Structural behaviors of Reinforced Concrete Beams with and without Geo-Grid Layers

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In this experimental work, eight beams are casted and tested under two-point load in order to study the influence of geo-grid layers on the performance of reinforced concrete beams. The tested beams have same dimensions (100 × 200) mm, clear span length (1000) mm, compressive strength ($f'c = 30$) MPa and shear reinforcement (θ4@100 mm C/C). The tested samples are divided into two groups according to existence of geo-grid layers. Each group consists of four samples and it is subdivided according to the main steel reinforcement ratio ranging from (0 to 0.0263). From tests results, it was noticed that, the geo-grids layers offers good improvements in the concrete performance and characteristics, like, load at first crack, load deflection respond, reduction of number and width of cracks and ultimate load as compared with the conventional beams.

Keywords: Geo-grids, Concrete performance, Honeycomb geo-grid meshes, load-deflection response, Structural behavior, first crack point, Ultimate load.

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1. Introduction

Geo-grids are presented in a variety of materials, strengths and sizes and they can be made of high tensile strength woven or plastics polyester yarns and are typically packaged at the factory in roll shape. It consists of two arrays of ribs crossing each other in opposite directions. First array is parallel to the machine direction, and the second array of ribs is perpendicular to the direction of machine and called cross-machine direction. Geo-grid can be divided into three groups as follows [1]:

1. Uniaxial geo-grid: It is extends only in one direction and the pressure is transmitted only along that axis.
2. Biaxial geo-grid: It is extends along two directions, so the pressure is equally distributed along both directions.
3. Triaxle geo-grid: It is also available with multi-directional properties, providing greater stiffness and stability than others, as shown in Fig. 1.

Many advantages of geo-grid that be used in many researches, geo-grid is defined as very light material used as shear and flexural reinforcement in concrete sections. Geo-grid has great resistance to rust that due to its raw compensates, thus it's more efficient than steel bars. Also it easy to transport, due to its lightweight, and its easiness to cut and used [2].

Now, the geo-grids are used as reinforcing material, especially in improvement of concrete components as internal layer in concrete requests. Using geo-grids as internal layer to decrease first cracking load, improve the stability of concrete elements, ductility and increase the maximum load. Many studies had been done. In 2013, Meski and Chehab investigated the flexural behaviour of geo-grid reinforced plain cement concrete beam subjected to monotonic loading [3].

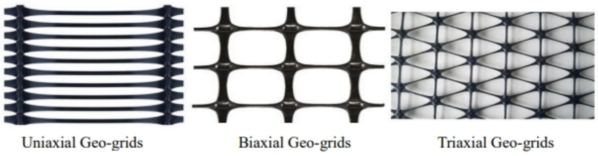

Fig. 1. Type of Geo-grids

Chidambaram and Pankaj studied the behavior of geo-grid confined the reinforced concrete beam consist of a steel fiber, it was found that the using of geo-grid were suitable for civil application and enhanced the ductility of tested beams [4, 5]. In 2014, El Meski and Chehab inspected the effect of geo-grids on the flexural strength of concrete beams; it was achieved that geo-grids can be provided the increase in load capacity and post cracking ductility for tested beams [6]. In 2015, Shobana and Yalamesh conducted experimental tests on concrete beams reinforced with uniaxial and biaxial geo-grids also; they concluded that the use of geo-grid increases ductility of member [7]. Kumar and Babu reported the behavior of concrete columns by using biaxial geo-grid [8].

In 2016, Al-Hedad et al. studied the mechanical properties and behaviors of Portland cement concrete and geo-grids and found that using of geo-grids reduced drying shrinkage of concrete to 20% in concrete prism with dimensions 7.5 cm x 7.5 cm x 28cm, and 15% in concrete slabs with dimensions 28 cm x 28 cm x 3 cm [9]. Itani et al. obtained that geo-grid layer provides significant enhancements to concrete overlay performance in the post cracking management in terms of strength, ductility, and mode of failure based on experimental and numerical modeling for concrete thin overlays with geo-grids [10]. In 2018, Tong et al. showed that the geo-grid layer improved the ductility of the post peak behavior of plain concrete and delay the collapse load, also, they showed that there was no slippage occurs between the geo-grids and the concrete [11], Al-Hedad and Hadi tested reinforced concrete slabs with and without geo-grid with dimensions (90 cm x 90 cm x 6 cm), it was found that geo-grids can improve the cracking resistance and flexural performance of concrete slab [12].

