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# Effect of Spacing of Grid Beams and Opening Size in a Waffle Slab with Central Opening

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**Abstract**—Whenever large spaces within a building need to be covered without hindrance and supports, architects often deploy waffle slabs to construct floors and ceilings. An assembly of intersecting beams placed at regular interval and interconnected to a slab of nominal thickness is known as Grid slab or Waffle slab, is a good choice for assembly halls, auditoriums, theatre halls. The Grid structure is monolithic in nature, stiffer and it can hold greater amount of loads compared to traditional concrete slab. Sometimes openings have to be provided in the floor slabs for stairs, elevators, and air conditioning ducts. This paper proposes a new kind of composite waffle slab that consists of orthogonal steel girders and flat RC slab. The steel beams help decrease the cracking in concrete. Composite slab structure has a good load-bearing capacity because it makes full use of the compressive resistance of concrete slab and the tensile resistance of steel. Since less concrete is used, slab is of less weight than traditional RC composite slabs. In this study a non – linear static analysis is conducted to investigate the effect of spacing of grid beams in the waffle slab with central opening and the effect of opening size in the waffle slab, using FEM software ANSYS 2015.

**Key words**: ANSYS 2015, composite waffle slab, FEM, grid beams, opening, steel girders, spacing

## INTRODUCTION

Waffle slab is a very popular structural configuration often deployed in the construction of hotel porticos, airport terminal buildings, large banquet hall, convention centres and car parks. Void space formed in the underside of waffle slabs are utilized for architectural lighting. This type of slab has more structural stability without using a lot of additional material. This makes a waffle slab perfect for large flat areas like foundations or floors. Waffle foundations are resistant to cracking and sagging and can hold a much greater amount of weight than traditional concrete slabs. In almost all constructions slab system includes openings for multitude purposes like stairs, air conditioning ducts and elevators. And also the opening with smaller dimensions is needed to accommodate heating, plumbing, and ventilating risers, floor and roof drains, and access hatches. The behaviour of waffle slabs are modified by the presence of these openings. Introducing openings will reduce the strength of waffle slabs.[7]

A waffle slab is usually regarded as a two-way system to cover square areas in buildings, which transfers loads in two mutually perpendicular directions. It takes advantage of two-way load-bearing capacity, and the engineering demand stays high. Traditional waffle slab uses RC beams as the slab ribs. In the composite waffle slab proposed in this paper, the RC ribs are replaced by steel girders that are connected to the flat slab by shear studs. The design of composite slabs can take advantage of the compressive strength of concrete slab and the tensile strength of steel girders. A good composite action can be obtained by preventing slip between the RC slab and steel girders using proper studs.[8]

Waffle slabs, also known as two-way ribbed flat slabs, are being used increasingly in modern construction to reduce dead weight and ensure efficient lateral distribution of loads. The most common types have large square voids or recesses between the ribs. In addition to the economic and architectural benefits, they are best suited for flat-plate structures with large spans as they exhibit higher stiffness and smaller deflections. Information on the strength and behavior of reinforced concrete waffle slabs is rather limited, but there have been a few theoretical and experimental investigations of waffle plates and slabs mostly in the elastic range. [8]

In this thesis a steel concrete waffle slab with central opening is selected, the deformation and load distribution of the specimens with different steel beam spacing are obtained and analyzed in detail. Steel concrete waffle slab with different central opening size is also selected and deformation and load distribution of the specimens were obtained.

## OBJECTIVES OF THE WORK

In this thesis a steel concrete waffle slab with central opening is selected, the deformation and load distribution of the specimens with different steel beam spacing in rectangular and diagonal waffle slabs are obtained and analyzed in detail. Steel concrete waffle slab with different central opening size is also selected and deformation and load distribution of the specimens were obtained.

