Jr. of Industrial Pollution Control 33(S2)(2017) pp 1323-1327
www.icontrolpollution.com
Research Article

ANALYTICAL STUDY OF PUNCHING SHEAR ON WAFFLE SLAB WITH DIFFERENT RIB SIZES

K. SAKETH*, C. ARUNKUMAR AND S. SRINIVASASENTHIL

[1]Department of Civil Engineering, SRM University, Chennai, India

(Received 17 June, 2017; accepted 20 September, 2017)

Key words: Waffle slab, Two-way slab, RC slab, ANSYS, Punching shear

ABSTRACT

This study presents the information of behaviour punching shear in waffle slabs at slab-column joint subjected to concentric punching shear. Although it was observedthat waffle slabs are very similar to that of flat slabs, the shear capacity is relatively reduced because some of the potential surfaces is lost when it extends into waffle section. The current IS code of practice do not consider the punching shear mechanism of waffle slabs. The analytical part is done using Finite Element software ANSYS, by applying the concentric load at the slab-column joint on waffle slabs, waffle slabs of different sizes and comparing the analytical results with normal RC slab. Waffle slabs of different sizes are created by increasing the depth of slab by 20%, width of the rib by 25% and one by increasing solid section. The comparison of the test results with the RC slab reveals that waffle slab gives more strength and when comparing between the waffle slab models of different sizes, providing more depth in slab and thickness of ribs gives extra strength to the structure against punching shear.

INTRODUCTION

Slabsfor which the applied loads are transferred in two directions and are supported along four edges by beams or walls are named two-way spanning slabs. Two-way slabs and plates can also be determined in which the dimensional ratio of length to width is less than 2. They may be either solid uniform slabs or, for longer spans waffle slabs are used (Moldovana and Mathea, 2015). Waffle slab, also called a two-way joist, ribbed slab system, or a coffered slab and essentially consists of thin top slab acting compositely with a closely spaced orthogonal grid of beam ribs. In waffle slab construction, the slab is often made solid near the supports to increase the shear and bending moment capacity. Two-way spanning slabs with square cross section tend to be the most economical shape since each supporting beam or wall carries the same amount of the total load from the slab that leads to the minimum required slab and beam depth (Obrien, *et al.*, 2012; Prahabkara, 2011).

Waffle piece is not utilised as a part of average customary development ventures. They are utilised for specific activities that include spaces requiring disengagement from low-frequency vibration or those requiring low floor deflections. This type of development is chiefly utilised as a part of aeroplane terminals, parking structures, business and mechanical structures, living arrangements and different structures requiring additional solidness. The primary motivation behind utilising this innovation is for its solid establishment attributes of crack and sagging. Two-way Waffle slab furthermore holds a more prominent measure of load compared with normal two-way solid slabs.

Similar to flat slabs, a waffle slab can develop a local shear failure known as a punching shear failure. However, despite an increasing popularity of waffle slabs a significant research has been carried out. The shear design procedures for waffle slabs subjected to punching have not been considered in current Indian design codes. The current project is being on

***Corresponding authors email: mahendrapratapsingh1206@gmail.com; gopinath.gusto@gmail.com**

this subject about the behaviour of punching shear in waffle slabs and the effect of solid portion, slab thickness and rib stiffness and spacing of ribs on it. Waffle Slab is designed by using direct design method and the punching shear is measured at the slab-column connection. The designed slabs are modelled and analysed by Finite element method software ANSYS 15.

RESEARCH SIGNIFICANCE

Current IS design codes do not provide design procedure recommendations specifically for waffle slabs. Thus punching shear mechanism for waffle slabs of different geometry within itself and normal RC slab is not compared thus far and hence this investigation helps in understanding the amount of strength waffle slab can resist.

Specimen Details

A two-way RC slab and 4 waffle slabs of different geometry are designed for a roof load of 3kN/mm^2 from (IS 875(part-2), 1987).

RC Slab

The size of the slab is scaled to 1:5 to a size of 1200 × 1200 mm and a depth of 50 mm is provided and simply supported on all four sides which is Model 1. Minimum reinforcement according to (IS 456:2000, 2000) is provided.