Reddy and Kumar show that the number of layers and strength of geo-grid play as an important role in enhancing load deflection response and flexural strength for tested samples, also, the test result showed that geo-grid can be used as an alternative material for steel in structural members [1]. Ramakrishnan studied the flexural strength of geo-grid beams. It was found that, the geo-grid layer can be used as an alternative material for steel in structural members [13]. In 2019, Tang et al. showed that the geo-grid layer carry's extra load after cracking occurrence and belated the failure load for slab [13].

Fig. 2. Geo-grid Mesh Type

Tharani et al. used Finite Element Analysis by using ABAQUS software to compare the experimental result of reinforced concrete slab with geo-grid layer. The outcomes presented that the addition of geo-grid layers improved the impact strength than conventional samples [14]. Ali tested 56 slabs divided into two groups with and without geo-grids; the experimental results showed that in the geo-grid increase the ultimate load [2]. In 2020, Park et al. showed that textile-reinforced mortar improves the flexural strength, stiffness strength for reinforced concrete beams and the textile prestressing prevents the damage in concrete beams [15].

2. Research Significance

The aim of this study is to make a comparison between reinforced concrete beams with and without geo-grid layers and show the influence of geo-grid layers on the performance of reinforced concrete beam.

3. Materials and Properties

3.1. Cement

Ordinary Portland cement (OPC) Type (I) was utilized in this research. Chemical and physical analyses were carried out for this cement and the test results of cement properties agree with ASTM C-150 standards [16].

3.2. Fine aggregates (Sand)

The maximum size of fine aggregate of 4.75 mm with (2.73) specific gravity had been used in this study. The test results of fine aggregate conformed to the ASTM C-136 standard [17].

3.3. Coarse Aggregate (Gravel)

A coarse aggregate of 12 mm maximum size was used. Crushed River Gravel was used in this study. The grading

Table 1. Mechanical characterizes of Honeycomb Geo-grid [19]

Property	Unit	Value
Width	m	2.5
Mesh Size	mm	(27 x 27)
Thickness	mm	5.2
Length	m	30-50
Weight length on unit area	g/m^2	660
Tensile Strength	kN/m	$\geqslant 20$
Ultimate Tensile Strength	kN/m	$\geqslant 40$

of this aggregate and the limits specified by ASTM C-136 standard [17] were achieved.

3.4. Water

Tap water was utilized for mixing the components and curing of the samples.

3.5. Steel Reinforcement

A deformed steel bar with nominal diameter θ 12 mm and θ 4mm were used as reinforcement and the results of their tests meet the requirements of BS 4449/1997 [18].

3.6. Geo-grid Mesh

Honeycomb geo-grid meshes are used in this study as shown in Fig. 2; and the mechanical properties of honeycomb geo-grid are displayed in Table 1 [19].

3.7. Mixing Normal Strength Concrete

Normal strength concrete (NSC) mixture containing of cement, fine sand and crushed aggregate was used to cast the samples. Table 2 gives mix proportions of NSC which are used in this study depending on previous research [20].

Table 2. Properties of Concrete Mix of NSC

Cement kg/m^3	Sand kg/m^3	Gravel kg/m^3	W/C	Target Strength ($f'c$)MPa
400	600	1200	0.45	30

4. Testing Procedure

4.1. Test Setup

The beams were tested under two point loads; the load was gradually increasing up to failure by utilizing a universal testing machine (MFL) with a 3000 kN-capability. Applied load was concerned on the top surface of the beam by using a rolled-steel shift with 50 mm diameter. Deflection of beams was measured using a 0.01 mm dial gauge sited below the midpoint of beam so as to read the central deflection at each load stage. The deflection readings had been taken until failure occurs. A typical test set up for testing machines and tested beam are shown in Fig. 3.

