PARAMETRIC STUDIES ON WAFFLE SLABS USING FINITE ELEMENT ANALYSIS

Pavithra B\(^1\), P. Ramadoss\(^2\)
\(^1\)Department of Civil Engineering, Pondicherry Engineering College, Puducherry-605014.
\(^2\)Department of Civil Engineering, Pondicherry Engineering College, Puducherry-605014.

Email: \(^1\)pavithrabaskaran.u@gmail.com, \(^2\)dosspr@pec.edu

ABSTRACT

In this paper, the finite element analysis of waffle slab or two-way ribbed slab models were carried out using ANSYS 17.0 Software. Large opening in the floor slabs may be provided for stairs, elevators, and air conditioning ducts. And also smaller size openings is needed to accommodate plumbing, floors and roof drains etc., providing opening in the slab weakens the slab strength. So, waffle slab with opening, providing stiffened ribs around the opening (stiffened ribs are the ribs which has the same features of main ribs in the waffle slab) and GFRP (Glass fibre reinforced polymer) sheeting around the opening are to be analysed. The effect of introducing opening and boundary conditions were studied. The structural behaviour of models was investigated. The element such as SOLID 65, LINK 180, and SOLID 185 are used to model concrete, reinforcement and loading element, GFRP sheeting of the waffle slabs in ANSYS 17.0. Verification of results is done along with the experimental data obtained from the previous studies. The results reveal that the parametric studies significantly influencing the load-deflection response of the waffle slab.

Key words: ANSYS 17.0, Waffle slab, Openings, GFRP, Stiffened ribs, Load-deflection response.

INTRODUCTION

From the earlier stage of existence of human life, man started to build. Even though the purposes varied, man has tried to employ a few major important concepts while constructing any new building. In conventional two way flat slab constructions, the need of longer spans and the necessity for heavier loads demands increased slab thickness in order to limit deflections. The dead load of the slab becomes the main portion of the design load because of increase in slab thickness. As the solution to this, concrete below the neutral axis is eliminated, this allows an economic increase on the total thickness of the slab with the creation of voids in rhythmic arrangement or providing ribs. This tends to reduction on the structure self-weight and a more efficient use of materials, steel and concrete.

The slab system is typically denoted as waffle slab construction.

A. WAFFLE SLAB

Two way spanning of ribs (beams) spaced at regular interval of slab is also known as waffle slab. Waffle slabs can be used in halls, industrial buildings and parking floors. Classifications of waffle slabs based on their rib arrangement are

- Orthogonal type
- Non-orthogonal type

1) Orthogonal Type: Waffle slab consists of equally spaced ribs are right angle to each other are known as ortho-grid or orthogonal.

2) Non-Orthogonal Type: Waffle slab consists of diagonally spaced ribs in both
direction are known as dia-grid or non-orthogonal.

B. **Stiffened Ribs**

Stiffened ribs are provided around the openings to restore the flexural capacity of waffle slabs. [3] Regarding the effectiveness of stiffening ribs in strengthening waffle slab with opening, it can be seen that stiffening ribs with same dimensions of waffle slab main ribs can be successfully used for increasing the ultimate carrying capacity and strength.

In this present work, the strengthening methods of waffle slab with opening are investigated. As per previous studies, Orthogonal spacing of ribs has less degree of severity. [7] Hence orthogonal spacing is adopted here. The slab with opening is strengthened by providing stiffened ribs around opening. The main aim is to study the load-deflection response of the slabs with openings. The modelling is done using finite element software. The non-linear static analyses were done to investigate the structural behaviour of waffle slab using ANSYS 17.0.

I. **DESCRIPTION OF SLAB MODEL**

The dimension of the slab and the material properties are taken from the journal. The overall dimension of the waffle slab is 1540x1540mm and orthogonally spaced ribs of thickness 50mm and 75mm depth. The ribs are placed at 300mm centre to centre. The slab portion of thickness 20mm with 0.7mm diameter mesh of size 25mm. The reinforcement of the ribs is 8mm diameter rebar at clear cover of 8mm. The slab is simply supported from 20mm at all the four edges.