Waffle Slab

There is no exact design method specified in IS 456:2000. Model 2 is designed by direct design method of flat slabs. The concrete and steel properties of waffle slabs are considered to be same as of conventional concrete slab. The size of a slab is 1200 × 1200 mm and a total depth of 150 mm of which rib depth is 100 mm. The resistance against the punching shear failure can be increased by one or more ways, waffle slab models of different sizes were created and mentioned in the following sections

Waffle Slab Thickness of 60 mm

By increasing the resistance of punching shear in a slab-column joint is by increasing the slab thickness about 20% the depth of waffle slab thickness which makes the total depth of the Model 3 be 60 mm. The remaining dimensions of ribs are same as the dimensions of normal waffle slab.

Waffle Slab 50 mm Rib width

In this Model 4 size of the slab is similar to that of RC Slab but by increasing the rib width by 25% and thereby decreasing the spacing between ribs to 180 mm centre to centre.

Waffle Slab with 250 mm spacing

By increasing the spacing between ribs and by providing a large solid portion near slab-column joint the effect of punching shear force can be minimised. This is designed as a Model 5. The main reinforcement provided is same in all four models and a minimum shear reinforcement is also provided (Fig. 1).

THEORETICAL STUDY

The (IS 456:2000) recommends the critical section for two-way shear shall be at a distance of 0.5d from the face of the column on all sides and this two-way shear is calculated in terms of shear stress. The theoretical ultimate load according to Indian standard code for the models were given in Table 1.

ANALYTICAL STUDY

The finite element method is a numerical analysis technique for obtaining approximate solutions to wide variety of engineering problems. The Finite Element Model is created by using the Finite Element Software ANSYS R15.0. The method used for creating the model is a bottom-up approach. By this method, at first the volumes were created and the areas, lines and key points are formed with the volumes.

Material properties of steel

LINK8 3D spar element is used for modelling steel reinforcement, which has three degrees of freedom at each node. This element models tension and compression force in its longitudinal direction. By merging the nodes bond is created between concrete and steel. Table 2 gives the linear elastic properties of Steel Bar (Table 2).

Material properties of concrete

The concrete was modelled using 3D 8-noded solid elements SOLID 65. The SOLID 65 element has the ability to crack in tension and to crush in compression and only three transitional degrees of the node are allowed with this element. Table 3 gives the linear material properties of concrete, Table 4 gives the Non-metal plasticity values of concrete Tables 3 and 4.

The plasticity model or the multi linear isotropic hardening material properties use the von Mises failure to define the failure of concrete. The assumed stress-strain values shown in (Fig. 1) helps in predicting the non-linear behaviour of concrete. The assumed stress-strain values in the graph were derived from (Desayi and Krishnan, 1964; Kohnke, 2009; Indrajit and Jitendra, 2010) model (Fig. 2).

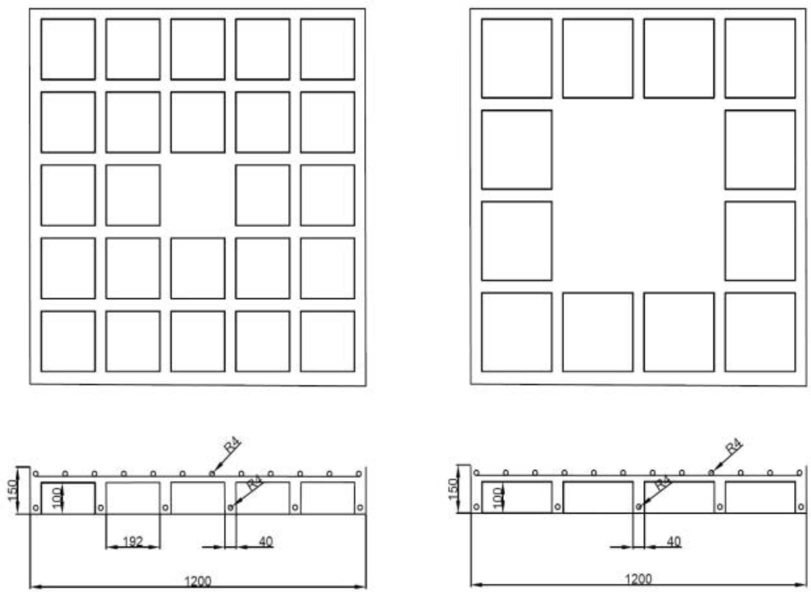

Fig. 1 Detailed plan and cross-sectional view of waffle slab model 2 and model.