Fig. 3. Testing Machine

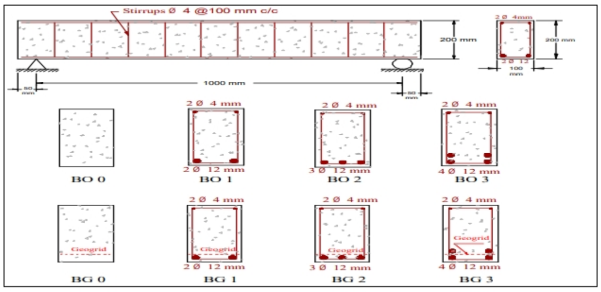

Fig. 4. Details of Tested Samples

4.2. Experimental setup

In the present experimental work, eight beams were constructed and had been tested under two-point load in order to investigate the influence of the inclusion of geo-grid layers on the structural behaviour of reinforced concrete beam. Tested beams have the same dimensions (100x200) mm, clear span length (1000) mm, compressive strength ($f'c$=30) MPa and shear reinforcement (θ 4 @100 mm C/C). Samples were divided into two main groups according to existence of geo-grid layers, with and without geo-grid, the geo-grid layer was provided as one layer lies in the tension region. Each group contains of four samples subdivided according to the steel reinforcement ratio (ρt) ranging from (0 to 0.0263). The details and descriptions of beams, geo-grid layers and samples after molding are shown in Fig. 4 and Fig. 5, while, Table 3 shows the samples identification and properties of beam tested.

5. Test Results and Discussions

Experimental results of beams tested are explained in Table 4. Several parametric study such as maximum load at first crack stage, cracks pattern load deflection responses, maximum central deflection maximum load, and modes of failure had been listed as follows:

Table 3. Specimens Identification and Properties of Tested Beams

Groups	Serial Codes	No. of steel bars	d (mm)	ρ_t	a/b
1 (Without Geo-grid)	BO0	-	-	-	-
	BO1	2θ12	182	0.0124	1.92
	BO2	3θ12	182	0.0186	1.92
	BO3	4θ12	172	0.0263	2.03
2 (With Geo-grid)	BG0	-	-	-	-
	BG1	2θ12	182	0.0124	1.92
	BG2	3θ12	182	0.0186	1.92
	BG3	4θ12	172	0.0263	2.03

Table 4. Test Results

Groups	Beams No.	Series Codes	Maximum Load (Pu), (kN)	Maximum Central def. Value (δ_u), (mm)	Load at First Crack (Pcr), (kN)
1 (Without Geo-grid)	1	BO0	10.0	0.90	4
	2	BO1	35.0	6.10	8.5
	3	BO2	50.0	5.05	10
	4	BO3	65.0	4.20	12.5
2 (With Geo-grid)	5	BG0	17.5	0.75	5
	6	BG1	50.0	4.40	11
	7	BG2	80.0	3.70	15
	8	BG3	90.0	3.35	17.5

Fig. 5. Geo-grid Layer, Details of Steel Reinforcement, and Samples after Molding

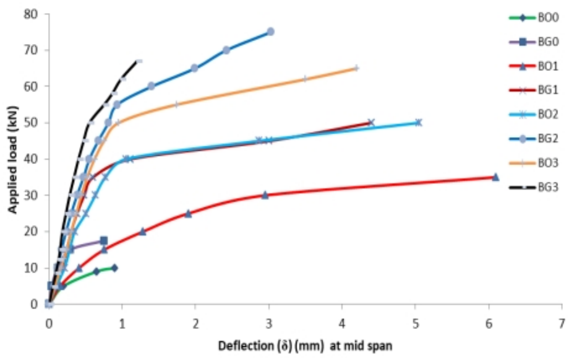

Fig. 6. Load Deflection Curves of Beams Tested

5.1. Load -Deflection Curves

From the test results, the load- deflection curves for tested beams with geo-grid layers are stiffer as compared with the conventional beam and the increasing percent in stiffness were increased with increasing in the steel reinforcement ratio that's due to inclusion of geo-grid as interior layer in concrete section that leads to enhance the properties of concrete such as, load- deflection response, acquired more efficiency to surround the particulars of concrete improved the strength of concrete, in addition to reduce the crushing of concrete beams tested for both groups at different values of flexural reinforcement are shown in Fig. 6.

