Experimental Investigation of Geogrid Reinforced Concrete Slab

Tharani K, Mahendran N, Vijay T J

Abstract: ***In recent days, reinforced concrete (RC) structures are highly affected by impact loading. In many places, the external surface of the structure is mainly prone to damage that are caused due to the impact of heavy mass substances like projectile, missile or aircraft impacts, terrorist attacks, and ice impacts. To resist the damages occurring due to impact in RC structures, geogrid material is utilized as an addition to steel reinforcement. This paper experimentally presents the impact behavior of reinforced concrete slab with geogrid as an additional reinforcement. Geogrid is one of the geosynthetic material that exhibits both tensile and flexural behavior similar to that of steel. The geogrid reinforced concrete slab was tested experimentally under drop weight impact loading using a steel ball having a mass of 7 kg with constant drop height of 3.4m. The impact behavior in terms of energy absorption was measured experimentally and was utilized to compare with results of Finite Element Analysis (FEA) carried out in ABAQUS software. The energy absorption, stresses, displacements, displacement versus strain energy and damage patterns were taken from the FEA. The results obtained for conventional and geogrid reinforced concrete slab were compared and discussed. The obtained results showed that the addition of geogrid layer increases the impact resistance than conventional reinforced slab.***

Keywords: ***Geogrid, ABAQUS, Impact loading, Stress, Displacement, Strain energy and Impact energy***

I. INTRODUCTION

Reinforced concrete is a versatile and most commonly used construction material. This composite material comprising of concrete is an intrinsically brittle material and steel as a ductile material provides resistance against compression and tension. This composite material is mainly prone to damage caused due to impact of huge masses. The impact load may be a sudden dynamic load and its intensity could also be considerably higher compared to other loads. Typical examples of impact load are rock falls, accidental events especially the one's occurring in factories and vehicle collisions, explosions, hitting of projectile, missile or aircraft impacts, terrorist attacks, and ice impacts. These effects could completely destroy a structure in a short span of time. The impact effect changes the mechanical properties of structural elements because of the dynamic effects. Roberto Pimental et al [7] observed the damage detection, assessment in reinforced concrete slab using impact test. An Experimental test was carried out at the level of change of fundamental frequency along the decay after impacting the slab. The results showed time-frequency curves obtained from the decay of cracks grows with the increase of the load. The propagation of cracks were parallel to the width of the slab.

Geogrid is an alternate material which can be used as a replacement or an addition for steel reinforcement as this material can reduce the damage due to impact in the structure. Geogrid is one of the Geosynthetics material that has long been used as reinforcement and stabilization elements in numerous civil and infrastructural works significantly, because it relates to Geotechnical engineering. In recent decades the usage of Geosynthetic material is increasing greatly in RC and pavement structures. Geogrid is one amongst the derivatives of geosynthetic material, that is currently utilized in RC and pavement structures.J. Radnic et al.[5] performed an experimental test on RC slab strengthened with CFRP under impact loading. Experimental test was carried on conventional RC slabs and CFRP slab, the slabs were tested until failure and a numerical model for a non-linear analysis was evaluated. The results showed that the slabs strengthened with Carbon Fiber Strips exhibited higher ultimate bearing capacities than conventional RC slab.Since the structures used for pavements are typically subjected to extreme dynamic loading conditions due to direct impact, geogrids will resist the sudden stress created due to impact loading. F. El Meski et al [3] described the flexural behavior of concrete beams reinforced with different types of geogrids. The results confirmed that geogrid reinforcement provided a ductile post cracking behavior, high fracture energy and large deflections. Azza Mohamed Elleboudy et al [8] presented an assessment of geogrids in gravel roads subjected to repeated cyclic loads.Experimental model test and numerical analysis using ABAQUS were conducted onboth geogrid reinforced and unreinforced unpaved road sections. From the test results it was observed that the vertical deformation depth increased rapidly during the initial load cycles; thereafter the rate of settlement is reduced as the number of loading cycles increased. The most effective location of geogrid was found to be in the top quarter of the base course layer. A similar test was carried by Yan-Li Dong et al [1]on geogrid placed at various structural elements to obtain the behavior of geogrid's application and its tensile properties. Abbas S.A et al [4] investigatedtheeffect of geogrid on the dry shrinkage behavior of concrete pavements.

