IJIRST –International Journal for Innovative Research in Science & Technology| Volume 3 | Issue 02 | July 2016
ISSN (online): 2349-6010

Comparative Study of Reinforced Concrete Flat Slabs with and without Openings using Finite Element Analysis

Aradhna A. Ganvir
PG Student
Department of Civil Engineering
Trinity College of Engineering & Research, Pune India

Prof. V. S. Singhade
Associate Professor & Head
Department of Civil Engineering
Trinity College of Engineering & Research, Pune India

Abstract

A reinforced concrete flat-plate floor system is widely used in various types of building structures including condominiums, parking garages, and office buildings. This floor system is advantageous in terms of simpler formwork, shorter construction period, reduced storey height, flexible room arrangement, more headroom, better air circulation, and better light penetration. In spite of the advantages, the system has its problems, one of which is the possibility of punching shear failure in the vicinity of the slab-column connections. Present aim of this study is to check the suitability of flat slabs with openings of different location & sizes. In this study FE analysis of flat slabs is proposed. Firstly a comparative study is carried out between experimental & analytical design of 500x500x110mm & 700x700x110mm slab panels. The analytical study has been done by using SAFE 12.2.0 4 for 500x500 & 700x700 mm panels with and without openings. The behavior of flat pates then compared w.r.t to maximum deflection, Failure load & first crack load.
Keywords: Finite Element Analysis, Flat Slabs, SAFE 12.2.0, Maximum Deflection

I. INTRODUCTION

Reinforced concrete slabs supported on columns were initially developed in the United States of America and Europe in the beginning of the 20th century. Flat slabs can be constructed relatively rapidly because the absence of drop panels results in simpler formwork arrangements, enabling rapid floor construction. In addition, flat slab constructions do not restrict the positioning of horizontal services and partitions and help to minimize floor-to-floor heights. This provides advantages in terms of lower building height, with reduced facade and installation costs.

In general, in this type of system, 100 percent of the slab load has to be transmitted by the floor system in both directions (transverse and longitudinal) towards the columns. In such cases the entire floor system and the columns act integrally in a two-way frame action.

The design of flat slabs is mostly governed by serviceability conditions on the one side (with relatively large deflections in service) and by the ultimate limits state of punching shear (also called two-way shear) on the other side. These two criteria typically lead to the selection of the appropriate slab thickness.

The design of flat slab with opening is not clearly stated in IS 456. As a result of that the buildings which consist of flat slab must to be devoted to requirements of connecting to public utilities such as deflation pipes or gas pipes or others. These requirements require opening to be placed in the system. However, there remains the most critical forces moments and punching shear. Fig (1) shows the shape of cracks formed from these forces. The most critical force is the punching shear force because it’s sudden failure. These forces' effects increased when an opening is placed at a location at which cut the path of the load to column.

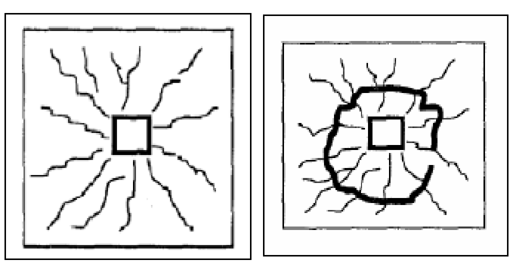


Fig. 1: Punching shear failure

A. Design Philosophy

There are three methods of analysis of flat slabs viz.

- Direct Design Method (DDM)

- Equivalent Frame Method (EFM)
- Finite Element Method (FEM)

Out of this, first 2 methods are recommended by the I.S. code for determining the bending moments in the slab panel (approximate methods); either method is acceptable (provided the relevant conditions are satisfied).

B. Finite Element Method using SAFE 12.2.0

The structures having irregular types of plans have limitations in analysis can be analyzed without any difficulties by the FEM. FEM is a powerful tool used in the analysis of flat slabs. Most finite element programs are based on elastic moment distribution and material that obey Hooke's Law. This works for steel plates but reinforced concrete is an elasto-plastic material and ones it cracks its behavior is nonlinear.