### DESCRIPTION OF WAFFLE SLAB MODEL

Based on the structure of RC waffle slab, this paper presents a new kind of composite waffle slab that consists of orthogonal steel grillages and flat RC slab. The shear studs are used to connect the RC slab and steel grillages, as shown in Fig. 4.1 Composite slab structure has a good load-bearing capacity because it makes full use of the compressive resistance of concrete slab and the tensile resistance of steel. The steel beams help decrease the cracking of concrete that occurs when the composite slab is subjected to positive bending moment. The method of using composite waffle slab reduces framework and speeds up the construction by first installing prefabricated RC slabs on the steel grillages and then pouring. [8]

Cast-in-place concrete to connect the RC slabs and the steel grillages. The design also gives the slab less weight than traditional RC composite slabs because less concrete is used. Therefore, it has a broad prospect of applications in China, where many large-span buildings and stadiums are constructed. [8]

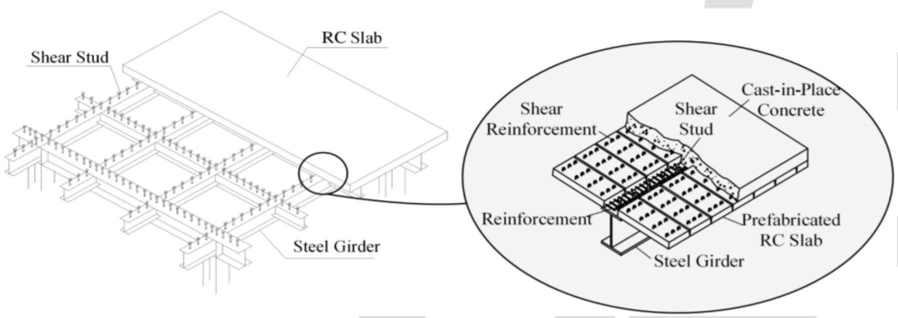


Fig. 1 Isometric view of two-way steel-concrete composite slab [8]

Composite waffle with thickness of RC slab (50 mm), type of steel section (200 mm in height), reinforcing bars (6 mm diameter), and dimension of the studs (10 mm diameter, 40 mm height, 50 mm transverse spacing, and 80 mm longitudinal spacing) were applied for both specimens. Different number of grillage beams was adopted for the specimens was divided into 3 × 3 regions, was to investigate the influence of beam spacing on bearing capacity, deformation, and load distribution.[8]

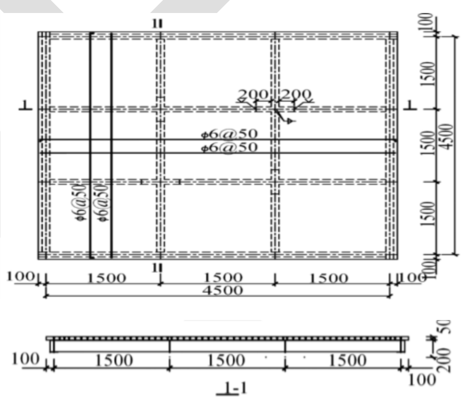

Fig. 2 Overall view of specimen (dimensions in millimeters) [8]

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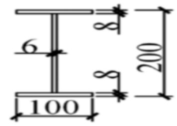


Fig.3 Steel beam section [8]

Table 1 Main Properties of Steel and Reinforcement

| Material | Concrete | Flexural Reinforcement Bars | Web | Flange |
|---|---|---|---|---|
| Young's modulus (MPa) | 30000 | 200000 | 200000 | 200000 |
| Tangent modulus (MPa) | | 2060 | 2060 | 2060 |
| Poisson's ratio | 0.17 | 0.3 | 0.3 | 0.3 |
| Characteristic compressive strength, fck (N/mm^2) | 33.8 | | | |
| Yield strength, fy (MPa) | | 369 | 337 | 431 |
| Ultimate strength, fu (MPa) | | 479 | 469 | 558 |
| Diameter (mm) | | 6 | 6 | 8 |

Fig. 4 Material properties: (a) constitutive curve of concrete; (b) tensile stress–crack width curve; (c) constitutive curve of steel

