Performance of Geogrid Reinforced Concrete Slabs under Drop Weight Impact Loading

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Abstract. Reinforced concrete (RC) structures are often subjected to extreme dynamic loading conditions, mainly caused by effects of impact loading. A countable studies have been carried out on the structural behaviour of RC slabs under static and dynamic loadings. However, it is relatively infrequent to examine the impact behaviour of RC slabs that are embedded with non-conventional reinforcement layouts. Consequently, an experimental study was performed to examine the impact behaviour of geogrid reinforced concrete slabs. A total of six RC slab specimens embedded with different combination of steel and geogrid reinforcement layers was tested under drop weight impact test. The impact response in terms of failure modes, impact energy, impact ductility index and maximum deflection produced at each impact blow were studied. The results showed that, the RC slab specimens provided with geogrid reinforcement layer at both faces of slab specimens along with the conventional reinforcement resisted the crushing of concrete by spreading the impact stress to a larger area. This configuration of reinforcement also helps to withstand for higher impact forces, thereby influencing the enrichment in impact energy and impact ductility index.

1. Introduction
Reinforced concrete (RC) slabs are one of the widely used structural elements in building structures. In other hand, polymeric materials like glass, carbon and steel fiber composites and Geosynthetics composites that include geogrid, geocells are used as reinforcement to enhance the properties of structural concrete elements [1-4]. The RC Slabs are most commonly designed by considering the static loading provisions alone. In most of the cases, for designing the RC slabs, both static and dynamic vertical load effects are not taken into the account. In specific, the impact loading is ignored or it is infrequently considered only for the specific problems in the design stage of slabs. The impact performance of RC slabs is still not well understood due to the marginal specific research work done in this field. However, a wide range of solicitations inspires to know the complete knowledge about the impact performance of RC slabs. Accidental loading scenarios like falling dense soil or rock, vehicle and ship collisions, wave current impact force on offshore structures are examples of impact effects that affect the need for impact resistance.
design process [5]. However, in the past decades, a countable research has been suggested to investigate the impact behavior of concrete materials. In particular, the static and dynamic impact study on RC elements, especially in RC slabs is marginal. The key explanation for this inadequate study is due to the inelastic behavior of RC elements under impact loading that creates difficulties in analysis and design work [6-7].

The research conducted in previous decades has been divided into two groups. In that, one group is focused on the constant distance projectile load application and another on the dropping of mass with varying heights. The key approaches have been done in previous research studies were focused primarily on raising the slab thickness, variation in the percentage of steel reinforcement and various strengthening techniques to enhance the impact performance of concrete slabs for a given compressive strength of concrete [8-10]. The RC Slabs, provided with a different reinforcement percentage were studied under impact loading by Zineddin and Krauthammer to examine the dynamical response of it. The three different reinforcement ratio was studied to explore the dynamic impact response of RC slabs. The impact loading was applied by three different drop height with a constant weight, in order to the study the effect of drop height. The results clearly showed that, with an increase in the drop height the rate of failure was increased and also the higher reinforcement ratio effects the enhancement in the impact resistance properties [8].

The effect of reinforcement configuration of the impact behavior of RC slabs was experimentally explored by Othman H et al. Two different steel configurations that include a percentage of the bottom steel ratio and the different arrangements with single and double reinforcement plates were the parameters considered in this analysis. The findings showed that, the adjustment in the reinforcement ratio and the arrangement of plate reinforcement layout has no significant effect on the impact performance [10].

The RC slab specimens were examined by Soltani et al. on externally bonded GFRP sheets under the impact loading. The results showed that the diagonal orientation of the GFRP sheets in the lower layer with higher counts, improves the performance of RC slabs under impact loading [11]. The behavior of retrofitted RC slabs with GFRP bars under drop weight impact loading conditions was examined by Sadrai H et al. The test parameters were considered as the thickness of the slab, reinforcement ratio of steel and the orientation of GFRP bars. The test results indicated that, increasing the thickness of the slab and the steel reinforcement ratio were not shown a significant improvement in the impact performance. The strengthening of slabs using GFRP bars with the effective arrangement has shown the noticeable improvement in the impact performance of the RC slabs [9]. Elnagar et al. did experimental and numerical investigation on the drop weight impact behavior of RC slabs that embedded with strain hardening cementitious composites (SHCC) in tension and compression sides. The addition of SHCC in RC elements effectively enhanced the impact performance by enriching the kinetic energy properties [16-19].

Tharani et al., studied the impact response of the geogrid reinforced RC slab. The different counts of the geogrid layer with an addition to the steel reinforcement was considered as the test parameter. The results revealed that the addition of geogrid layers greatly enriched the impact response of the RC slab [4]. Vijay et al. studied the polypropylene reinforcement in order to evaluate the bond and flexural behavior. The polypropylene bars with threaded surface greatly enhanced the bond and flexural properties [1-2].