C. Advantageous Features of SAFE 12.2.0

SAFE is the ultimate tool for designing concrete floor and foundation systems. Generating pattern surface loads is easily done by SAFE with an automated option. Design strips can be generated by SAFE or drawn in a completely arbitrary manner by the user, with complete control provided for locating and sizing the calculated reinforcement. Finite element design without strips is also available and useful for slabs with complex geometries. Two types of cracked-section analysis are available, including:

- Immediate cracked deflection
- Long-term cracked deflection accounting for creep and shrinkage

II. LITERATURE REVIEW

Mostly among all available literature and experimental work is based on the analytical parts of flat slab floors. A lot of research work has taken place in this field addressing all relevant issues pertaining to the modeling, analysis and construction of flat slab structures.

Dr Samal M. Rashied: This paper deals with the aims compilation of the state of review on the evaluation of the predicted punching shear strength. A total of 79 tested slabs without shear reinforcement were selected from literature to study the treatments by these methods. The comparisons from their failure loads comparing to their reference specimens without opening shows that the punching shear resistance is inversely proportional to the opening size, location and distance to the face of the related columns.

Ashraf Mohamed Mahmoud: This paper deals with a three dimensional finite element model (FEM) is developed through Ansys 10 computer software, to carry out the nonlinear analysis of 16 flat-slab models with and without punching shear reinforcement. Several important parameters are incorporated in the analysis, namely the column size, the slab thickness and the punching shear reinforcement system in order to study their effects on the flat slab behavior. Good correlation is observed between the results of the proposed model and other experimental one, resulting in its capability of capturing the fracture of flat slab under punching shear behavior to an acceptable accuracy.

Chee Khoon Ng, Timothy Julius Edward, Daniel Kim Tee Lee proposed “Theoretical Evaluation on Effects of Opening on Ultimate Load-carrying Capacity of Square Slabs” a study on simply-supported and fixed-end; square slabs with opening at ultimate limit state using the yield line method was carried out and the results are presented herein. For simply-supported slabs, the analytical study on the ultimate load capacity of the slab shows that the ultimate total load decreases with the size of the opening. In the study of fixed-end slabs, the results show that the opening has insignificant effect on the ultimate area load capacity for a small opening size of up to 0.3 times the slab dimension.

Liana L. J. Borges, Guilherme S. Melo, and Ronaldo B. Gomes : This paper deals Punching shear tests were conducted on 13 reinforced concrete flat plates with and without openings or/and shear reinforcement. The openings (one or two) were adjacent to the shorter sides of rectangular supports and had widths equal to those of the supports. The methods of calculating punching shear strengths given in ACI 318-11 and MC90/EC2 are reviewed along with some proposed formulations, and their predictions are compared with the test results.

Ozgur Anil. & Tolga kina: They studied the effects of opening size and location on the punching shear behaviour of two-way reinforced concrete (RC) slabs were investigated. The experimental study was carried out on eight experimental specimens with openings at different variable locations and a reference specimen with no opening. Two-way square slabs (2000x 2000 x120 mm) were tested by applying an axial load from the top of a square column (200 x200 mm) located at the centre of the slab specimen. The test specimens studied had different opening sizes (300 x 300 mm and 500 x 500 mm) and locations: each size of opening was positioned in parallel and diagonal locations adjacent to the column and 300 mm from the column. The test results indicate that the punching shear resistance decreases with an increase in opening size

III. RESEARCH SIGNIFICANCE

In the present study 12 experimental flat slab panels with and without opening have been casted and cured for 28 days with M25 & FY500 grade of concrete and steel. The results then compared and validate with SAFE 12.2.0.

A. *Experimental Test Program*

The experimental work has been carried out for two sizes of RCC slab panels casted and cured on site for 28 days. Two panels of sizes 500x500 mm & 700x700mm with and without opening have been casted with M25 & FE500.Opening size is kept 20% of the panel dimension for the casting. The detail description is mentioned in below table.