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The test results showed Geogrid reinforcement reduced the drying shrinkage strains of the concrete prism specimens between 0.7% and 15%, than the control specimens.Ailaterin S, et al [2] performed a nonlinear finite element analysis on Reinforced concrete slab-column connections under static and pseudo dynamic loading. The coupled damaged plasticity was carried out in ABAQUS for 3D finite element analysis, with acceptable modelling of element size and mesh. The results showed that the cracking initiates when the maximum principal plastic strain is positive. The orientation of the cracks wasperpendicular to the maximum principal plastic strains. Tingbian Zhan et al [6] observed the failure behavior of reinforced concrete beams subjected to high impact loading. The results showed that the load carrying capacity of beams increased with increase in reinforcement. The crack opening displacement increased as the height of drop weight increased.

In this present study, the behavior of reinforced concrete slab has been tested under drop weightimpact loading with geogrid as an additional reinforcement. The impact energy capacity for each slab was determinedusing impact testing apparatus. Impact energy was determined and results were compared with the conventionally reinforced concrete slab. The experimental results were compared with analytical results.

II. EXPERIMENTAL PROGRAM

2.1 Material Properties

Ordinary Portland cement of 53 grade conforming to the specifications given in IS 12269-1987 was used in this experiment. The specific gravity of cement used for preparing the concrete mix was 3.14. River sand or natural fine aggregate passing through the sieve size of IS 4.75mm possessing a specific gravity of 2.64 with fineness modulus value of 3.75 was used.Locally available crushed coarse aggregate of size 12.5mm and having a specific gravity of 2.65 with fineness modulus of 4.28 was used. The 6mm diameter steel bars with yield strength of 514.28N/ was used as reinforcement.

2.2 Properties of Geogrid

The biaxial typeof geogrid was used as a drying shrinkage restraining layer. This is because the arrangement of ribs and roughness of nodes in biaxial geogrid's surface will provide an appropriate bond between the geogrid layer and the surrounding concrete. Biaxial type of geogrid is shown in Fig 1. Biaxial geogrid was formed by stretching of punching sheets in both transverse and longitudinal directions so that the material exhibits tensile strength in both directions. The ribs of the biaxial geogrid are interconnectedat one point called the node(junction). The size of thebiaxial geogrid rib was 35mm×35mm. The physical and mechanical properties of geogrids are presented in Table 1.

Fig 1: Biaxial geogrid

Table 1: Physical and mechanical properties of geogrid

Material	Geogrid
Form	Sheet
Colour	Black
Width (m)	0.635
Length (m)	0.635
Thickness (m)	0.004
Mesh Aperture size(m)	0.035 × 0.035
Tensile Strength (kN/m)	5.8
Elongation at maximum Load (%)	16

2.3 Mix Proportion

The mix proportion was designed confirming to Indian standard code IS 10262-2009. The grade of concrete was selected as M_{25}. Details of mix proportions are presented in table 2.

Table 2: Mix Proportion

Cement (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	Water (lit/m^3)
1	1.92	2.1	0.5
429.6	825.6	903	214.6

2.4 Test Specimens

Drop weight impact tests were carried out on steel reinforced concrete slabs and Geogrid reinforced concrete slabs. These slabs were square shaped with dimension of 675×675×100mm. Details on the position of geogrid reinforcement in slabs are presented in table 3. The designed compressive strength of concrete cube was 25 N/mm^2at 28 days. The concrete compressive strength wasdetermined by testing cubes of size 150mm×150mm×150mm. These cubes were tested under compressive strength testing machine after 28 days of curing. The average compressive strength of concrete cubes after 28 days of curing was 26.82 N/mm^2.The arrangement of steel and geogrid is shown in fig 2. All slabs were water cured with equal time duration to attain the same concrete properties.

