

Analysis of Two-way Slabs with and Without Opening for Different Boundary Conditions

Roshini T. Mohan, Sankaranarayanan K.M.

Department of Civil Engineering, SIMAT, Vavanoor, Palakkad

Abstract- Concrete slab with opening are usually designed with help of traditional rules of thumb proposed by building codes. Such methods however introduce limitations concerning size of opening and magnitude of applied loads. Furthermore there is a lack of sufficient information about the load carrying capacity of slab with opening. It is also difficult to model the complex behaviour of reinforced concrete structures analytically in its non-linear zone. This has led engineers in the past to rely heavily on empirical formulas which were derived from numerous experiments for the design of reinforced concrete structures. Nowadays, for structural design and assessment of reinforced concrete members, the non-linear finite element (FE) analysis has become an important analytical tool. This thesis investigates the structural behaviour of two way reinforced concrete slab with and without openings for different slab length ratios and different opening ratios. The effect of openings sizes on crack formation is also analysed. For this different models of slab with and without opening were modelled in finite element software ANSYS.

Index Terms- ANSYS, Crack pattern, Equivalent stress, Slab opening, Two-way slab.

I. INTRODUCTION

In the design of concrete slabs with openings the building codes propose instructions that are not supported by the underlying theories such as empirical methods and strip method. The problems concerning with design of slab with opening cannot be solved by analytical methods since such structures like concrete slabs with openings, are too complicated. Nowadays, access to powerful computers and advanced software gives possibility to create accurate models by means of the finite element method. Advanced finite element modelling is in most cases time-consuming and for this reason it might be too expensive for design offices or when the number of needed openings is limited. Accurate methods obtained from academic researchers can prepare a background for evaluation of simple design methods and ready solutions for designers. Due to lack of accurate calculation methods, the size of an opening and magnitude of allowable load are limited by code. In this study, two way reinforced concrete slab with and without openings are modelled using commercial software package ANSYS to understand the behaviour of slab with different opening size. The aim of this study is to determine the effect of opening on stresses and deflection in two way reinforced concrete slab. Analysis of slabs are performed for different opening size at different location and thus to find out the variation in stresses. Finite element stresses are used to determine the moment coefficient for different

opening size. Based on these results a design guide line recommendation is prepared for the design of two way slabs with opening. The project work may offer the structural engineer with guidance on understanding the crack pattern of slab having different boundary conditions with and without opening.

II. LITERATURE REVIEW

Chee Khoon Ng et.al (2008) [4] carried out, a study on simply-supported and fixed-end, square slabs with opening at ultimate limit state using the yield line method. A study on the effect of opening on the load carrying capacity of simply-supported and fixed-end slabs was presented. After their analysis they came to a conclusion that, since most of the slabs have small opening of size up to 0.3 times the slab dimension, a simply-supported slab would have a reduction in ultimate area load of up to 11% and a reduction of ultimate total load of up to 19% and a fixed-end slab would experience less significant reduction in both ultimate area load and ultimate total load capacities of 4% and 7%, respectively. They also presented charts in normalized load capacity and opening size which could be used as guidelines for predicting the load capacity of simply-supported and fixed-end slabs with openings.

Koh Heng Boon.et.al (2009) [10] carried out an experimental work to determine the structural performance of one way reinforced concrete slabs with rectangular opening. Five types of RC slab which consist of two panels for each type were tested by four points bending test. These include one control slab without opening and other four with rectangular opening at the center. Based on the experiment result it was found that the reduction of 15% area due to the rectangular opening located at the centre of RC slabs reduces 36.6% of flexural strength. The crack pattern obtained for slab with opening and without additional reinforcement around was found to be same as that of slabs with opening and additional reinforcement of either rectangular bars or diagonal bars around opening. The provision of additional reinforcements surrounding the opening increases the flexural capacity of the RC slab. Also the cracking pattern found in the opening slab shows a high concentration stress occurred at the corner of the opening when vertical load applied.