5.2. Maximum Load Applied Values

The maximum load capacity for tested beams were increased to 75%, 42.6%, 60% and 34.46% with increasing in the steel reinforcement ratio as compared with the conventional beams without geo-grid layers, that due to the inclusion of geo-grid as interior layer and acted with reinforcement concrete as one unit, that leads to increase the strength of concrete section under applied load [2]. On the other hand, the geo-grid layers supported further load after cracks appeared, that led to increase the collapse capacity [10] also, the geo-grid layers carried additional tensile forces kept in tension zone of tested beams which led to increase the maximum load [11, 18, 21]. Maximum applied and percentage of increasing in the applied load for the

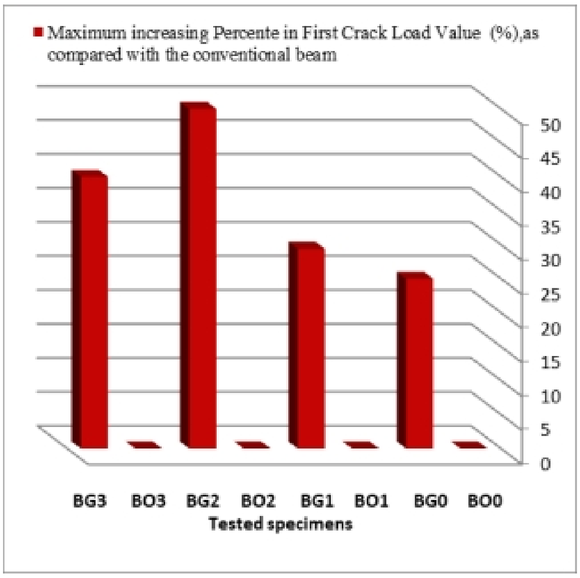

Fig. 7. Increasing Percent in Maximum load of Beams Tested

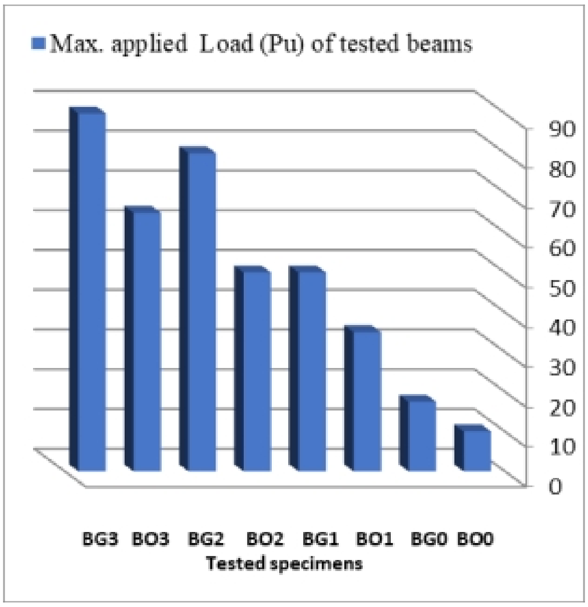

Fig. 8. Maximum Applied of Tested Beams

tested beams is listed in Table 5 in addition to Fig. 7 and Fig. 8.

5.3. Deflection Values

The maximum deflection values were decreased to 16.67%, 27.87%, 26.73% and 20.24% with increasing in the steel reinforcement ratio as compared with the conventional beams without geo-grid layers, as a result of inclusion of geo-grid layers as interior layer, that improved the resistance of impact load and acted with steel reinforcement as a one unit, that lead to enhance the section resistance for tested beam and reduce the deflection for tested beams [2]. The percentages of decreasing in the maximum deflection and maximum deflection value of the tested beams are listed in Table 6 and Fig. 9 and Fig. 10.

5.4. First Crack Load Values

First crack load were increased to 25%, 29.41%, 50% and 40% with increasing in the steel reinforcement ratio as compared with the conventional beams without geo-grid layers; as a result of inclusion of geo-grid layers as interior layer which acted with steel reinforcement as a one unit, and lead to enhance the section resistance for tested beam also to get rid of damage in concrete cover, as a result of swelling of steel bars during applied load [2]. On the other hand, the inclusion of geo-grid layers supported further load after first crack appeared, that's led to delay in the collapse capacity [10] also, the geo-grid layer carried an additional tensile forces kept in tension zone of reinforced concrete beams which lead to decrease the number and size of cracking and increase the first crack load as compared to other conventional beams [21]. The percentages of increasing in the first crack load value are listed in Table 7 in addition to Fig. 11 and Fig. 12.