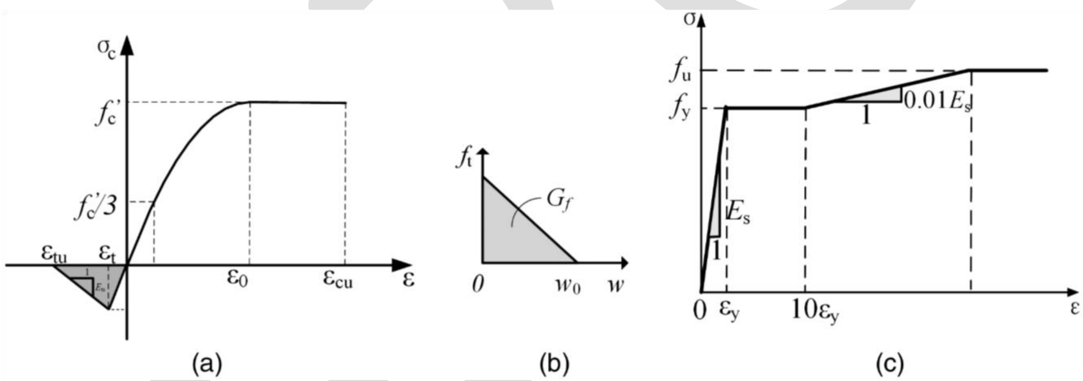


Table 2 Dimensions of rectangular waffle slabs with beam different spacing

| Slab name | Dimensions of slab (mm) | Grid beam spacing | | opening size (mm) |
|---|---|---|---|---|
| | | x (mm) | y (mm) | |
| S1 | 4700 x 4700 | 1500 | 1500 | 1000 x 1000 |
| S2 | 5000 x 4700 | 1600 | 1500 | |
| S3 | 5300 x 4700 | 1700 | 1500 | |
| S4 | 5600 x 4700 | 1800 | 1500 | |
| S5 | 5900 x 4700 | 1900 | 1500 | |
| S6 | 6200 x 4700 | 2000 | 1500 | |

Table 3. Dimensions of Rectangular Waffle Slabs with Different Opening Size

| Slab name | Dimensions of slab (mm) | Grid beam spacing | | opening size (mm) |
|---|---|---|---|---|
| | | x (mm) | y (mm) | |
| B1 | 4700 x 4700 | 1500 | 1500 | 1000 x 1000 |
| B2 | | | | 1100 x 1100 |
| B3 | | | | 1200 x 1200 |
| B4 | | | | 1300 x 1300 |
| B5 | | | | 1400 x 1400 |
| B6 | | | | 1500 x 1500 |

## BOUNDARY CONDITIONS

Vertical displacements of the bottom of steel girder ends were constrained in the z-direction. In-plane rotation was prevented by constraining the displacements of the bottom of steel girder ends in the x- and y-directions.

## LOADING

Monotonic concentrated loads were applied synchronously at the crossing point of perpendicular steel girders. Multiple point constraints to the loading points were used to achieve the same load value to the different loading points.

## MATERIAL MODELING

### Concrete

A Solid65 element was used to model the concrete. This element has eight nodes with three degrees of freedom at each node translations in the nodal x, y, and z directions. Solid65 is used for the 3-D modeling of solids with or without reinforcing bars (rebar). The solid is capable of cracking in tension and crushing in compression. The concrete element is similar to a 3-D structural solid but with the addition of special cracking and crushing capabilities. The most important aspect of this element is the treatment of nonlinear material properties. The concrete is capable of cracking (in three orthogonal directions), crushing, plastic deformation, and creep. The rebar are capable of tension and compression, but not shear. They are also capable of plastic deformation and creep. The solid capability of the element may be used to model the concrete while the rebar capability is available for modeling reinforcement behavior.