Most of the structural components should be designed with durable and also sustainable, hence employ of sustainable materials in those structural elements should be included [20-26]. In addition to that the studies done with the utilization of GFRP and CFRP polymer composite were mainly focused on the strengthening technical aspects. However, the studies related to utilization of geogrid materials as a reinforcement in concrete slabs are relatively marginal. In other hand, a countable testing procedures were proposed by various researchers that involved projectile impact test, charpy impact test, drop weight impact test and explosive test. However the ACI committee 544 suggested the drop weight impact test is a simple and efficient method to study the impact response RC elements [8-11]. Therefore, an attempt was made to examine the impact performance of geogrid reinforced concrete slabs under the drop weight impact
loading conditions. The test parameters considered in this investigation include the addition of various counts of geogrid reinforcement layers along with the conventional steel reinforcement and the positions of geogrid layers in the slab. The drop weight impact characteristics include the impact energy, impact ductility index and failure mode of geogrid reinforced RC slabs were examined.

2. Experimental Study

2.1. Test Specimens and materials
In this present experimental study, totally six different configurations of geogrid reinforcement embedded in concrete slab specimens were tested under drop weight impact loading. In that six specimens, one of the specimen was provided only with conventional reinforcement pattern and it is indicated as “CS”. The design of CS specimens is done as per Indian standard codes (IS 456:2000) [12]. Another five specimens are provided with the different combination of geogrid reinforcement layers in addition to the steel reinforcement. Those types of slab specimens embedded in combination with steel and geogrid reinforcement are indicated as “GS” series. The reinforcement configuration details of RC slab specimens are shown in Figure 1. The dimension of the test specimen is 825 X 825 X 70 mm. The specimens were produced at the same time and preserved for 28 days prior to testing under curing conditions.

![Diagram of test specimens](image)

a) CS

b) GS1
c) GS2
d) GS3
2.2 Concrete Materials

The basic properties of materials used to produce concrete were tested as per Indian standard codes [13]. The fine and coarse aggregate was taken from the nearby locality. The coarse aggregate used in the concrete mix was collected from the aggregates passed on 10 mm sieve size and retained on 12.5 mm sieve to avoid segregation. The good quality portable drinking water is used in the preparation of concrete mix. The specific gravity of cement is 3.11; fine aggregate is 2.67 and coarse aggregate is 2.78. Mix ratio designed with reference to IS 10262:2019 is 1: 1.68: 3.08 with 0.55 water cement ratio [14]. The tested average compressive strength, tensile strength, poisson’s ratio and the modulus of elasticity values of concrete is $f_c = 25.5$ MPa, $f_t = 3.15$ Mpa, $\mu_c = 0.17$ and $E_c = 23501.8$ MPa, respectively.

2.3 Steel Reinforcement

A steel bars of 6mm in diameter having the tested yield strength $f_y = 486.5$ MPa, ultimate strength $f_u = 584.8$ Mpa, poisson’s ratio $\mu_s = 0.28$ and the modulus of elasticity $E_s = 211.2$ GPa is utilised as a reinforcement in the RC slab specimens.

2.4 Geogrid Reinforcement

The biaxial geogrid layer is used as reinforcement in this work. With reference to ASTM D6637 / D6637M-15 standard, the tensile testing of biaxial geogrid was done [15]. The inside dimension of the geogrid is 40 X 40 mm with 2.8 mm thickness. The tested tensile strength, young’s modulus, poisson ratio of biaxial geogrid specimens were 55 MPa/m, 32 GPa/m and 0.24 respectively. The biaxial geogrid is shown in Figure 2.
2.5. Drop weight impact test setup

The impact loading was generated by the drop weight impact loading arrangement with reference from the impact investigation done by Elnagar et al. to test the RC specimens [16]. Figure 3 shows the arrangement of drop weight impact loading setup. To make four side fixed support condition of the test specimens, the edges of RC slab specimens were rigidly hold by 95 X 90 X 12 mm channel section which was tightly fixed to the rigid foundation block. Therefore, the clear dimension of the RC slab specimens were reduced to 675 X 675 X 70mm when it rigidly fixed with the channel section. The impact load was applied in the exact center of the RC slab specimen with the help of cylindrical hammer with hemispherical striking tip of 80 mm radius with 13 kg of total weight. The drop hammer is allowed to drop freely at the loading point and it was prevented to avoid lateral movement. The hammer was dropped from the clear distance of 1.2m to measure the effect of impact force. The computerized linear variable differential transformer (LVDT) was attached to the bottom side of RC slab specimen to measure the maximum deflection caused at each loading blows.