5.5. Failure Patterns for Beams Tested

At first stage of applying load, fine vertical cracks appeared between the points loads of beam tested. With increasing load, a new flexural crack was witnessed in the mid span region and some of these cracks were increased with increasing in the applied loading [21]. Slenderness ratio of tested beams (a/d) can affect the mode of failure [22], the (a/d) ratio ranging between 1.92 and 2.03, were adopted in this research. Cracks in reference beams (with and without geo-grid) were saw in the middle region and then immediately brittle failure occurs by crushing of the concrete, on the other hand, the cracks in beams with steel reinforcement appeared in the bottom fiber between the two concentrated load, beams stayed stable when cracks happened and then continued toward the top of the beam with an angle about 45° toward the compression zone [23]. With increasing the applied load, the cracks will progressively produce a diagonal crack extended to loading point [24–27]. The experimental results show the inclusion of geo-grid layers can improve the concrete performance beginning from first cracking load until failure occur as compared with the conventional beams [10, 21]. Failure patterns of the tested beams are shown in Table 6 and Fig. 13.

Table 5. Maximum Load Capacity for Beams Tested

Beams No.	Series Codes	Maximum load capacity, (kN)	Percentage Increases in maximum applied load, (%)
1	BO0	10	0
2	BG0	17.5	75
3	BO1	35	0
4	BG1	50	42.86
5	BO2	50	0
6	BG2	80	60
7	BO3	65	0
8	BG3	90	38.46

Table 6. Maximum Deflection Values of Tested Beams

Beams No.	Series Codes	Deflection at middle span, (mm)	Percentage decreasing In Max. def., (%)
1	BO0	0.9	0
2	BG0	0.75	16.67
3	BO1	6.1	0
4	BG1	4.4	27.87
5	BO2	5.05	0
6	BG2	3.7	26.73
7	BO3	4.2	0
8	BG3	3.35	20.24

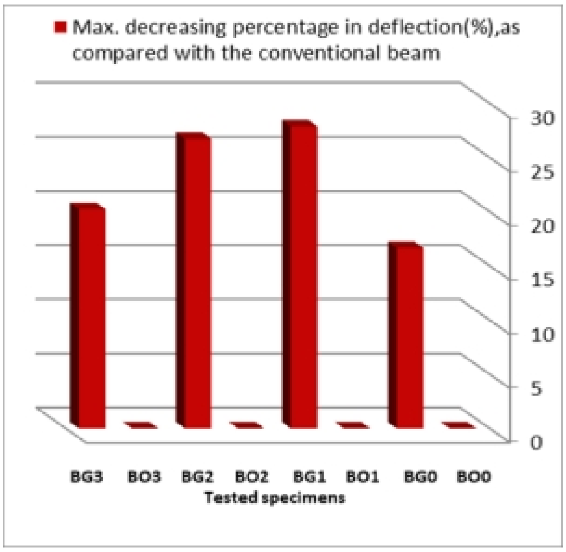

Fig. 9. Maximum Percentages of Decreasing in Maximum Deflection

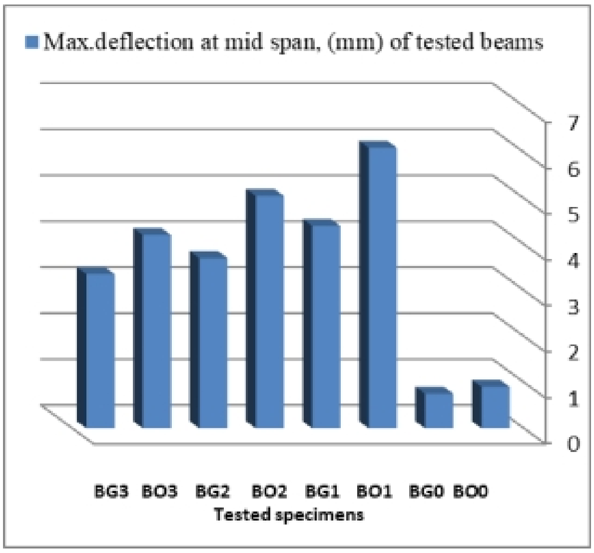

Fig. 10. Maximum Deflections value at mid span

6. Conclusions

The main conclusions obtained from the experimental results can be summarized as follows.