II. **NUMERICAL STUDY**

In this paper the parametric study was performed using finite element software ANSYS 17.0. The validation is made with the previous available experimental results. SOLID 65, LINK 180 and SOLID 185 are the elements used to model the concrete, reinforcement and loading element, GFRP sheeting.

SOLID 65 element has eight nodes with three degrees of freedom at each node translations in
the nodal x, y and z directions used to model the concrete. This element is used to model solids with or without reinforcement. The solid is capable of cracking in tension and crushing capabilities. The most important aspect of this element is the treatment of non-linear material properties.

LINK 180 element or 3D spar element was used to model steel reinforcement. It has two noded with three degrees of freedom translations in the nodal x, y and z directions. This element is capable of plastic deformation. The element is used to model trusses, sagging cables, links, springs etc., Plasticity, creep, rotation, large deflection and large strain capabilities are included.

SOLID 185 element is used to model the loading elements and for GFRP sheeting. The element is defined by eight nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions. The element has plasticity, stress stiffening, large deflection, and large strain capabilities. The waffle slab models created using the above elements are shown in the following figures.
Fig. 6 Reinforcement provided in ANSYS

Fig. 7 Loading & Boundary conditions

Fig. 8 Square Opening (300mm x 300mm)

Fig. 9 Stiffened ribs around opening

Fig. 10 Displacement of waffle slab
TABLE-1
MATERIAL PROPERTIES

<table>
<thead>
<tr>
<th>Material</th>
<th>Properties</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete</td>
<td>Young’s modulus</td>
<td>25600N/mm²</td>
</tr>
<tr>
<td></td>
<td>Poisson ratio</td>
<td>0.2</td>
</tr>
<tr>
<td>Steel</td>
<td>Young’s modulus</td>
<td>200000N/mm²</td>
</tr>
<tr>
<td></td>
<td>Poisson ratio</td>
<td>0.3</td>
</tr>
<tr>
<td>GFRP</td>
<td>Young’s modulus</td>
<td>7200000N/mm²</td>
</tr>
<tr>
<td></td>
<td>Tensile strength</td>
<td>460 N/mm²</td>
</tr>
<tr>
<td></td>
<td>Density</td>
<td>2530Kg/m³</td>
</tr>
</tbody>
</table>

TABLE-2
COMPARISON OF EXPERIMENTAL & ANALYTICAL RESULTS

<table>
<thead>
<tr>
<th>Sl.No</th>
<th>Validation</th>
<th>Ultimate Load (KN)</th>
<th>Ultimate Deflection (mm)</th>
<th>Percentage Error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Experimental Value</td>
<td>45</td>
<td>10.2</td>
<td>12%</td>
</tr>
<tr>
<td>2</td>
<td>Analytical Value</td>
<td>49</td>
<td>9.01</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 12 Load Deflection curve comparison of experimental and analytical result

Fig. 13 Load Deflection Curve comparison

Fig. 14 Load Carrying Capacity

III. CONCLUSION
This paper concludes that the four models of waffle slabs are analysed using ANSYS 17.0. The results of three models (waffle slab without...
opening, with opening, stiffened ribs around opening, GFRP sheets around the opening) were compared. Providing opening in the slab will reduces the strength of the slab. The load carrying capacity is achieved by the slab with stiffened ribs around the openings.

- The validation of waffle slab model is done with the available previous experimental result [13]. The percentage of variation is 12%.
- The slab with stiffened ribs attains higher load carrying compared to the other waffle slab models.
- On changing the boundary conditions, the slab which is simply supported will have higher deflection than the slab fixed. The percentage difference is 35%.
- While providing GFRP sheets around opening the value of deflection is reduced by 31% and the load carrying capacity is increased 62% while compared to the waffle slab with opening.

So, by providing stiffened ribs and GFRP sheets around the opening can reduce the deflection value of the waffle slab with opening.

The maximum analytical deflection values obtained using ANSYS software is less than the experimental deflection values because the stiffness between the elements in the ANSYS library is more. The analytical values show good agreement with the experimental results.

**ACKNOWLEDGEMENT**

I take this opportunity to express my sincere thanks to Dr. P. Ramadoss, Professor, Department of Civil Engineering for his guidance, co-operation and encouragement.

**REFERENCES**