Table 1. Theoretical values of punching shear

Model Number	V_{code} (kN)
1	38.32
2	107
3	116
4	101
5	101

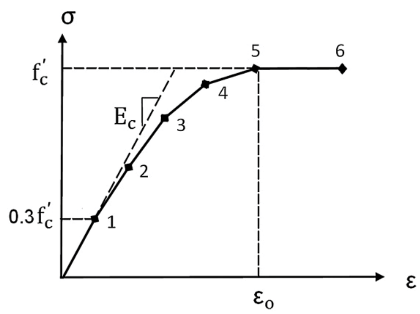

Fig. 2 Assumed stress vs. strain values of concrete.

Table 2. Linear elastic properties of steel bar

Material	Modulus of Elasticity (Mpa)	Poisson Ratio	Diameter (mm)
Steel	200000	0.3	8

Table 3. Linear elastic properties of concrete

Material	Modulus of Elasticity (Mpa)	Poisson Ratio
Concrete	31623	0.2

Table 4. Non-metal plasticity values of concrete

Open shear transfer coefficient, β*t*	0.3
Closed shear transfer coefficient, β*c*	0.9
Uniaxial cracking stress	4.42 Mpa
Uniaxial crushing stress, f'c	40 Mpa

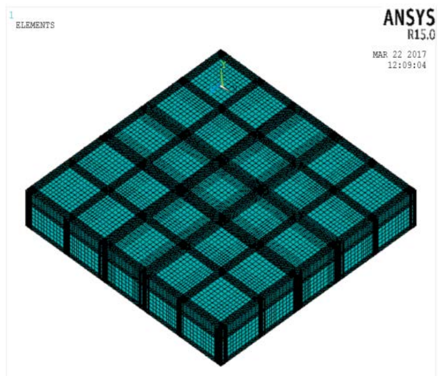

Fig. 3 Finite element meshing of model.

$$\varepsilon_0 = \frac{2f'}{E} \quad (3)$$

$$\sigma = \frac{E_c \varepsilon}{1+(\varepsilon/\varepsilon_o)^2} \quad (4)$$

$$E_c = \frac{\sigma}{\varepsilon} \quad (5)$$

Where

f_c^1 = Ultimate compressive strength

σ= Stress at any strain

ε = Strain at stress σ

ϵ_0= Strain at ultimate compressive strength

Ec = Concrete modulus of Elasticity (Fig. 3)

RESULTS AND DISCUSSION

As per the analytical study, the results of non-linear static analysis of solid slab and different waffle slab models with varying depth in slab, width of ribs and increase in spacing between ribs are compared. Ultimate load carrying capacities of the structures are used to compare the performance of slab models under gradually increasing load are shown in following Table 5 and (Fig. 4-6) (Table 5).

The deflection of RC slab is more since it is resting on beams whereas the deflection of waffle slab is less when compared to RC slab because the slab is resting on grids and the slab with grids behaves as single, which decreases the deflection of slab and is shown in (Fig. 4-6).

From (Fig. 5 and 6) the load vs. deflection graphs shows that model 4 with 25% increase in rib width has 1.14 times more stiffness than the model 2. The minimum solid portion should be greater than the sum of column size and effective depth of the slab to completely utilise its strength. The theoretical values are deviating with analytical values because the IS code does not consider the Moment of inertia of waffle slab (Ibrahim, *et al.*, 2011; Howard and Hansen, 2003).

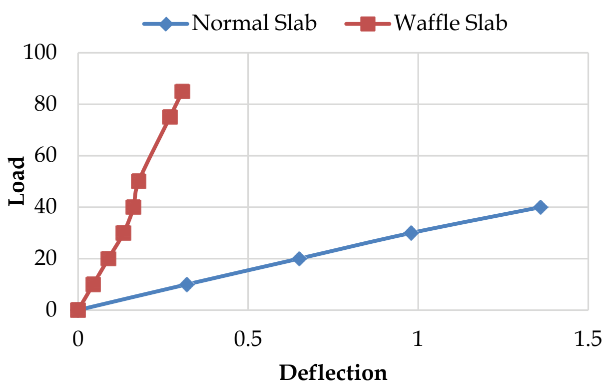

Fig. 4 Load vs. deflection between normal slab and waffle slab.

