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Experimental and Analytical Investigation on Strengthening of Cutout in a Composite Slab

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Abstract: *This work focuses on the investigation of the behavior of a biaxial geogrid-stimulated composite slab with an opening close to the support. The usage of composite decking slabs in contemporary buildings is growing daily because of their cost-effectiveness in terms of strength, finance, and labor efficiency. Therefore, a cutout in these slabs causes a loss of strength. The mechanical behavior of composite floors, including the deck slab's stability, rigidity, and bearing capacity, is impacted by openings in the floor structures. Typically, openings are made for storm drain pipes, mechanical ducting, or a collection of tiny holes. This research investigates the effectiveness and proper orientation of strengthening the composite slab with geogrids to mitigate the impact of openings on structural performance.*

Key Word: *Composite Slab, Cutout, Geogrid, Flexural Behaviour.*

I.INTRODUCTION

Composite floor deck construction has become very popular because it combines structural efficiency with the speed of construction to offer an economic solution for a wide range of building types, including commercial, industrial, health, and residential building sectors. The composite deck slab refers to a structural slab system created by combining concrete with a cold-formed steel decking sheet, as illustrated in Figure 1. Besides, the steel deck serves as permanent formwork for supporting the concrete. The strength and performance of the composite slab are also influenced by various factors such as the profile geometry, thickness of steel sheeting, concrete density, the strength of steel and concrete, shear interactions in the form of dimples or indentation, span length, and the presence of openings in the composite slab.

Openings in floor decks are a common part of any building. These openings can range from small holes for pipes and conduits to large-size openings in composite floor decks, openings for mechanical ductwork, storm drain pipes, or a group of small holes. Openings in composite deck floor structures, affect the mechanical behavior of composite floors such as bearing capacity, rigidity, and stability of the deck slab. The use of geo- grids as reinforcing material with concrete setups a new dimension for employing geosynthetics in structural engineering. So many investigation examined the effect of geo-grid with or without steel reinforcement in reinforced concrete structural elements. Due to several advantages of geo-grids, they are used for structural repair and strengthening. A few studies have been performed on the behavior of structurally strengthened grids. In the present research work, an investigation has been carried out to study the effect of geo-grid on strengthening the cutout of composite deck slabs.

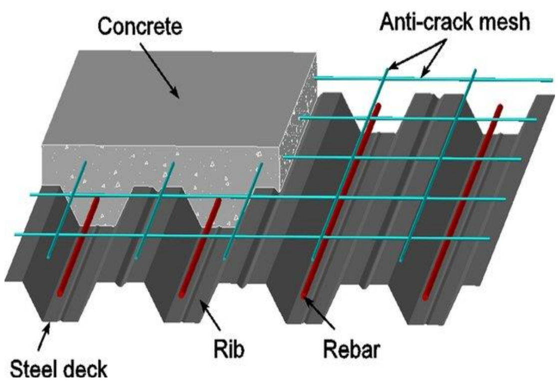

Fig 1. Composite Slab

II.MATERIAL PROPERITIES

2.1 Biaxial Geogrid

The biaxial geogrid is made up of polypropylene. Geogrid properties as obtained from the manufacturer are shown in Table 1.

Fig 2. Biaxial Geogrid

Table 1. Properties of Geogrid

Sl.No	Properties	Units	Values
1.	Ultimate Tensile Strength (MD)	kN/m	31.42
2.	Ultimate Tensile Strength (CD)		31.81
3.	Tensile Strength@2% (MD)		11.98
4.	Tensile Strength@2% (CD)		11.9
5.	Tensile Strength@5% (MD)		23.31
6.	Tensile Strength@5% (CD)		23.2
7.	Elongation @ Design Load (MD)	%	9.22
8.	Elongation @Design Load (CD)		8.16
9.	Carbon black content		5+
10.	Junction Efficiency		100
11.	Aperture Dimension (MD)	mm	38
12.	Aperture Dimension (CD)		38
13.	Rib Thickness (MD)		2.65
14.	Rib Thickness (CD)		2.16

2.2 Cold Formed Decking Sheet

A Cold formed steel decking sheet was used on composite slabs. It is having the length 1200 mm and width 500mm and thickness of the sheet is 0.8mm. The sheet had yield strength of 240MPa.