Table – 1
Experimental Work

Slab size mm	*Fck N/mm^2*	*Fy N/mm^2*	*Opening size*	*D mm*
500x500	*25*	*500*	*-*	*110*
500x500	*25*	*500*	*100x100*	*110*
700x700	*25*	*500*	*-*	*110*
700x700	*25*	*500*	*140x140*	*110*

Fig. 2: Slab panels casted on site

B. *Interpretation of Experimental Test Results*

12 panels of slabs have been casted on site for dimension of 500x500 mm & 700x700 mm without and with opening. Depending upon the literature review size of opening is kept 20% of the panel dimension i.e. 100mm for 500 slab & 140 mm for 700 mm slab panel. Deep curing process has been adopted for the 28 days strength & then the flexural testing performed on UTM. Two point loads applied on the slab with centre to centre distance 0f 200 mm. A steel framed structure using Channel sections is modeled with c/c distance of 400 & 600 mm with roller support which provides the hinge support to the slab. The UTM provides the reading of first crack load v/s deflection & failure load v/s deflection. Graphs have been plotted for the above mentioned parameters. Depending upon the load v/s deflection parameter stress v/s strain calculated.

Table – 2
Nomenclature of slab panels for analytical & experimental comparison

Slab Panel size	*Designation*
500x500 slab without opening (EXP)	*ES1*
500x500 slab with opening (EXP)	*ES2*
700x700 slab without opening (EXP)	*ES3*
700x700 slab with opening (EXP)	*ES4*
500x500 slab without opening (SAFE)	*SS1*
500x500 slab with opening (SAFE)	*SS2*
700x700 slab without opening (SAFE)	*SS3*
700x700 slab with opening (SAFE)	*SS4*

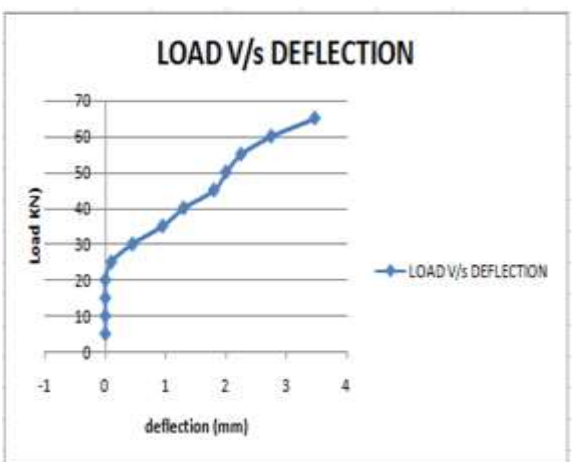
Fig. 3: Test setup on UTM

Table – 3
First crack load, deflection, stress and strain values for ES1

500x500 mm slab panel without opening			
First crack load (KN)	*Deflection (mm)*	*Stress*	*strain*
5	*0*	*0.09*	*0*
10	*0*	*0.18*	*0*
15	*0*	*0.27*	*0*
20	*0*	*0.36*	*0*
25	*0.1*	*0.45*	*0.0009091*
30	*0.45*	*0.54*	*0.0040909*
35	*0.95*	*0.63*	*0.0086364*
40	*1.3*	*0.72*	*0.0118182*
45	*1.8*	*0.81*	*0.0163636*
50	*2*	*0.9*	*0.0181818*
55	*2.25*	*0.99*	*0.0204545*
60	*2.75*	*1.08*	*0.025*
65	*3.473*	*1.17*	*0.0315727*

Table – 4
Failure load, deflection, stress and strain values for ES1

500x500 mm slab panel without opening			
failure load (KN)	*Deflection (mm)*	*Stress*	*strain*
5	*0*	*0.09*	*0*
10	*0*	*0.18*	*0*
15	*0*	*0.27*	*0*
20	*0*	*0.36*	*0*
25	*0.1*	*0.45*	*0.000909*
30	*0.45*	*0.54*	*0.004091*
35	*0.95*	*0.63*	*0.008636*
40	*1.3*	*0.72*	*0.011818*
45	*1.8*	*0.81*	*0.016364*
50	*2*	*0.9*	*0.018182*
55	*2.25*	*0.99*	*0.020455*
60	*2.75*	*1.08*	*0.025*
65	*3.473*	*1.17*	*0.031573*
70	*3.9*	*1.26*	*0.035455*
75	*4.3*	*1.35*	*0.039091*
80	*4.5*	*1.44*	*0.040909*
85	*4.7*	*1.53*	*0.042727*
90	*4.95*	*1.62*	*0.045*
95	*6.3*	*1.71*	*0.057273*
100	*6.75*	*1.8*	*0.061364*
105	*8.16*	*1.89*	*0.074182*