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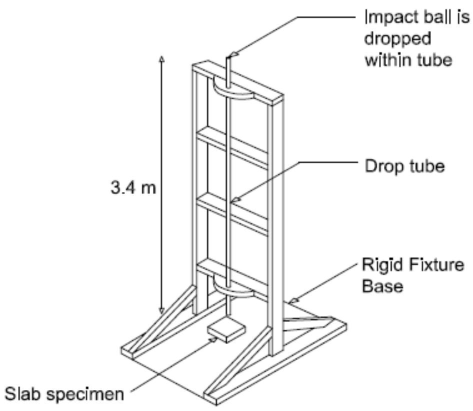
Fig 2: Arrangement of steel and geogrid

Table 3. Details of geogrid reinforcement in concrete slabs

S. No	Specimens	Details of Reinforcement
1	RC	Reinforcement was placed at 25mm from the bottom of the slab.
2	GC1	Two layers of geogrid reinforcement were additionally placed at 25mm and 75mm from the bottom of the slab.
3	GC2	Two layers of geogrid reinforcement were additionally placed at 75mm from the bottom of the slab.

2.5 Testing Program

Three RC slabswith the addition of geogrid reinforcement were subjected to impact loading. The drop weight impact loading setup was used to apply the impact load on reinforced concrete and geogrid reinforced concrete slab. Drop weight impact testing apparatus is shown in fig 3. All four sides of the slabs were clamped to provide symmetric support condition. The slabs were impacted in the centre by applying constant drop weight using steel ball of mass 7kg from a constant height of 3.4m. The generated impact force was measured.



3(a)

3(b)

Fig 3: Impact testing apparatus and slab specimen

III. EXPERIMENTAL RESULTS

3.1 Impact energy

The impact resistance of slab specimens was determined at 28 days of curing time. The numberof drops, resulting in the initial crack and number of drops required for final fracture of reinforced concrete and geogrid reinforced concrete slab was measured during the experimental observation. Impact energy capacities of each slab are shown in table 4.

The impact energy of initial and final drops wascalculated using the formula as follows.

$$E = m \times g \times H \times N$$

Where
E = Impact energy(N-m) or (kJ)
m = drop mass of ball
H = height of drop mass
N = number of drops at ultimate failure

Table 4: Experimental Impact energy

S. No	Specimens	No of Drops		Impact Energy (kJ)	
		Initial	Final	Initial	Final
1	RC	3	14	700.43	3268.69
2	GC1	4	34	933.91	7938.25
3	GC2	3	19	700.43	4436.08

IV. ANALYTICAL VIEW

4.1 Finite element analysis

The finite element analysis was performed using ABAQUS standard/explicit software. The software was used to investigate the behavior of geogrid reinforced concrete slab subjected to drop weight impact loading. The analysis process involved providing discretized geometry, section properties, material properties, proper step, load, the connection between surfaces of elements, mesh size, boundary conditions, and output requests. Initially, an 8 nodded linear brick element (C3D8R) for slabs wascreated. Then, steel and geogrid reinforcement were modelled by 2 nodded linear truss elements (T3D2) connected to the nodes by adjacent solid elements. Finally, the steel ball was created as a discrete rigid element and revolved in 360 degrees to produce the sphere shape. Concrete damaged plasticity models were utilized to assign concrete properties. The material properties of concrete, steel, and geogrid are given in table 5.

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Table 5: Properties of Materials

Property	Material		
	Concrete	Steel	Geogrid
Density (kg/m^3)	2400	7850	900
Modulus of Elasticity (MPa)	25610	210000	27750
Poisson's ratio	0.18	0.3	0.25

Time steps had a very important effect on the results of the impact analyses. For this purpose, each step and total time spans were checked simultaneously. When the time increments were defined as 0.0012 seconds before the contact point, they were set to 4×10^{-8}seconds when the contact between the steel ball and the slab had started. The finite element models were analysed for accuracy and minute time increments till proper results were obtained. An embedded technique was utilized to constrain the two node truss elements (steel and geogrid reinforcement) into the slab element. Surface to surface contact was created for proper interaction between the steel ball and slab element. Fixed support conditions were to be adopted for all four sides of the slab element. Assembly and support condition of the slab is shown in fig 4. The mass of the steel ball was 7kg and the velocity was taken to be 8.16 m/s in a direction perpendicular to the slabs.