Hosam A. Daham (2010) [9] carried out finite element analysis by using ANSYS 5.4 program with a non linear concrete model satisfying complex support condition to predict the ultimate load for different types of RC slabs. The effects of openings for different types of boundary conditions were studied. Effect of supports status on the deflection of the slabs with and without opening was studied and the results shows that the opening in slabs supported on four edges have little effects on

slab. Results obtained from the analysis carried out for different boundary conditions shows that the deflection for slabs with opening fixed on all four sides was about 5.6% of that of slab simply supported at all four sides. Also the deflection of slab with opening fixed at two opposite side and fixed free at other two opposite side was about 9.6% of that of slab simply supported at two opposite sides and simply supported free at other two opposite sides. The values distributions of normal stresses were also greatly affected by opening in slabs especially at opening region.

Ahmed Ibrahim et.al.(2011) [1] used numerical simulations using ANSYS to study the response of waffle slabs with and without openings and the design coefficients for the column and the field strips of the internal panel of a waffle slab. He also studied the effect of openings and stiffening ribs on the design coefficients. The linear modeling results were used to study the moment coefficients before cracking, whereas the nonlinear models were used to calculate the moment coefficients at ultimate loads. Finite element models were used to study the effect of column size, slab thickness, solid portion size, and opening size and location on the moment coefficients. By comparing the results it was found that the linear analyses gave higher values for the moment coefficients than the ones obtained from the nonlinear analyses and the ACI code coefficients. Also by increasing the solid portion size, it was found that the negative moment coefficient of the column and field strips increased for column strips and field strips, whereas the positive moment coefficient of the column and field strips decreased for column strips and field strips.

Sheetal Gawas and Dr. S.V.Itti (2013) [14] presented finite element analysis of RCC slab models to study variation of displacement and stresses, in slab with different boundary conditions. Non-Linear static analysis was carried out using ANSYS 10 Software and a rectangular RC slabs with tensile reinforcement was analyzed. Comparing the slabs with different boundary conditions both with and without opening, the slab simply supported on all the edges shows highest displacement and slab fixed all the edges shows least displacement. The slab having fixed support on all the edges with and without opening shows highest stresses, whereas slab simply supported on all edges shows least stresses among all other slabs.

Prof. Dr.Nazar K. Oukaili, and Thaar Saud Salman,(2014) [13] conducted an experimental test on six half-scale reinforced concrete flat plates connections with an opening in the vicinity of the column. The tests were designed to study the effect of openings on the punching shear behavior of the slab-column connections. From the results it was found that all the specimens have failed in punching shear mode. The capacity of the flat plate was greatly affected by size of the opening. The ultimate strength of the flat plate with the larger opening decreased by 29.25% with respect to the ultimate strength of solid specimen. For the specimen with a smaller opening, the decrease in capacity was 12.42%. For the specimen with opening at distance h (70mm) from the front face of the column, the shear capacity decreased by 13.47% from control one. For specimen with the opening next to the column, the decrease in capacity was 19.65%. The opening located at the front of the column decreases the shear capacity of the flat plate more than the same size opening located at the corner of the column. The opening location adjacent to the front

column face decreased the shear capacity by 19.65% from control one, while that adjacent to the column corner decreased the capacity by 11.43%. The presence of openings in flat plates decreases the stiffness depending on the sizes and locations of these openings.

Anjaly Somasekhar and Preetha Prabhakaran (2015) [3] examined the structural behaviour of waffle slabs (ribbed flat slabs) with and without openings and the effect of openings sizes and locations on the ultimate loads. These items were studied using finite element software by analyzing nonlinear finite element models of an internal panel of waffle slab under uniform loading. Results obtained from numerical study showed that opening dimensions and its locations have a significant effect in the structural behaviour of waffle slab. The size of openings in the region bounded by two column strips should be limited to 10% of the column strip width while in the region bounded by a column strip and a middle strip, size limit is 20% of the column strip width. But for the region bounded by two middle strips, no such limitation has been found in opening size leading to a conclusion that in this region, opening size can be even up to 40% of the width of column strip. It was concluded from the results that special measures have to be taken to improve the performance of waffle slabs having large openings in the regions bounded by two column strips and that bounded by a column strip and middle strip.