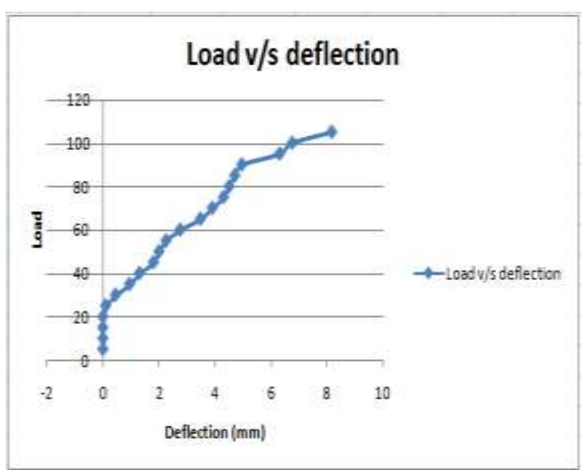


Fig. 4: Deflection v/s failure/first crack load for ES1

Table - 5
First crack load, deflection, stress and strain values for ES2

500x500 mm slab panel with opening			
First crack load (KN)	Deflection (mm)	Stress	strain
5	0	0.09	0
10	0	0.18	0
15	0	0.27	0
20	0	0.36	0
25	0	0.45	0
30	0.5	0.54	0.004545
35	0.55	0.63	0.005
40	0.7	0.72	0.006364
45	0.72	0.81	0.006545
50	1.05	0.9	0.009545
55	2.13	0.99	0.019364

Table – 6
Failure load, deflection, stress and strain values for ES2

500x500 mm slab panel with opening			
failure load (KN)	Deflection (mm)	Stress	strain
5	0	0.09	0
10	0	0.18	0
15	0	0.27	0
20	0	0.36	0
25	0	0.45	0
30	0.5	0.54	0.004545
35	0.55	0.63	0.005
40	0.7	0.72	0.006364
45	0.72	0.81	0.006545
50	1.05	0.9	0.009545
55	2.13	0.99	0.019364
60	2.45	1.08	0.022273
65	3.3	1.17	0.03
70	4.1	1.26	0.037273
75	4.6	1.35	0.041818