![Drop weight impact test setup diagram](image)

**Figure 3.** Drop weight impact test setup

3 Results and Discussion

3.1 Failure Characteristics

The typical crack patterns obtained at the failure point under the drop weight impact test are shown in Figure 4. The comparison among the sustained numbers of blows for all test slabs is shown in figure 5. The initiation of first crack for the CS, GS1, GS2, GS3, GS4 and GS5 specimens was initiated at the 4th, 3th, 5th, 5th, 5th and 6th number of blow. The observed initiation of crack was similar for CS, GS2, GS3, GS4 and GS5 specimens and it was different for GS1 specimen. The CS, GS2 and GS3 specimens were observed with initiation of first crack at the bottom side edges of the slabs. Whereas, the GS1 specimen was observed with crushing of concrete at the top and bottom portion slab at the line of loading. However the GS2 and GS5 specimens were observed with a hair line crack of smaller length and thickness compared to other specimens. This evidences that the CS, GS2, GS3, GS4 and
GS5 specimens were observed with the flexural type of failure initiation and GS1 was observed with the concrete compressive crushing type of failure behaviour.

Further increasing in the numbers of blows, the initiated cracks at all the bottom side edges were propagated and connected at the center portion of the slab at the bottom face in CS, GS2, GS3, GS4 and GS5 specimens. There was no formation of cracks observed in the GS1 specimen, however, it was noticed with the excessive crushing of concrete in the top and bottom portion of the slab. The failure of the CS, GS1, GS2, GS3, GS4 and GS5 specimens was attained at the 12th, 12th, 22th, 19th, 20th and 27th number of blows. While the specimens reach the failure stage, the enlargement of cracks and removal of concrete at both faces at its center portion were observed for the CS, GS2 and GS3 specimens. A slight enlargement of cracks without much removal of concrete at bottom side was noticed in GS4 and GS5 specimens. The concrete surface at the loading point of GS4 specimen was crushed, but the GS5 specimen resisted the crushing of concrete at the loading point. The GS2, GS4 and GS5 specimens performed better in impact behavior than all specimens and it was noticeably higher for GS5 specimen.

Figure 4. Crack pattern at failure stage of (a) CS, (b) GS1, (c) GS2, (d) GS3, (e) GS4 and (f) GS5 specimen.

The marginal impact performance of CS specimens was due the bending of steel reinforcement bars and sudden failure occurred while increasing the impact loading blows after the first crack initiation. The GS1 specimens resisted the crack formation and propagation, but it failed to resist the sudden failure due to the crushing of concrete at the center portion on the both faces. The specimens provided with a combination of geogrid and steel reinforcement helps to resist the tensile force
transferred by means of impact loading. This effect influences the better impact performance in slabs specimen embedded with combined geogrid and steel reinforcement compared to the steel reinforced slabs. Especially, the RC slab specimens provided with geogrid reinforcement layer at both faces of slab in addition to steel reinforcement influence the resistance in crushing of concrete and spreads the tensile force to the wide concrete surface area. This significant performance of geogrid layers slows down the formation and propagation of cracks and the rate of failure.

3.2 Impact response

The RC slab specimens are examined in terms of impact energy and impact ductility index in order to validate their impact performance. The drop-weight impact energy (E) corresponding to first crack and failure stage and impact ductility index (μ) of different test slabs specimens were calculated by Eq. (1) and Eq (2) respectively [16].

\[
E = N \times m \times g \times h \quad \text{Eq (1)}
\]

\[
\text{Impact ductility index (}\mu\text{)} = \frac{N \text{ (failure)}}{N \text{ (first crack)}} \quad \text{Eq (2)}
\]

Where N is the number of blows corresponding to either the first crack (N first crack) or failure stage (N failure); \( m \) is the mass of the drop hammer = 13 kg; \( g \) is the acceleration of gravity = 9.8 m/s²; \( h \) is the drop-height = 1.2 m.

![Figure 5. Comparison among the sustained numbers of blows for all test slabs.](image1)

![Figure 6. Impact Energy for all test slabs](image2)
Figure 7. Maximum mid-span deflection versus the number of blows

Table 1. Experimental Results

| Specimen | N (first crack) | N (failure) | \( \Delta \) (first crack) (mm) | \( \Delta \) (failure) (mm) | E (first crack) (J) | E (failure) (J) | \( \mu \) |
|----------|----------------|-------------|---------------------------------|---------------------------|---------------------|----------------|--------|
| CS       | 4              | 12          | 1.52                            | 3.8                       | 612.144             | 1836.432       | 3      |
| GS1      | 3              | 12          | 1.25                            | 2.95                      | 459.108             | 1836.432       | 4      |
| GS2      | 5              | 22          | 0.88                            | 2.7                       | 765.18              | 3366.792       | 4.4    |
| GS3      | 5              | 19          | 1.24                            | 3.1                       | 765.18              | 2907.684       | 3.8    |
| GS4      | 5              | 20          | 1.01                            | 2.95                      | 765.18              | 3060.72        | 4      |
| GS5      | 6              | 27          | 0.85                            | 2.55                      | 918.216             | 4131.972       | 4.5    |

\( \Delta \) (first crack) = displacement at first crack; \( \Delta \) (failure) = displacement at failure; Impact energy at first crack is termed as E (first crack) and at failure is termed as E (failure); \( \mu \) = impact ductility index.

