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RESEARCH ARTICLE

EFFECT OF OPENING ON YIELD AND ULTIMATE STRENGTH OF TWO WAY REINFORCED CONCRETE SLAB

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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 yield area capacity is also analysed. For this different models of slab with and without opening were modelled in finite element software ANSYS.

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 modeled using commercial software package ANSYS to understand the behavior 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.

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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.

Literature Review

Chee Khoon Ng *et al.* (2008) 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 e used as guidelines for predicting the load capacity of simply- supported and fixed-end slabs with openings.

Koh Heng Boon *et al.,* (2009) 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) 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)* 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) 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) 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) 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.

MATERIAL AND METHODS

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.

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.

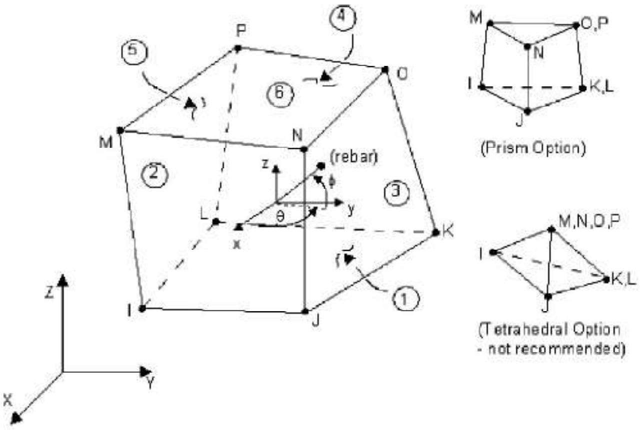

Fig. 1. Solid 65 elements

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.

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, βt	0.3
Closed shear transfer coefficient, βc	0.9
Uniaxial cracking stress	2.5 Mpa
Uniaxial crushing stress f'c	25 Mpa

The multi linear isotropic concrete model uses the von Mises failure to define the failure of concrete. The compressive uniaxial stress-strain relationship for the concrete model was obtained using the following equations to compute the multilinear isotropic stress-strain curve for the concrete.

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

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

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

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

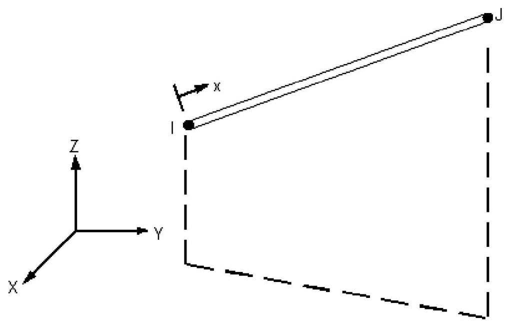

Fig. 2. Link 180 – 3-D spar

Table 3. Reinforcement properties within link180 element

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

Table 4. Reinforcement parameters beyond initial yield surface

Yeild strength	415 MPa
Tangent Modulus	0

RESULTS AND DISCUSSION

In the present work the results for slabs with two different types of boundary conditions are being analyzed and studied. The models of slabs contain a slab without opening and other slabs having length of opening about 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.

Slab with fixed support on all four edges

The effect of size of opening on the yield and ultimate area load carrying capacity of slab are analyzed and the results are expressed as graphs. The x axis of the graph represents length to breadth ratio changing and y axis represents the normalized yield and ultimate area load. The normalized area load is the ratio of load of slab with opening to that without opening. Figure 3 shows the effect of opening on yield load that is the load at which first crack forms.