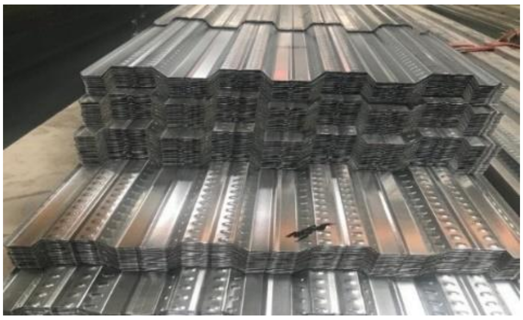

Fig 3. Decking Sheet

2.3 Steel

Thermo Mechanically Treated (TMT) High Yield Strength Deformed (HYSD) bars of characteristics tensile strength of 500 MPa is used for the reinforcement. In this work a reinforcement mesh of 6mm diameter bars are given in both direction at a spacing of 110mm center to center in order to reduce the thermal and shrinkage effects.

2.4 Concrete

All concrete slabs used the same concrete mixtures of M20, consisting of Portland Pozzolana Cement, fine aggregates, and coarse aggregates. The water/cement ratio of the mixtures is 0.48. The concrete mixture design has a 28-day compressive strength of 25.65MPa and a split tensile strength of 2.7 MPa, for all the concrete specimens. The nominal maximum size of the coarse aggregates is 12 mm, which is smaller than the opening apertures of the geogrids, and allows the coarse aggregates to pass through the apertures and avoid blocking the geogrid.

III. EXPIREMENTAL STUDY

The dimensions of the test specimens are 1200 mm length, 500mm wide and depth of 120mm. An opening is provided at a distance 195mm from the edge of slab in longer dimension and a distance of 170mm along the shorter span. The size of the opening is 160 x 160 mm. The profiled steel sheet consisted of embossments which act as a shear connector between the concrete and decking sheet. It helps to get a good shear bond between steel and concrete. The composite slab were casted and cured and also these were tested at the 28th day after casting. A total of 5 types of specimens were casted.

3.1 Design

A total of five types of specimen were studied in this experimental work. They are designed in accordance with the euro code (EN 1994.1.1.2004) and Indian code (IS 11384: 2022). The dimensions of the strengthening material were designed using SCI Publication P300. The specimen details and their detailing is given below.

Table 2 Specimen Details

Specimen	Description
S.1.	Composite slab without opening
S.2.	Composite slab with opening
S.3.	Composite slab with additional reinforcement as geogrid at 45°
S.4.	Composite slab with additional reinforcement as geogrid at 90°
S.5.	Composite slab with additional reinforcement as geogrid at 45°,90°