III. MATERIAL AND METHODOLOGY

ANSYS is a general purpose software, used to simulate interactions of all disciplines of physics, structural, vibration, fluid dynamics, heat transfer and electromagnetic for engineers. So ANSYS, which enables to simulate tests or working conditions, enables to test in virtual environment before manufacturing prototypes of products. Furthermore, determining and improving weak points, computing life and foreseeing probable problems are possible by 3D simulations in virtual environment. ANSYS can work integrated with other used engineering software on desktop by adding CAD and FEA connection modules. ANSYS can import CAD data and also enables to build a geometry with its "preprocessing" abilities. Similarly in the same preprocessor, finite element model (a.k.a. mesh) which is required for computation is generated. After defining loadings and carrying out analyses, results can be viewed as numerical and graphical.

A. Modelling of Concrete

Element geometric modelling of concrete has been done using 3D 8 noded solid brick element shown in Figure 1. The solid element (Solid 65) has eight nodes with three degrees of freedom at each node and translations in the nodal x, y, and z directions. The element is capable of plastic deformation, cracking in three orthogonal directions, and crushing. The geometry and node locations for this element type are shown in the figure.

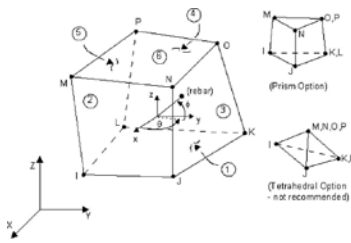


Fig 1. Solid 65 element

Table-1 lists concrete properties within Solid65 element prior to initial yield surface. The solid65 element is capable of cracking in tension and crushing in compression. The multi linear isotropic concrete model uses the von Mises failure to define the failure of concrete.

**Table-1.
Concrete properties prior to initial yield Surface**

Material	Material model	Modulus of elasticity (MPa)	Poisons ratio
concrete	Linear elastic	25000	0.2

**Table-2
Concrete parameters beyond initial yield surface.**

Open shear transfer coefficient, β_t	0.3
Closed shear transfer coefficient, β_c	0.9
Uniaxial cracking stress	2.5 Mpa
Uniaxial crushing stress f_c	25 Mpa

The compressive uni-axial stress-strain relationship for the concrete model was obtained using the following equations to compute the multi-linear isotropic stress-strain curve for the concrete.

$$f = \frac{E_c \varepsilon}{1 + \left(\frac{\varepsilon}{\varepsilon_0}\right)^2} \quad (1)$$

$$E_c = \frac{f}{\varepsilon} \quad (2)$$

$$\varepsilon_0 = \frac{2 \times f_c'}{E_c} \quad (3)$$

B. Modelling of steel reinforcement

Reinforcement modelling could be discrete or smeared. In our work, a discrete modelling of reinforcement has been done.

The reinforcement has been modelled using link elements in ANSYS. LINK180 is a 3-D spar that is useful in a 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-compression element with three degrees of freedom at each node: translations in the nodal x, y, and z directions. 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.

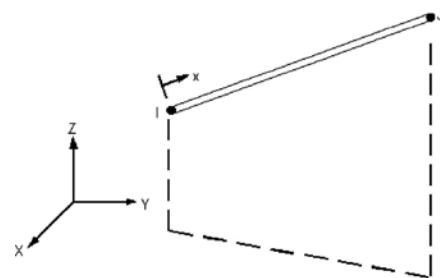


Fig 2: Link 180 – 3-D spar

**Table-3
Reinforcement properties within link180 element**

Material	Material model	Modulus of elasticity (MPa)	Poisons ratio
Structural steel	Linear elastic	200000	0.3

The bilinear law, elastic-perfectly plastic, is assumed as shown in Figure 6. The initial elastic part has the elastic modulus of steel E_s . The second line represents the plasticity of the steel with hardening and its slope is the hardening modulus E_{sh} . In case of perfect plasticity $E_{sh} = 0$. Limit strain ε_L represents limited ductility of steel.