### Reinforcement

A Link180 element was used to model steel reinforcement. This element is a 3D spar element and it has two nodes with three degrees of freedom translations in the nodal x, y, and z directions. This element is capable of plastic deformation. Link 180 useful for variety of engineering applications. The element can be used to model trusses, sagging cables, links, springs, and so on. The element is a uniaxial tension or compression element. Tension-only (cable) and compression-only (gap) options are supported. As in a pin-jointed structure, no bending of the element is considered. Plasticity, creep, rotation, large deflection, and large strain capabilities are included. The element is capability of plastic deformation. LINK180 includes stress-stiffness terms in any analysis that includes large-deflection effects. Elasticity, isotropic hardening plasticity, kinematic hardening plasticity, Hill anisotropic plasticity, and creep are supported. To simulate the tension or compression only options, a nonlinear iterative solution approach is necessary, therefore, large-deflection effects must be activated prior to the solution phase of the analysis.

In this study modelling is done by using symmetrical boundary conditions at the two continues edges of waffle slab.

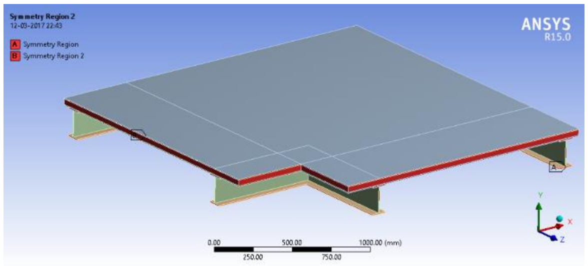


Fig. 5 Symmetry in slab S1

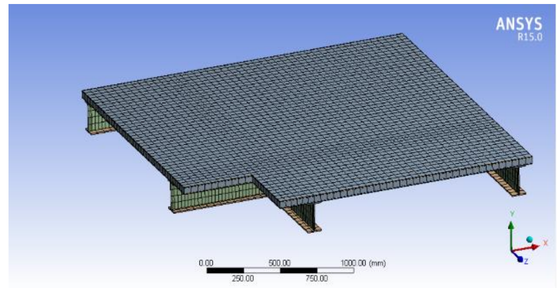


Fig. 6 Meshed model of slab S1

### Meshing

The slabs were meshed using mapped hex meshing. The meshing size is set so that the nodes of meshed concrete can be overlapped with nodes of reinforcement.

## RESULT AND DISCUSSION

Here the ultimate load carrying capacity, displacement and stress of waffle slab models with different grid spacing and opening size are compared.

### Study 1

Jianguo Nie et al. studied the behavior of composite waffle slab of size 4700 x 4700 with grid beam size 1500 x 1500 mm without opening, get the ultimate load carrying capacity as 988.4 kN and corresponding deflection as 120.16mm.