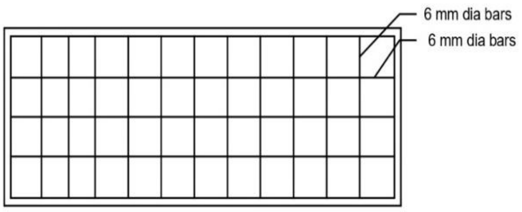

Fig 4. Detailing For Slab S1

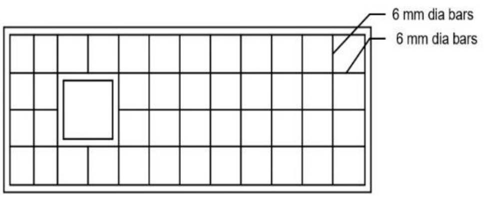

Fig 5. Detailing for slab S2

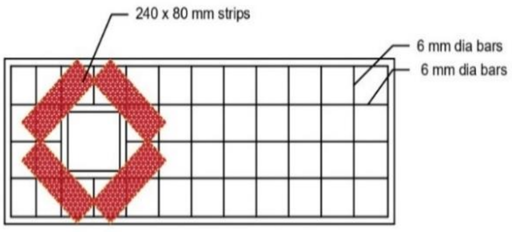

Fig 6. Detailing for Slab S3

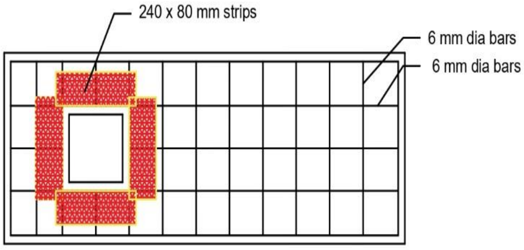

Fig 7. Detailing for Slab S4

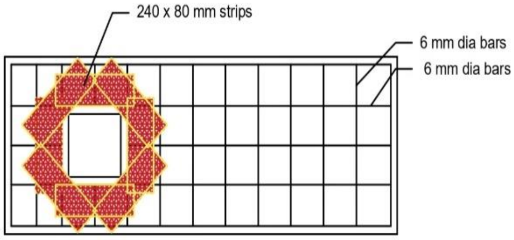

Fig 8. Detailing for Slab S5

3.2 Casting and Curing

- The casting process for slabs involves the construction of the slab using formwork and pouring concrete into the formwork to create the desired shape
- The required quantities of cement, coarse aggregate, fine aggregate was manually mixed uniformly and the required quantities of water are added to the mix
- The concrete was placed in the formwork and the required compactions were provided with the tamping rod
- The curing was done with the help of gunny bags

3.3 Testing

The slabs were subjected to testing in a loading frame with a capacity of 100 tones. The slabs were set in a simply supported configuration, and a single point load was applied at the center. LVDT was placed at the center of the panel and at the support. The load was applied using a load cell, and a computerized data acquisition system was used to record the load and deflection values. After completing these initial preparations, the load was applied at the center of the panel, and cracks were observed on the panels.

Fig 9. Testing

IV. EXPIREMENTAL RESULTS

The dimensions of the test specimens are 1200 mm length, 500mm wide

Table 3. Experimental Results

Specimen	Ultimate Load (kN)	Deflection (mm)
S.1.	56.3	31.3
S.2.	34	40.2
S.3.	46.2	36.98
S.4.	43.8	38.9
S.5.	48.6	39.05

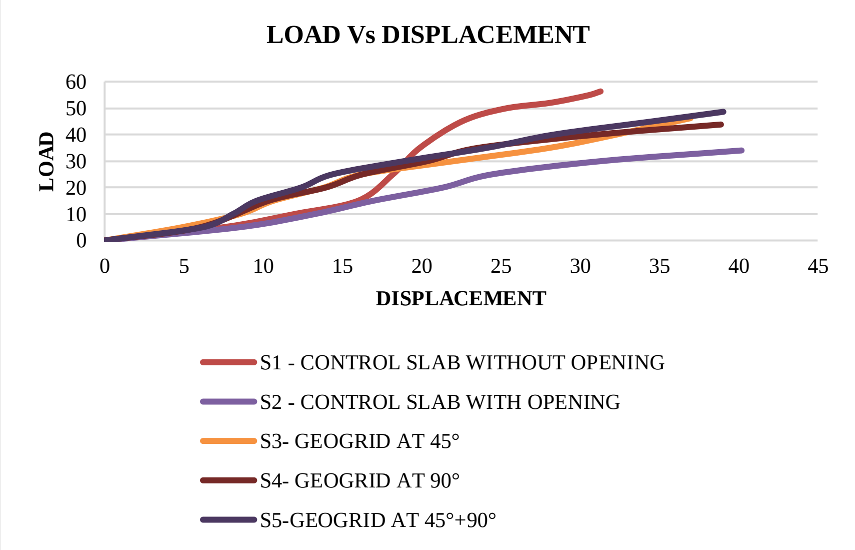

Fig 10. Load vs Displacement Plot

The general observations are as follows:
- Initial cracks were found in the flexure zone
- The flexural cracks continued to grow to the top surface of the slab upon increase in loading
- The flexural cracks originated exactly below the point of application of loads at two locations
- In case of slabs with opening i.e. S2, the crack propagation started from the opening and later the flexural cracks were also observed
- The cracks were not formed near the opening for the strengthened slabs
- At failure stage, the width of the already formed cracks increased without further development of additional cracks near the mid span
- The mode of failure was flexure and later upon reaching the ultimate value it was accompanied with a debonding