**Table-4.
Reinforcement parameters beyond initial yield surface.**

Yeild strength	415 MPa
Tangent Modulus	0

IV. RESULTS AND DISCUSSION

In the present work, slabs with and without opening for two boundary conditions are being analyzed and studied. The opening varies as the length of opening as 12.5% , 25%, 37.5%, and 50% of length of slab and each opening varying in opening length to breadth to ratio as 2, 1.8, 1.6, 1.4, 1.2, and 1.

A. Slab with fixed support on all four edges

The variation in stress due to slab opening for a load of 17KN/m² is graphically shown in figure 3. From the figure it is

clear that the stress for a slab with opening is higher than that without opening, also the stresses are high for the slab with large length to breadth ratio. Here the stress is more for l by b ratio 2 and less for l by b ratio 1, which is when the opening is a square.

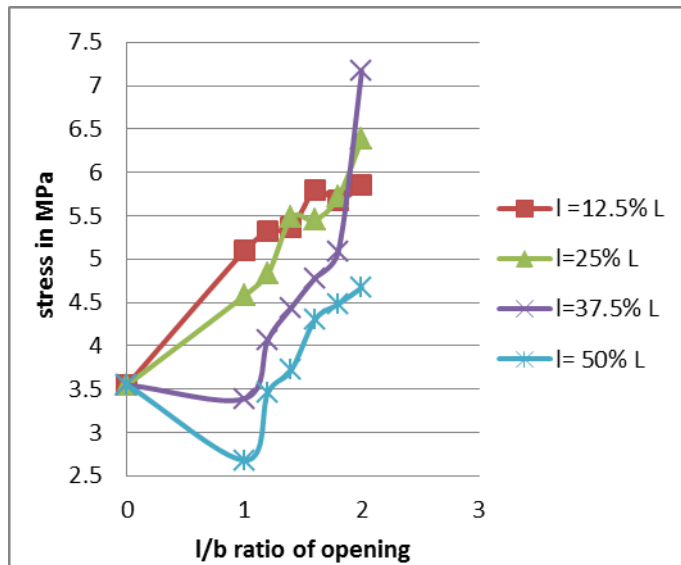


Fig: 3 Stress versus opening length to breadth ratio for interior slab

In this project the slabs with and without hole are also analysed for the load at which the slab shows first crack. . The variations in load carrying capacity of the slabs are tabulated in table 5. From the table it is clear that presence of opening have reduced the load carrying capacity of slab. Also the load carrying capacity increases when the opening length to breadth ratio decreases and attains a maximum value when length to breadth ratio is equal to one, which is when opening is a square. The results also shows that the first crack occurs at the edge of hole up to a particular value of l by b ratio, after that the crack is mainly concentrated at the edges of slab. This is due to the reason that the area of slab on which load is applied decreases as the size of opening increases and hence the load transferring is mainly concentrated at the edge of slab.

Table-5.

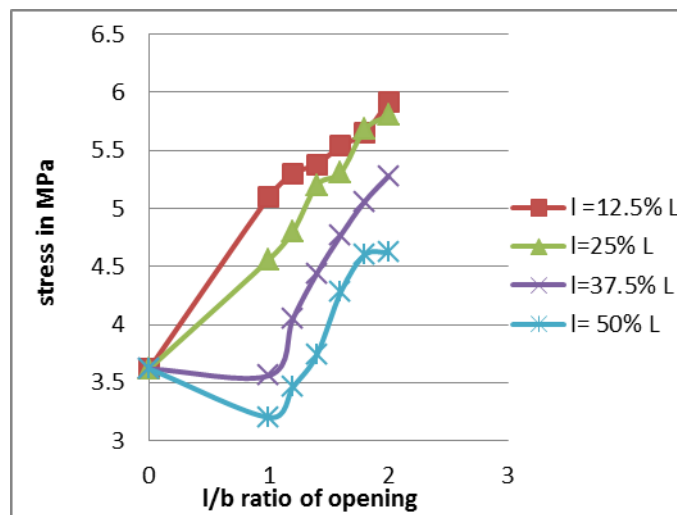
The load and position at which the first crack form for a slab with fixed support on all four edges having varying opening size

l/L	l/b	Load (KN/m ²)	first crack at the edge of
0.125	0	29	hole
	1	25	hole
	1.2	24	hole
	1.4	23.5	hole
	1.6	23	hole
	1.8	22.5	hole