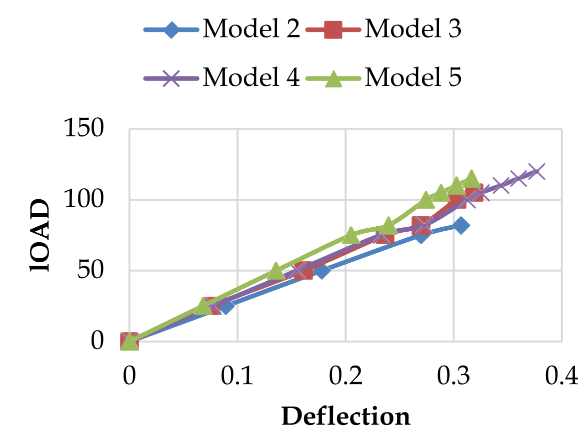

Fig. 5 Load vs. deflection for waffle slab models.

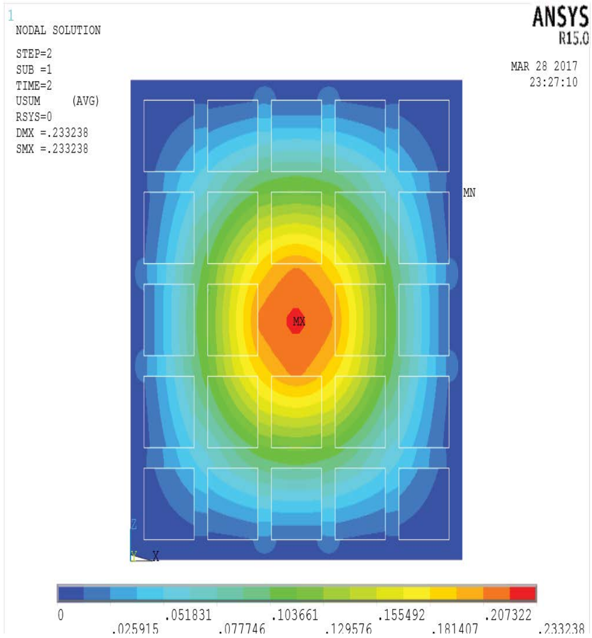

Fig. 6 Deflection contour of model 4.

Table 5. Comparison of ultimate load values for waffle slab models

Model Number	V_{code} (kN)	V(kN)
1	38.32	40
2	107	85
3	116	105
4	101	120
5	101	115

CONCLUSION

The following conclusion is taken from the results of all 5 models.

i. The punching shear strength at slab-column joint is twice for waffle slab when compared with the Normal two-way slab due to the grid portion which reduces the deflections of the slab.

ii. Model 3 with 20% increase in slab depth shows that strength is increased significantly by around 24%, which can further increase by providing bottom and top reinforcement in ribs.

iii. Model 4 gives the highest ultimate load of all the 3 models by 42% when compared with the Model 2 which is having the highest moment resistance capacity.

iv. The increase of solid portion and spacing between ribs for model 5 also gives more strength to the waffle slab but ultimately the increase of rib width proves to be achieving more strength.

REFERENCES

Chowdhury, I. and Singh, J.P. (2010). Analysis and design of waffle slab with different boundary conditions. *The Indian Concrete Journal*. 1-10.

Desayi, P. and Krishnan, S. (1964). Equation for the stress-strain curve of concrete. *Journal of American Concrete Institute*. 61(3) : 345-350.

Howard, C.Q. and Hansen, C.H. (2003). Vibration analysis of waffle floors. *Computers and Structures*. 81 : 15-20.

Ibrahim, A., Salim, H. and El-Din, H.S. (2011). Moment coefficients for design of waffle slabs with and without openings. *Engineering Structures*. 33 : 2644-2652.

IS 456:2000. (2000). Code of practice-plain and reinforced concrete. Fourth Revision, Bureau of Indian Standards, New Delhi.

IS 875 (part-2). (1987). Code of Practicefordesign loads (other than earthquake) for buildings and structures, Part 2 imposed loads. Second Revision, Bureau of Indian Standards, New Delhi.

Kohnke, P. (2009). Theory reference for the mechanical APDL and mechanical applications. Release 12.0. ANSYS, Inc. Canonsburg, PA, USA.

Moldovana, I. and Mathea, A. (2015). A study on a two-way post-tensioned concrete waffle slab. 9th International conference interdisciplinary in engineering, INTER-ENG. 227-234.

Obrien, E., Dixon, A. and Sheils, E. (2012). Reinforced and prestressed concrete design to EC2. The complete process. Second edition. Spon Press.

Prahabkara, B. (2011). Prestressed concrete design to eurocodes. University of Glasgow, UK.