Finite element models were to be separated into small pieces known as meshing. The mesh size was taken to be 25mm for each element. The process continued until the slab reaches failure, damage in which maximum stresses, displacements, and impact energy were obtained.

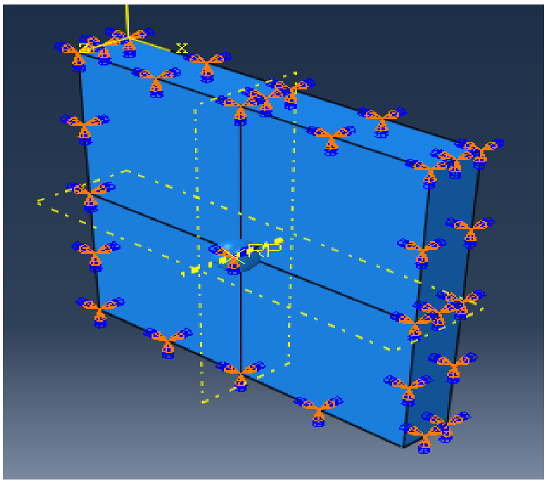

Fig 4: Assembly and support condition

4.2 Analytical results

The finite element analysis was carried until the reinforced concrete slab and geogrid reinforced concrete slab attained failuredamage condition that occurred at the final drop movement of the ball. Final analysis results in terms of stress (mises), displacementand displacementversusstrain energy graph were obtained for the final drop movement of the ball for each is shown in Fig 5, 6 and 7. Impact energy capacity for each slab is given in table 6.