	2	22	hole
0.25	0	29	slab
	1	28	slab
	1.2	27.5	slab
	1.4	27	slab
	1.6	26.8	slab
	1.8	25	hole
	2	22.5	hole
0.375	0	29	slab
	1	28.8	slab
	1.2	27.6	slab
	1.4	26.5	slab
	1.6	26	slab
	1.8	24.9	slab
	2	17	hole
0.5	0	29	slab
	1	30.9	slab
	1.2	30.5	slab
	1.4	28.6	slab
	1.6	26.8	slab
	1.8	25.2	slab
	2	24	slab

B. Slab simply supported on all four edges

The effect of opening on stresses for slabs having all four sides are discontinuous is shown in table 5. The load applied is 17KN/m². From the table it is clear the stress for a slab with opening is higher than that without opening and also the stress is more when l/b ratio is 2 and is least when l/b ratio is 1, which is when the opening is a square.



The load at which crack pattern appears on slab are analysed for slab with different opening size and without

opening. The variations in load carrying capacity of the slabs are graphically shown in figure 4. From the figure it is clear that presence of opening have reduced the load carrying capacity of slab without any crack formation. Also the load carrying capacity increases when the opening length to breadth ratio decreases and it is maximum when this ratio is equal to one, which is when opening is a square.

Table-6.

The load and position at which the first crack form for a slab with simply supported on all four edges and having varying opening size

<i>l/L</i>	<i>l/b</i>	<i>Load (KN/m²)</i>	<i>first crack at the edge of</i>
0.125	0	30.1	hole
	1	25.1	hole
	1.2	24	hole
	1.4	23.7	hole
	1.6	22.5	hole
	1.8	22	hole
	2	18.8	hole
0.25	0	30.1	slab
	1	28.4	slab
	1.2	27.8	slab
	1.4	27.3	slab
	1.6	27.2	slab
	1.8	24.8	hole
	2	24.6	hole
0.375	0	30.1	slab
	1	28.5	slab
	1.2	27.7	slab
	1.4	26.5	slab
	1.6	25.8	slab
	1.8	25	slab
	2	24.7	hole
0.5	0	30.1	slab
	1	31	slab
	1.2	30.5	slab
	1.4	28.4	slab
	1.6	26.6	slab
	1.8	25.2	slab
	2	23.8	slab

V. CONCLUSION

1. For slabs continues at all the four edges (fixed support) having area of opening from 1.25 to 2.67% of slab area the reduction in load carrying capacity is from 24 to 13.8%. For the same boundary condition when the area of opening in between 5.2 to 10.42% of slab area, the reduction in load carrying capacity is about 22 to 4%, area of opening in between 11.75 to 23.47% of slab area, the reduction in load carrying capacity is from 20 to 1% and for area of opening in between 20.8 to 29.8 % of slab area, the reduction in load carrying capacity is about 17 to 2%

2. When area of opening greater than 35% of slab area, the slab shows cracks at higher load than that shown by slab without opening.

3. For slabs discontinues at all the four edges having area of opening from 1.25 to 2.67% of slab area, the reduction in load carrying capacity is from 37.5 to 16.7%. For the same boundary condition when the area of opening in between 5.2 to 10.42% of slab area, the reduction in load carrying capacity is about 18.2 to 6%, area of opening in between 11.75 to 23.47% of slab area, the reduction in load carrying capacity is from 18 to 5.4% and for area of opening in between 20.8 to 29.8 % of slab area, the reduction in load carrying capacity is about 20.6 to 3.7%.

4. When area of opening greater than 35% of slab area, the slab shows cracks at higher load than that shown by slab without opening.