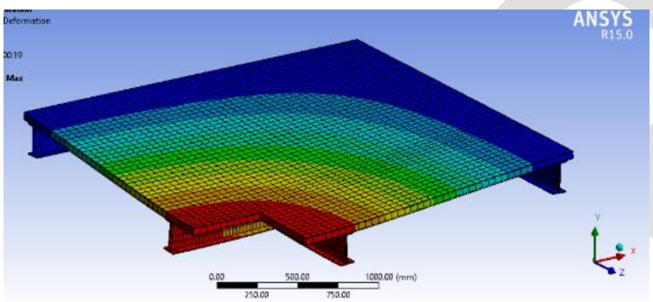


Fig. 7 Deformation in slab S2

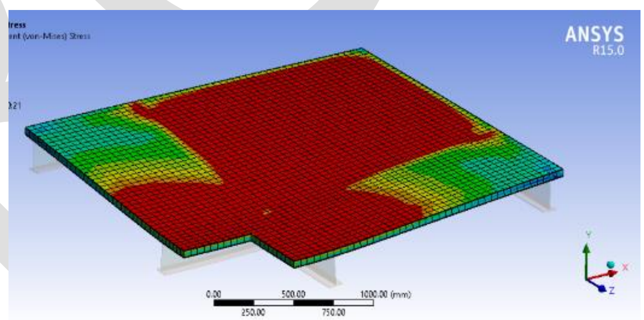


Fig. 8 Stress in S2

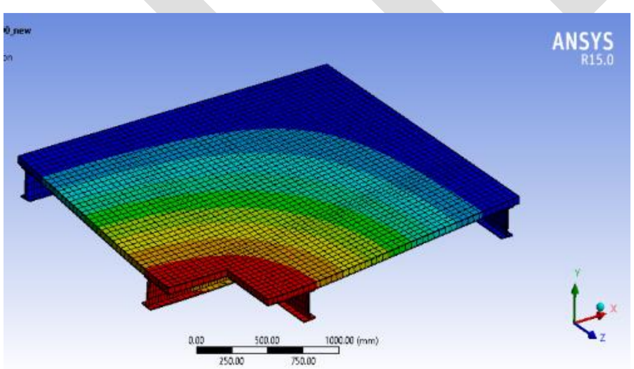


Fig. 9 Deformation in slab S3

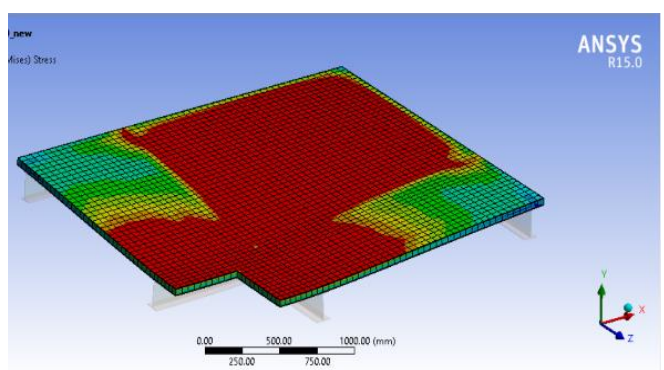


Fig. 10 Stress in S3

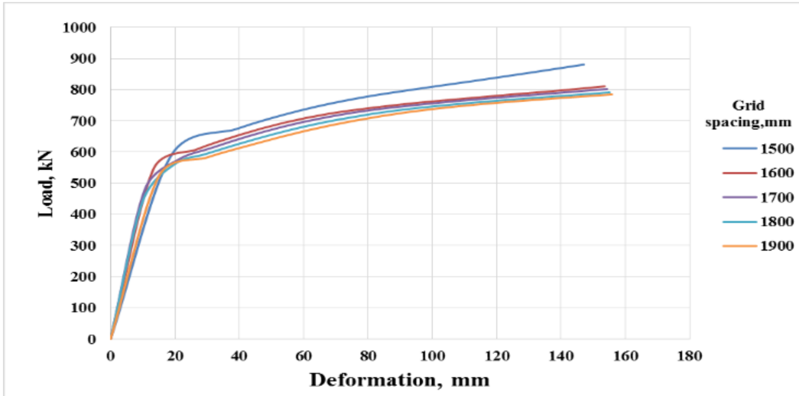


Fig. 11 load Vs deformation graph

a. From the graph it can be seen that, when grid beam spacing of waffle slab increases, there is a decrease in ultimate load carrying capacity and increase in total deformation.

b. For grid beam spacing 1500 x 1500 mm the ultimate load carrying capacity is very high and deformation is very less compared to other grid beam spacing.

c. When grid beam spacing in one of the direction increases from 1600 mm to 2000 mm, there is a small decrease in ultimate load carrying capacity and a small increase in total deformation.

d. Comparing to a composite waffle slab of size 4700 x 4700 mm and grid beam spacing of 1500 x 1500 mm without opening with same concrete, reinforcement and steel girder properties there is a reduction in load carrying capacity and increase in deflection.