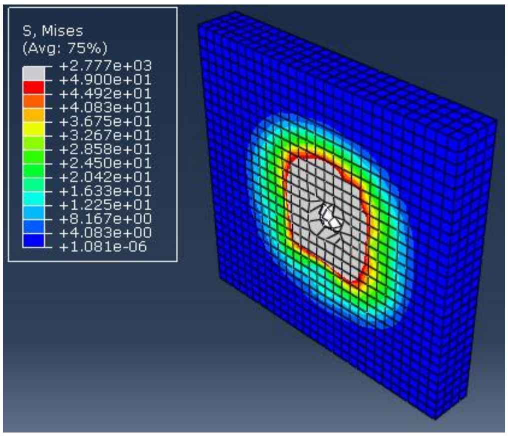

Fig 5(a): stress for RC slab

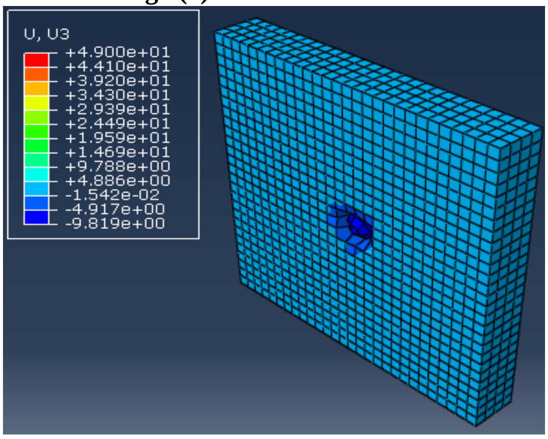

Fig 5(b): Displacement for RC slab

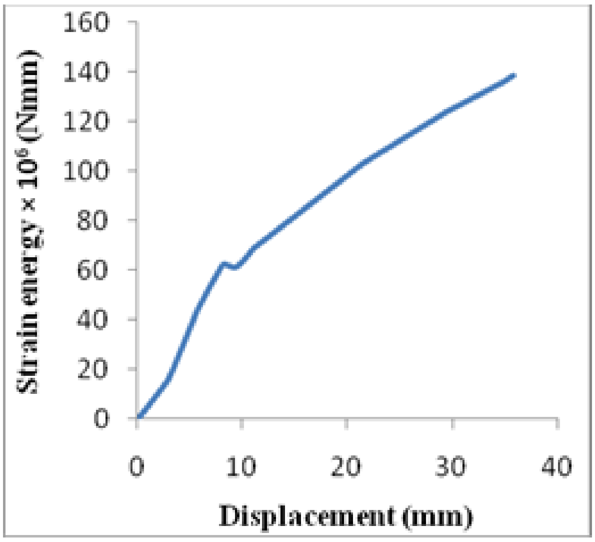

Fig 5(c): Displacement –Stain energygraph for RC slab

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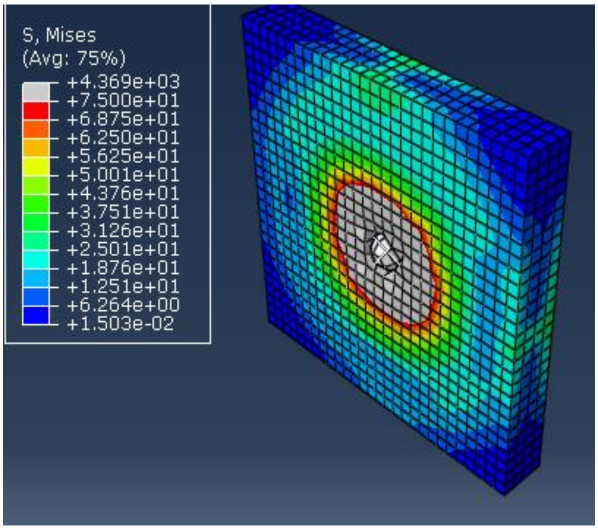