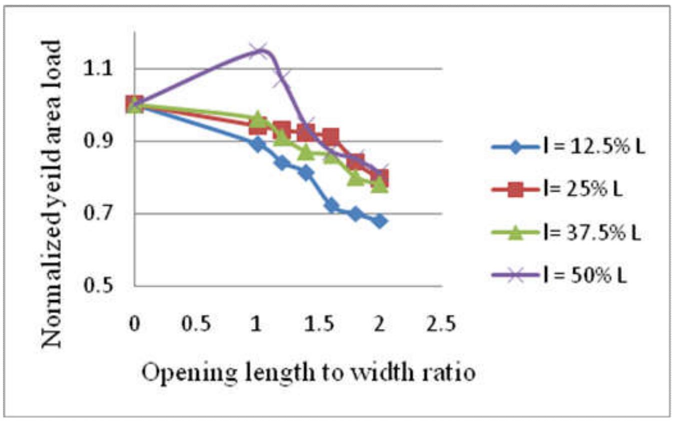

Fig. 3. Effect of size of opening on yield area load of interior slab

Here the size of opening varies from 0 to 0.5 times the slab area. The yield area load capacity of slab decreases for opening up to 0.3 times the slab area. The maximum decrease is for an opening with length of 0.125 times the length of slab and length to breadth ratio 2. During the analysis it was found that the first crack was likely to appear on the edge of opening for slabs with opening length 0.125 times the slab length and length to breadth ratio 2 to 1and openings with length 0.25 times the slab length and length to breadth ratio 2 to 1.6. This is due to the reason that load is still distributed near to the center of the slab. For all other openings up to0.3 times the slab area a portion of load is get distributed to the supports as well. Hence first crack is likely to occur at the edge of slab. For opening beyond 0.3 times the slab area the load is concentrated towards the supporting edges and hence such slabs yield at a load greater than the yielding load of slab without opening. The figure 4 shows effect of opening in fixed end slab on ultimate area load. From the figure it is clear that the ultimate load carrying capacity of a fixed end slab is same or even a bit higher (for opening length 0.5 times the slab length), than that of normal slab when the length to width ratio of opening is equal to one, which is when the opening is square. For slab with openings, having its length 0.125 times the slab length, when the length to breadth ratio changes from 1 to 2, there is a sudden decrease in the load carrying capacity of slab, with a maximum decrease of 27 % occurring at slab length to width ratio of 2. When the area of opening is greater than 0.3 times the slab area the expected ultimate load capacity is higher than that of normal slab, showing an increase of 103% occurring at opening length to width ratio of one.

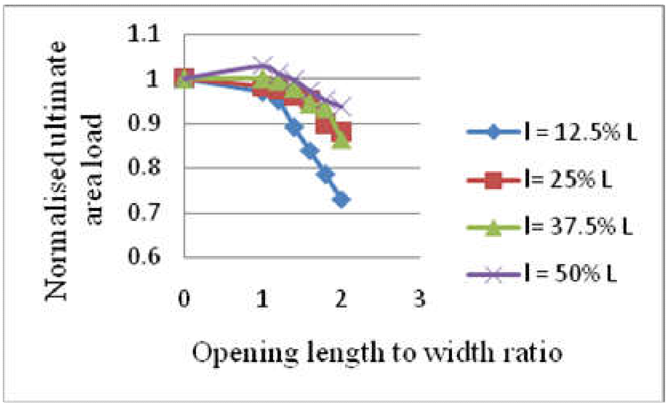

Fig. 4. Effect of size of opening on ultimate area load of interior slab

Slab simply supported on all four edges

Figure 5 shows the effect of opening on yield load that is the load at which first crack forms. Here the yield area load capacity of slab decreases for opening up to 0.3 times the slab area. The maximum decrease is for an opening with length of 0.125 times the length of slab and length to breadth ratio 2. During the analysis it was found that the first crack was likely to appear on the edge of opening for openings with length 0.125 times the slab length and length to breadth ratio 2 to 1 and openings with length 0.25 times the slab length and length to breadth ratio 2 to 1. This is due to the reason that load is still distributed near to the center of the slab. For all other openings up to0.3 times the slab area a portion of load is get distributed to the supports as well. Hence first crack is likely to occur at the edge of slab. For opening beyond 0.3 times the slab area the load is concentrated towards the supporting edges and hence such slabs yield at a load greater than the yielding load of slab without opening.