**Study 2**

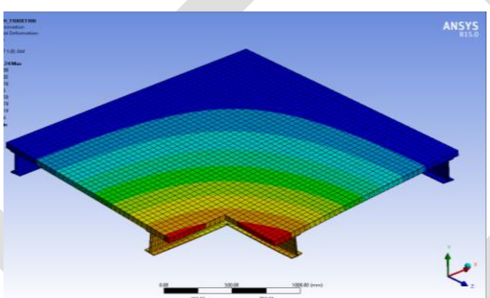


Fig.12. Deformation in slab B2

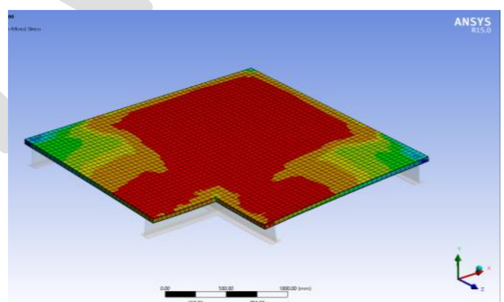


Fig. 13 Stress in slab B2

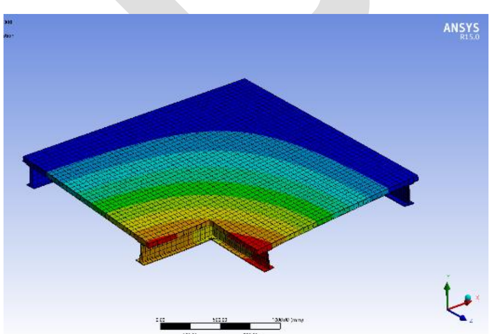


Fig. 14 Deformation in slab B4

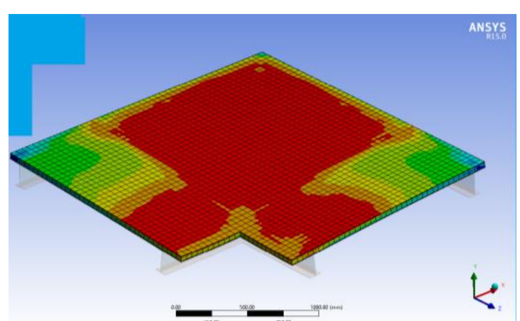


Fig. 15 Stress in slab B4

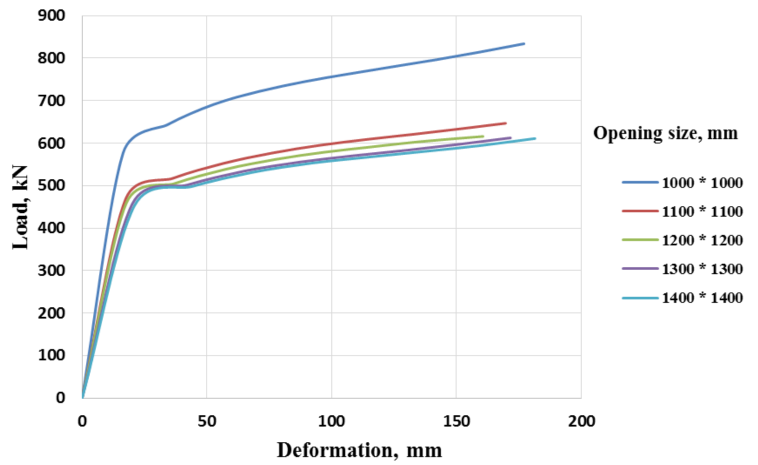


Fig. 16 load vs deformation graph

From the graph it can be seen that,

**a. when grid beam spacing of waffle slab increases, there is a decrease in ultimate load carrying capacity and increase in total deformation**
**b. For the opening size 1000 x 1000 mm the ultimate load carrying capacity is very high and deformation is very less compared to other higher opening size**
**c. When opening size increases from 1100 x 1100 mm to 1400 x 1400 mm ultimate load carrying capacity decreases and deformation increases, but at a small rate.**

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## CONCLUSION

1. **By analyzing different grid beam spacing, provide smaller spacing between grid beams for better performance.**
2. **By analyzing different opening sizes, for higher load carrying capacity and better performance provide small opening sizes.**

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