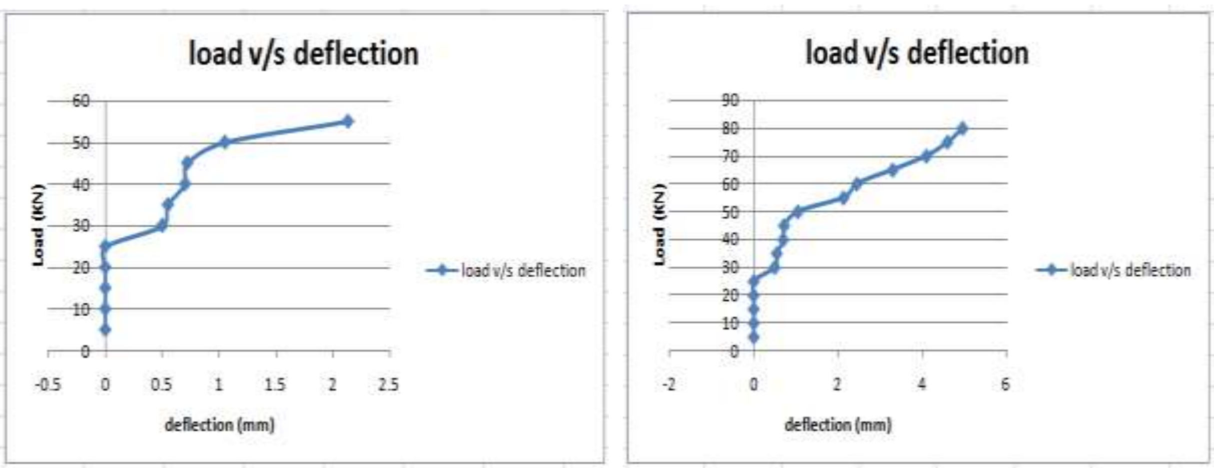


Fig. 5: Deflection v/s failure/first crack load for ES2

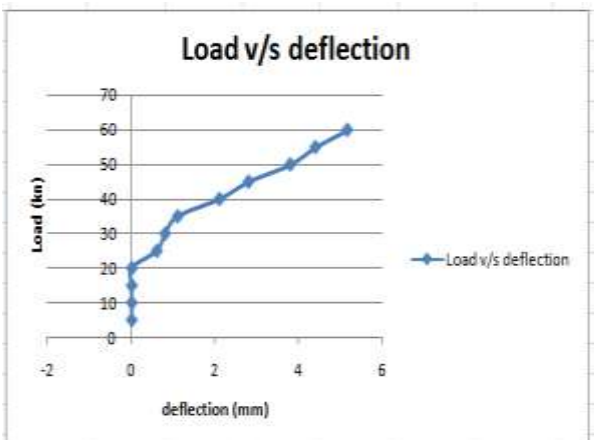
Table - 7
First crack load, deflection, stress and strain values for ES3

700x700 mm slab panel without opening			
First crack load (KN)	Deflection (mm)	Stress	strain
5	0	0.065	0
10	0	0.13	0
15	0	0.195	0
20	0	0.26	0
25	0.6	0.325	0.005455

30	0.8	0.39	0.007273
35	1.1	0.455	0.01
40	2.1	0.52	0.019091
45	2.8	0.585	0.025455
50	3.8	0.65	0.034545
55	4.4	0.715	0.04

Table - 8
Failure load, deflection, stress and strain values for ES3

700x700 mm slab panel without opening			
failure load (KN)	*Deflection (mm)*	*Stress*	*strain*
5	0	0.065	0
10	0	0.13	0
15	0	0.195	0
20	0	0.26	0
25	0.6	0.325	0.005455
30	0.8	0.39	0.007273
35	1.1	0.455	0.01
40	2.1	0.52	0.019091
45	2.8	0.585	0.025455
50	3.8	0.65	0.034545
55	4.4	0.715	0.04
60	5.168	0.78	0.046982
65	6.28	0.845	0.057091
70	7.63	0.91	0.069364
75	8.4	0.975	0.076364
80	9.726	1.04	0.088418



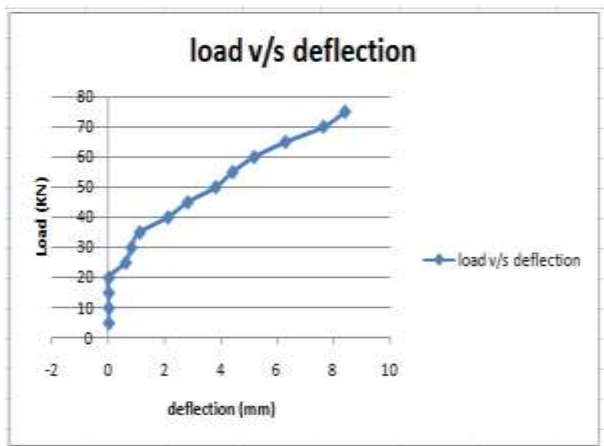


Fig. 6: Deflection v/s failure/first crack load for ES3

Table - 9
First crack load, deflection, stress and strain values for ES4

700x700 mm slab panel with opening			
First crack load (KN)	*Deflection (mm)*	*Stress*	*strain*
5	0	0.0645	0
10	0	0.129	0
15	0	0.1935	0
20	0.6	0.258	0.005455
25	1.25	0.3225	0.011364
30	1.7	0.387	0.015455
35	2.4	0.4515	0.021818
40	3.25	0.516	0.029545