The experimental results of different test specimens are presented in Table 1. Figure 6 shows the impact energy variation for different slab specimens. The enriched impact energy absorption and impact ductility index are greatly biased by the basic characteristic includes the dowel action of reinforcement, aggregate interlocking mechanism and the formation of an effective compressive strut mechanism to transfer the impact strain to the foundation. The calculated drop weight impact energy at the first crack stage of GS2, GS3 and GS4 specimens was 25% higher than the CS specimens and it was 50% higher for GS5 specimen. However the calculated drop weight impact energy at the first crack stage of GS1 specimen was 25% lower than the CS specimen. Similarly the calculated drop weight impact energy at the failure stage of GS2, GS3, GS4 and GS5 specimens was 83%, 58%, 67% and 125% higher than the CS specimen. Noticeably, the GS5 specimen behaved enriched performance in impact energy absorption characteristics compared to the other test specimens. However the calculated drop weight impact energy at the failure stage of CS and GS1 was similar. The impact ductility index of GS1, GS2, GS3, GS4 and GS5 specimens was 33%, 47%, 27%, 33% and 50% higher when compared to the CS specimen. This showed the geogrid reinforced specimens withstands a larger count of impact blows than the steel reinforced slab specimens. The GS5 specimen behaved with higher impact ductility index compared to all other specimens.
As seen in several previous studies [5-11,16] the measured deflection at each loading blow is observed as an initial pulse like waveform with a high magnitude followed by a dull waveform with a relatively low magnitude. The maximum deflection taken in each loading blow versus the number of blows in shown in Figure 7. The deflection behavior of all test specimens was similar that deflection increases with an increase in the number of blows. The GS1, GS2, GS3, GS4 and GS5 specimens resisted about 18%, 42%, 18%, 34% and 44% deflection at the first crack stage; about 22%, 29% 18%, 22% and 33% deflection at the failure stage than the CS specimen. The GS2 and GS5 specimen resisted higher percentage of deflection which is the essential behavior to survive under the impact loads by avoiding the sudden collapse due to the crushing of concrete.

The behavior of CS and GS1 specimens are almost similar with marginal performance in the impact energy absorption and impact ductility index properties due to the sudden failure which was caused by the lower resistance to concrete crushing characteristics. In GS series specimens, except the specimen provided only with geogrid reinforcement (GS1), all other specimens showed better impact performance. In particular, the GS2 and GS5 specimen exhibited with an enriched impact energy absorption and impact ductility index performance than the other specimens. The geogrid reinforcement layer provided on the tension and compression side of the slabs helped to arrest and spread the tensile stress from impact loading to a large area. This aids to resist the sudden failure and crushing of concrete at the loading point and bottom face of loading point. Also, the confinement offered by geogrid reinforcement to resist the impact load is higher. From the results, it is clearly identified that, the RC slabs embedded effectively with a combination of steel and geogrid reinforcement performed better in dowel action and formation of compressive strut action by effectively transferring the tensile stress to the foundation. This influenced the enriched impact energy absorption and impact ductility index performance of RC slabs embedded effectively with a combination of steel and geogrid reinforcement than the RC slabs embedded with steel alone or the geogrid alone.

4. Conclusion
An Experimental investigation on RC slabs was performed using the drop weight impact test to examine the impact response of geogrid reinforced RC slab specimen. In this regard, six RC slab specimens were manufactured with the different combination of steel reinforcement and geogrid reinforcement layers. The following conclusion was made from the test results.

The RC slab specimens embedded with combined geogrid and steel reinforcement behaved with a better performance by improving the resistance to the impacted shear stress through dowel action. This combined reinforcement layout also helps to spread the tensile stress from the impact loading to a large area, thus avoiding the accumulation stress at a specified loading point.

As a result, the combined geogrid and steel reinforcement embedded RC slab specimens sustained for higher counts of impact loading blows which influences the enhanced impact performance in terms of impact energy absorption and impact ductility index. In particular, the slab specimens embedded with the single layer of geogrid reinforcement in both tension and compression side in addition to conventional steel reinforcement influence the enriched performance under impact loading. It also noticed that, the RC slab specimens embedded with steel reinforcement alone or geogrid reinforcement alone is not significantly increases the impact performance due to the sudden concrete crushing failure.

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