Fig 11. Crack Pattern in S1 Slab

Fig 12. Crack Near Opening

Fig 13. Crack pattern for S5 Slab

Fig 14. Flexural Cracks

Table 4. Comparison

Specimen	Ultimate load	Comparison with S1	Comparison with S2
		$((S_x/S_1)-1)$ x100	$((S_x/S_2)-1)$ x100
S1	56.3	-	-
S2	34	39.6%	-
S3	46.2	17.9%	35.8%
S4	43.8	22.2%	28.8%
S5	48.6	13.6 %	42.9%

V.ANALTICAL STUDY

The analytical study was conducted using simulation software called ANSYS. In the validation phase, a specimen with the same specifications as in the experimental study was generated, and its results were compared to those obtained from the experimental study to ensure the accuracy.

Validation can be defined as the process of establishing or checking the validity of something, or it is a method of demonstrating a procedure, process, or activity carried out in testing which maintains the covetable level of compliance. Here the composite slabs are validated and the slab is modelled as same as in the experimental study. Support conditions are provided as simply supported and loading condition are provided in terms of displacement. The meshing size used are 10mm for steel and 25mm for decking sheet and concrete.

The load corresponding to the maximum displacement from the experiment were plotted using the software. The components of the slab were modelled using space claim option in the ANSYS software. The concrete were modelled as a solid element, decking sheet were modelled as a shell element and the rebar were modelled as bar element.