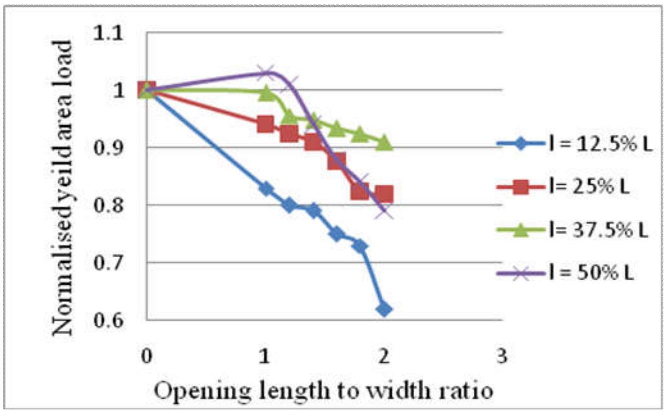

Fig. 5. Effect of size of opening on yield area load of simply supported slab

The figure 6 shows effect of opening in fixed end slab on ultimate area load. From the figure it is clear that the ultimate load carrying capacity has a gradual reduction. Openings having length 0.25 times the slab length shows more reduction in ultimate strength, in that opening having length to breadth ratio 2 has the least value. Slab with length of opening 50% of slab length and length to width ratio 1 have same strength as that of normal slab.

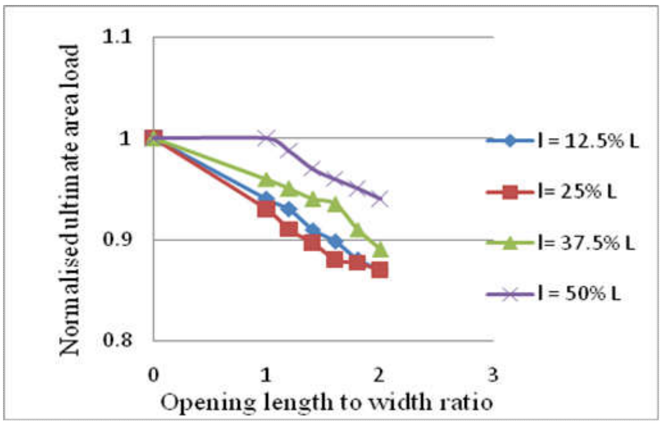

Fig. 6. Effect of size of opening on ultimate area load of simply supported slab

Conclusion

- For an opening area up to 5% of slab area, slabs with all four edges continuous show a reduction in yield strength about 11 to 32 % and ultimate strength about 3 to 27 %. For the same, slabs with all four edges discontinuous shows a reduction of 17 to 38% of yield strength and 6.8 to 13% of ultimate strength.
- When the area of opening is in between 5 to 11%, slabs with all four edges continuous shows a reduction of 6 to 20.4 % of yield strength and 1.7 to 12 % of ultimate strength, and slabs with all four edges discontinuous shows a reduction of 6 to 18% of yield strength and 8 to 12.5% of ultimate strength.
- For slabs with area of opening in between 11 to 20 %, the reduction in yield strength is about 9 to 22% and reduction in ultimate strength is about 0.5 to 13.5% for slabs with all four edges continuous and 8 to 18% and 5 to 9% of reduction in yield and ultimate strength for slabs with all four edges discontinuous.
- When area of opening is in between 20 to 30% of slab area, the reduction in yield strength is about 4 to 19% and reduction in ultimate strength is 0 to 6.4% for slabs with all four edges continuous. For slabs with all four edges discontinuous the reduction in yield strength is 6 to 5%. When area of opening is greater than 30%, there shows an increase in yield strength in all cases of boundary condition.
- In all cases the least value is for opening with length to breadth ratio 2 and highest value is for square slabs, which is when length to breadth ratio is one. In case of slab with all four edges continuous, the reduction in ultimate strength is about 0 to 6% for opening area 20 to 30% of slab area.

From the above analysis results it could be concluded that, the percentage reduction in yield strength is more for slab with all edges simply supported and opening size about 5% of slab area, and the percentage reduction in ultimate strength is more for slab with all edges fixed and opening size about 5% of slab area.

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