Table - 10
Failure load, deflection, stress and strain values for ES4

700x700 mm slab panel with opening			
failure load (KN)	*Deflection (mm)*	*Stress*	*strain*
5	0	0.065	0
10	0	0.13	0

15	*0*	*0.195*	*0*
20	*0.6*	*0.26*	*0.005455*
25	*1.25*	*0.325*	*0.011364*
30	*1.7*	*0.39*	*0.015455*
35	*2.4*	*0.455*	*0.021818*
40	*3.25*	*0.52*	*0.029545*
45	*3.6*	*0.585*	*0.032727*
50	*4.074*	*0.65*	*0.037036*

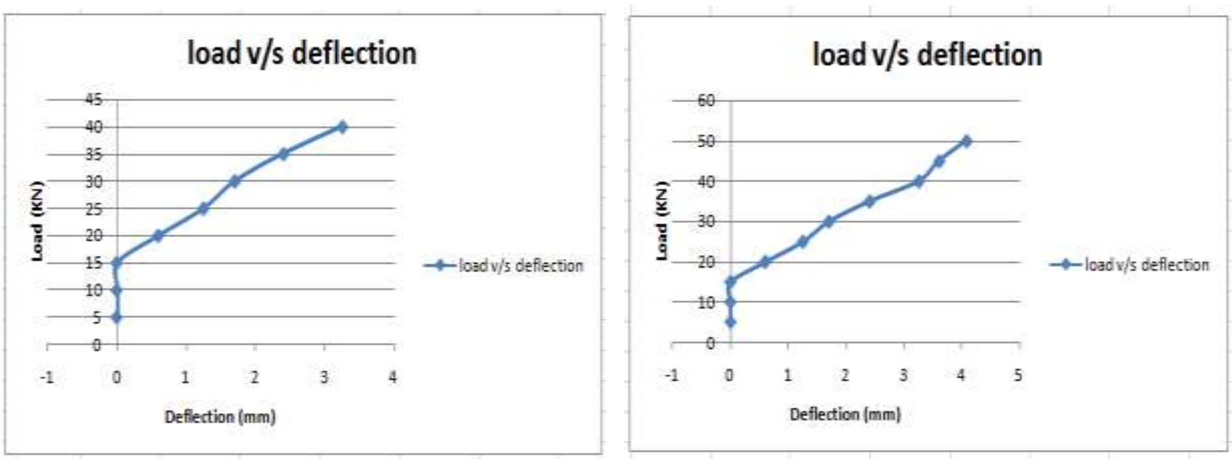


Fig. 7: Deflection v/s failure/first crack load for ES4

C. Analytical Investigation using SAFE 12.2.0

Four panels of slabs of 500x500 mm & 700x700 mm with and without opening have been modeled using SAFE 12.2.0. The failure load obtained from the experimental readings has been applied in the software. The conditions of loading are kept same by providing the hinge support in form of the columns at ends. Two point loads (failure load) is given under SUPERDEAD cases. The maximum deflection is checked and compared with the experimental results.