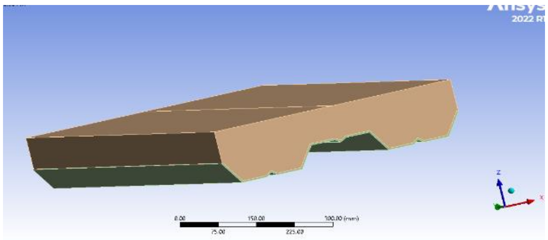

Fig 15. Model of S1 Slab

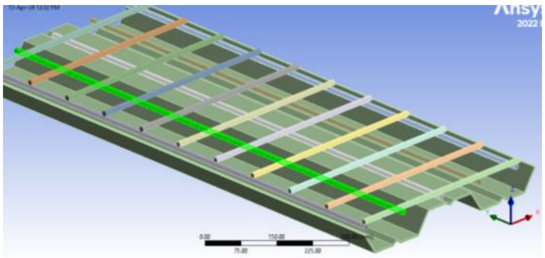

Fig 16. Sheet and Rebar

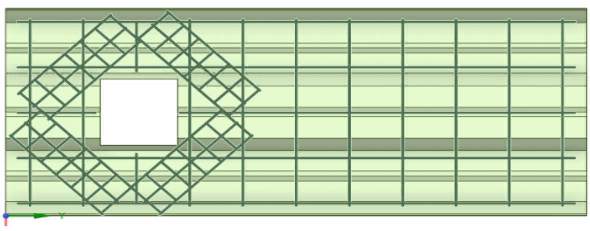

Fig 17. FEM model for S3 Slab

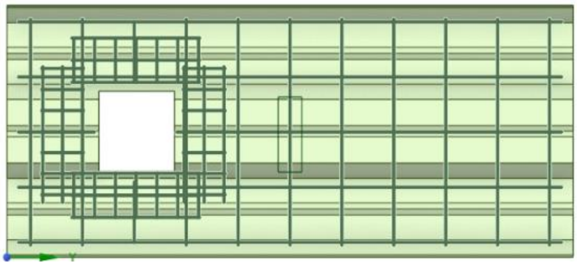

Fig 18. FEM Model for S4 Slab

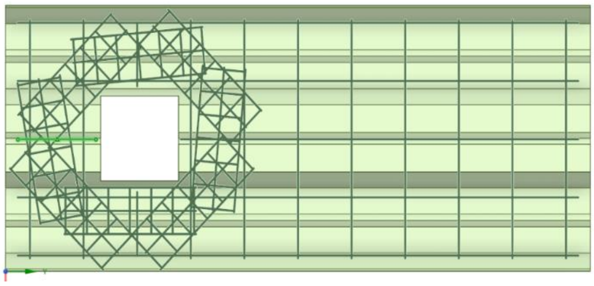

Fig 18. FEM Model for S5 Slab

VI.ANALYTICAL RESULTS

The following results were obtained from finite element analysis:

- For the S1 slab, the load corresponding to maximum displacement obtained from experimental is 63.446 kN
- For the S2 slab, the load corresponding to maximum displacement obtained from experimental is 38.39 kN
- For the S3 slab, the load corresponding to maximum displacement obtained from experimental is 51.1 kN
- For the S4 slab, the load corresponding to maximum displacement obtained from experimental is 47.76 kN
- For the S5 slab, the load corresponding to maximum displacement obtained from experimental is 52.86 kN.

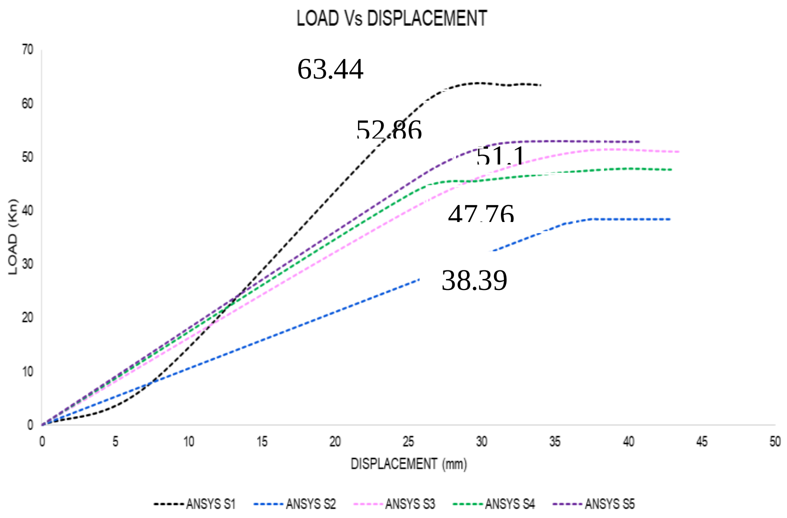

Fig 19. Analytical Plot

Table 5. Analytical Results

Sl.No	Slab Number	Ultimate Strength kN	Maximum Displacement *mm*
1.	S.1.	63.44	31.3
2.	S.2.	38.39	40.2
3.	S.3.	51.1	36.98
4.	S.4.	47.76	38.9
5.	S.5.	52.86	39.05

VII.CONCLUSIONS

The study demonstrates the potential of utilizing of biaxial geogrid for strengthening of cutout in a composite slab. The findings provide valuable insights into the strength enhancement achieved through these techniques, offering guidance for engineers and researchers in the field of structural strengthening and rehabilitation.

- Through the experimental investigation, it was found that the load-carrying capacity was reduced due to the presence of openings compared to a non-opening slab
- Due to the cutout, the composite slab had a strength loss of 39.6%
- The loss strength thus produced was compensated using geogrid at a different orientation
- The openings are the prime cause of crack propagation due to the more stress concentration at the corners and that too in the high shear region
- Out of the three combinations, geogrid at 45°+90° proved to have a better performance than the other two orientations with an increase of 42.9% strength
- This was due to the presence of more amount of strengthening material and the orientation covered the perimeter as well as the corners which enhanced a better load transfer to the support
- While comparing with the orientation of 90° and 45°, 45° had a better performance due to its positioning in the corners with an increase of 35.8% strength
- Geogrid at 45° orientation was able to cover the corners and the perimeter of the opening better than at 90° orientation since it was not able to cover the corners properly

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