Fig 6(a): stress for GC1 slab

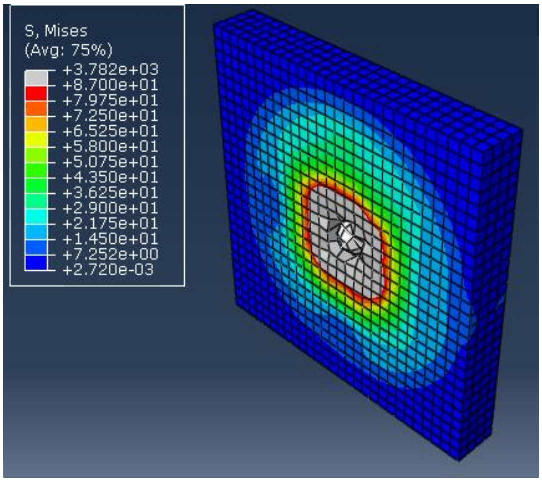

Fig 7(a): stress for GC2 slab

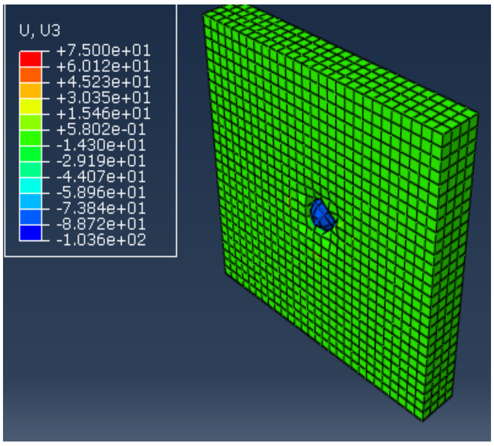

Fig 6(b): Displacement for GC1 slab

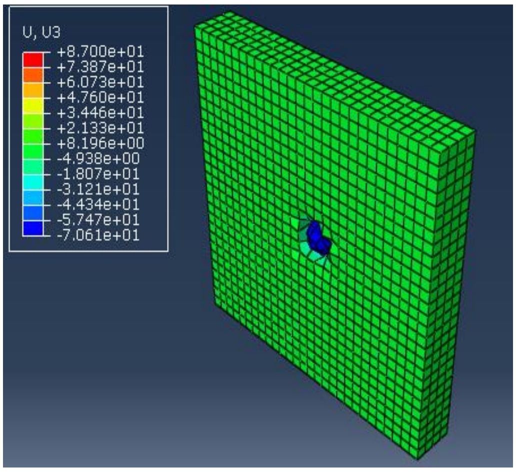

Fig 7(b): Displacement for GC2 slab

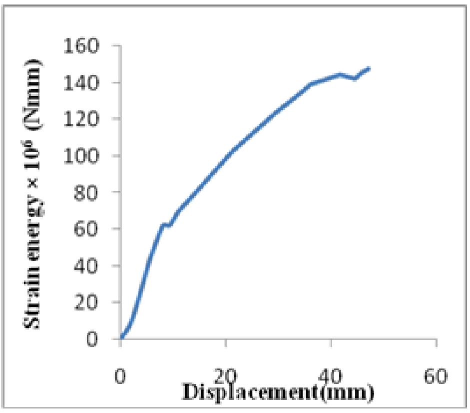

Fig 6(c): Displacement –Stain energygraph for GC1slab

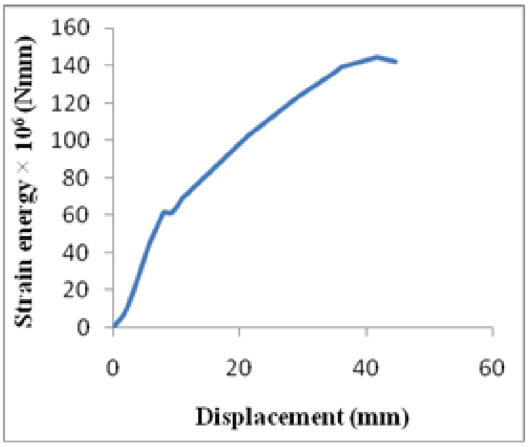

Fig 7(c): Displacement –Stain energygraph for GC2 slab

Table 6:Impact energy capacity

Specimen	Impact Energy Capacity (kJ)
RC	3167.39
GS1	8101.30
GS2	4634.34

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5. Results and Discussions

From the experimental and analytical results, the geogrid reinforced concrete slab specimen exhibited a higher rate of energy capacity when compared to that of conventional reinforced concrete slab specimens.

It was observed that the specimen GC2 exhibited a lower impact energy capacity than GC1 which had higher energy.

The number of blows required to cause the initial and final crack was increased when the geogrid layer is provided at the bottom of the slab. The initial crack was observed at 3^{rd}blow for RC and GC2 slab, while 4^{th}blow for GC1 slab. The crack pattern of each slab specimens is shown in fig 8.

The displacement versus strain energy graph for different specimens showed that while the deflection is increased, the strain energy also increased.

From the analytical results, it is observed that the stress values increased as the number of drops increased.

Comparing both analytical and experimental results a slight variation occurred in the impact energy of the reinforced concrete slabs.

Fig 8(a): Crack pattern for RC slab

Fig 8(b): Crack pattern for GC1 slab

Fig 8(C): Crack pattern for GC2 slab

V. CONCLUSIONS

- Addition of geogrid layers at the top and bottom of the slab, results in the increase of impact energy required to cause the first and final cracks.
- It is found that the impact resistance of slabs can be increased significantly by utilizing geogrid as an additional reinforcement.
- It is evident that geogrid reinforced concrete slabs tend to provide a higher rate of impact energy capacities as the layer of geogrid reinforcement gets increased.
- Though it comes at an economically affordable cost when compared to conventional steel reinforcement,this can beapplicable in places where the steel reinforced concrete structure is exposed to high moisture conditions.
- The easy availability, low cost, and resistance against corrosion makes it an efficient replacement for steel reinforcement.
- Using geogrid as an additional reinforcement results in lower rate of concrete spalling in reinforced concrete slabs.

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