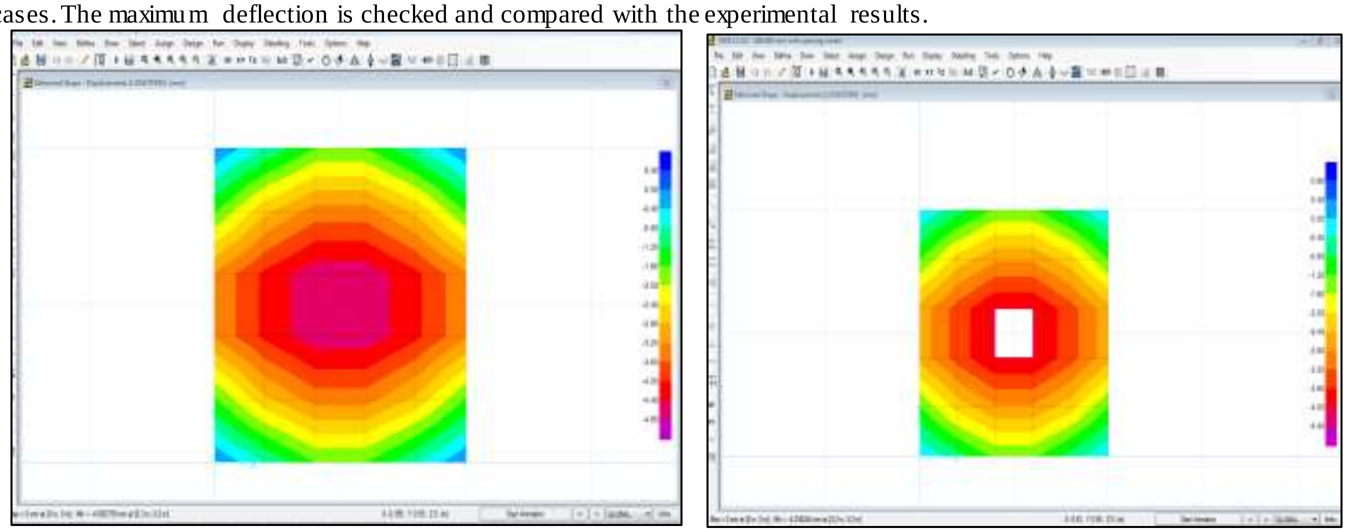


Fig. 8: Maximum deflection contour for SS1, SS2, SS3, SS4 in SAFE 12.2.0

Table - 11
Maximum deflection in SAFE 12.2.0

Model designation	*Maximum deflection (mm)*
SS1	*4.680*
SS2	*4.036*
SS3	*8.798*
SS4	*6.397*

The comparisons of maximum deflections by SAFE 12.2.0 & experimental is shown in the form of bar chart below.

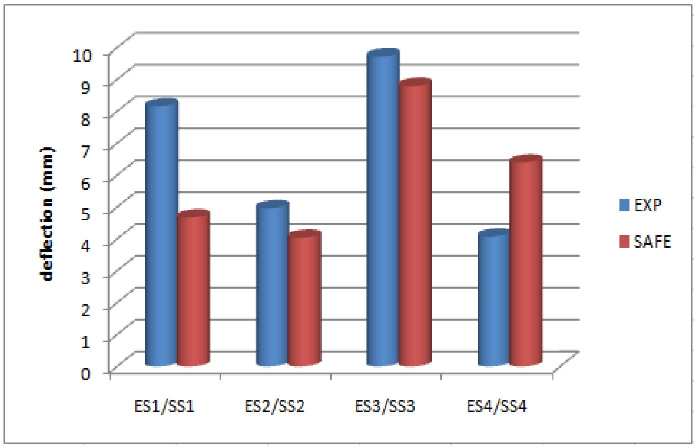


Fig. 9: Comparison of Maximum deflection in mm

IV. CONCLUSIONS

1) The finite element method for analysis of flat slab gives results close to the experimental values.
2) Approximately 17-19% reduction is observed in the values of first crack load for 500x500x110 slab panel with opening as compared to panel without opening.
3) Failure load decreases by 23-25% for panel with opening for 500x500x110 mm panel.
4) Approximately 32% reduction is observed in the values of first crack load for 700x700x110 slab panel with opening as compared to panel without opening.
5) Failure load decreases by 40% for panel with opening for 700x700x110 mm panel.
6) According to IS 456 clause. 23.2.1 L/d = 20 (for simply supported slab), as the span of slab increases the deflection value increases, which is observed in both the slabs.
7) When comparing the results of maximum deflection in SAFE, the values so obtained as approximately same from the experimental test for the same grade of concrete and HYSD bars.
8) The effect of opening is remarkable for the ultimate load carrying capacity of the slab.
9) Approximately 40% decrease in failure load is observed in 700x700mm slab size, when compared to 500x500 mm slab panel.

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