- Load deflection curves for beams with geo-grid layers are stiffer in comparison with the conventional beam without geo-grid layer and the percentage increasing in stiffens was increase with increasing in the steel reinforcement ratio.
- Maximum load capacity increased to 75%, 42.6%, 60% and 34.46% with increasing in the steel reinforcement ratio as compared with the conventional beams without geo-grid layers.
- Maximum deflection value decreased to 16.67%,

Table 7. First Crack Load Values and failure modes for Tested Beams

Beams No.	Series Codes	First Crack Load (kN)	Percentage Increases in First Crack Load (%)	Failure Mode
1	BO0	4	0	Brittle Failure
2	BG0	5	25	Brittle Failure
3	BO1	8.5	0	Diagonal Shear
4	BG1	11	29.41	Diagonal Shear
5	BO2	10	0	Diagonal Shear
6	BG2	15	50	Diagonal Shear
7	BO3	12.5	0	Diagonal Shear
8	BG3	17.5	40	Diagonal Shear

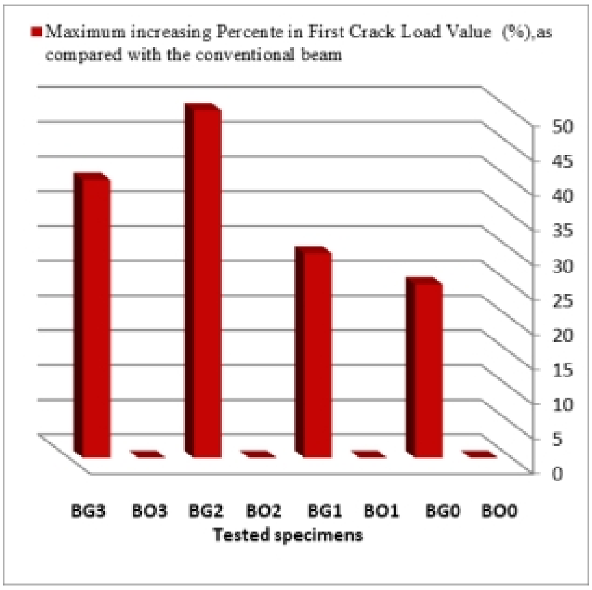

Fig. 11. Maximum increasing Percent in First Crack Load Value

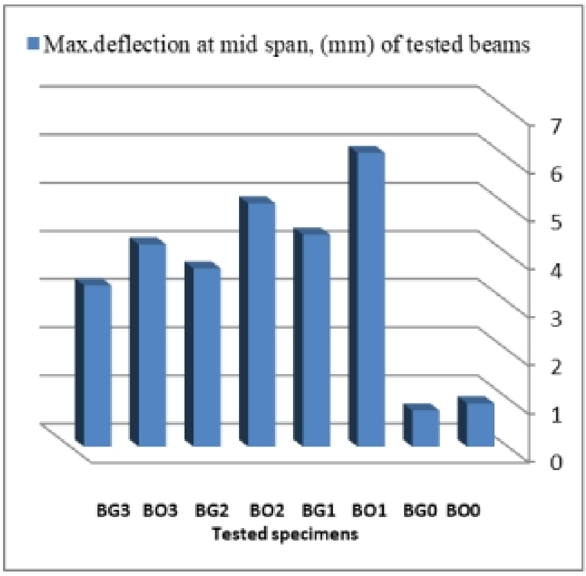

Fig. 12. First Crack Load Value for Tested Beams

27.87%, 26.73% and 20.24% as compared with the conventional beams without geo-grid layers.

- Load at first crack load increased to 25%, 29.41%, 50% and 40% as compared with the conventional beams without geo-grid layers.
- Geo-grid layers can be improved the concrete performance beginning from first cracking load until failure of tested beams as compared with the conventional beams without geo-grid layers.
- From above conclusions, the suggestion of using geogrid in retrofitting may be more effective than using in construction

7. Acknowledgements

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Fig. 13. Failure Patterns of Tested Beams

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