ACKNOWLEDGEMENT

Foremost, I would like to thank my God for His graciousness, unlimited kindness and with the blessings of whom the good deeds are fulfilled. I am extremely thankful to our Principal Dr. S.P. Subramanian and our HOD Er. Sudheer K.V. for giving me their consent for this project. I am indetbly thankful to my thesis guide Er. Sankaranarayanan K.M. Assistant professor, Department of civil engineering, for his constant help and support throughout the presentation of the thesis work by providing timely advices and guidance. Last, but not least I am also thankful to all our friends for the support and encouragement they have given me during this thesis work.

REFERENCES

- [1] Ahmed Ibrahim, Hani Salim and Hamdy Shehab Eldin (2009), Analysis of Waffle Slabs with and without Openings, Journal of Structural Engineering, ASCE.
- [2] Anjaly Somasekhar and, Preetha Prabhakaran (2015), Analysis Of Reinforced Waffle Slab With Opening, International Journal of Emerging Technology and Advanced Engineering.
- [3] Chee Khooon Ng, Timothy Julius Edward and Daniel Kim Tee Lee (2008), Theoretical Evaluation on Effects of Opening on Ultimate Load-carrying Capacity of Square Slabs, Electronic Journal of Structural Engineering.
- [4] Dr.B.Kawadkar, Dr.D.V.Bhope and S.D. Khamankar (2012), Evaluation of Stress Concentration in Plate with Cutout and its Experimental Verification, International Journal of Engineering Research and Applications (IJERA).
- [5] Dheeraj Gunwant and J. P. Singh (2013), Stress and Displacement Analysis of a Rectangular Plate with Central Elliptical Hole, International Journal of Engineering and Innovative Technology (IJEIT).
- [6] Dr. Adnan Sadiq Al-Kuaity (2011), Flexural Strength Of Flat Plate With Opening Under Combined Linear And Uniformly Distributed Loads, Kufa Journal Of Engineering.

- [7] Dr. Samal M. Rashied (2015), Punching Shear Resistance Of Flat Slabs With Opening, International Journal Of Civil Engineering And Technology (IJCIET).
- [8] Hosam A. Daham(2010), Analytical Study Of Reinforced Concrete Two-way Slabs With And Without Opening Having Different Boundary Conditions, journal of Al-Rafidain Engineering
- [9] Koh Heng Boon, Abu Bakar Mohamad Diah, And Lee Yee Loon (2009), Flexural Behaviour Of Reinforced Concrete Slab With Opening, Malaysian Technical Universities Conference On Engineering And Technology.
- [10] Liana L. J. Borges, Guilherme S. Melo, And Ronaldo B. Gomes,(2013), Punching Shear Of Reinforced Concrete Flat Plates With Openings, ACI Structural Journal,
- [11] M. Suneel Kumar1, P. Alagusundaramoorthy and R. Sundaravadivelu (2007): Ultimate Strength Of Square Plate With Rectangular Opening Under Axial Compression, Journal of Naval Architecture and Marine Engineering.
- [12] Prof. Dr.Nazar K. Oukaili and Thaar Saud Salman (2014), Punching Shear Strength of Reinforced Concrete Flat Plates with Openings, Journal of Engineering.
- [13] Sheetal Gawas and Dr. S.V.Itti (2014), Study On Two Way RC Slab Using ANSYS With And Without Central Opening, International Journal Of Scientific Engineering And Technology (ISSN : 2277-1581).
- [14] Sunil Kumar M. S. and B.S.Suresh Chandra (2014), Experimental Study On Self Compacting RC Slab With And With Out Opening, International Journal Of Engineering Research & Technology (IJERT).
- [15] Vera Nikolic , Cemal Dolicanin and Mladen Radojkovic (2011), Application Of Finite Element Analysis Of Thin Steel Plate With Holes, Technical journal.

AUTHORS

First Author – Roshini T. Mohan, M.Tech Student, Sreepathy Institute of Management and Technology,

roshinimurali3@gmail.com.

Second Author - Sankaranarayanan K.M. Assistant Professor, Sreepathy Institute of Management and Technology, sankaranarayanan.km@simat.ac.in