected to impact behaviour was the specimen clamped with four steel hinge supports. The simulation presented that the impact force which hit the surface of RC slab specimens were distributed and travelled equally with the aid of four steel hinge supports.

3. The researchers can observe the crack path, stress, strain, deflection, maximum acceleration, maximum acceleration ratio, displacement and displacement ratio of RC slabs numerically through analysis in FEM software.

4. The results obtained from any FE analysis software proved that increase in concrete material structures strength, diameter of impacted location and slab thickness boosted the energy absorption capacity of RC slab models effectively.

5. Overall, the procedure or methods in reviewed experimental and numerical papers can be applied for all fibers reinforced polymer (FRP) strips-based projects as the process was appropriate to be used for any externally bonded FRP based material on RC slab specimens.

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