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Punching Shear Simulation of Flat Slab Using Truss, Stirrup and Stud

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Abstract— *Flat slab construction has been widely used in construction today because of many advantages that it offers. Punching shear reinforcement system such as truss, studs and stirrups are used for the analysis. For the analysis a three dimensional finite element model (FEM) of flat slab is developed through Ansys16.1. Slab with and without punching shear reinforcement is used for the analysis. Punching shear reinforcement is an efficient way to increase the strength and deformation capacity of slab column connection. Three different arrangements of shear reinforcements are studied: rectangular, angular and radial. Amount and the arrangement of the shear reinforcement influence the performance and failure mode. Load carrying capacity and stress distribution pattern is considered for taking the best model. Finite Element Analysis model from each arrangement having high load carrying capacity and better stress distribution pattern is considered for the result comparison. Stress distribution pattern shows the intensity of crack developed on slab. Smaller the value of stress means there is a reduction in the crack developed on the slab. Along with punching shear analysis (impact loading), lateral load acting at an angle of forty five degree and ninety degree is also used for analysing the slabs performance. And the result shows that slab with shear reinforcement also have resistance against lateral load acting on it.*

Keywords— *ANSYS software, deformation, impact load, lateral load, punching shear, shear reinforcement, stress.*

I. INTRODUCTION

Flat-slab construction has been widely used in construction today because of many advantages that it offers. Punching shear reinforcement is an efficient way to increase the strength and deformation capacity of slab - column connection. Flat slabs without capitals become prevalent all over the world from 1950 onwards. Because of their simplicity in construction they have become very common for medium height residential and office buildings and for parking garages. The design of flat slabs is mostly governed by serviceability conditions and by the ultimate limits state of punching shear on the other side. These two criteria typically lead to the selection of the appropriate slab thickness.

Vertical shear and unbalanced moment developed at the slab-column connection is responsible for the punching shear failure. This weakens the slab-column connections, and then leading to serious damage or even collapse to the whole flat-slab structure. Unbalanced moments commonly occur in buildings with flat slabs, caused by unequal spans or loading on either side of the column. Differences of temperature or differential creep between two adjacent floors results in differential displacements of the top and bottom of the columns, which induce moments in the slab-column connection, even if the columns, as is assumed for this study, do not participate in the horizontal load resisting system. In the presence of such moments, the phenomenon of punching becomes unsymmetrical, and the punching strength of the slab decreases. This phenomenon has been described by researchers.

Finite element analysis of flat slab helps to investigate the failure modes, loads and the crack patterns on flat slab under impact loading. Failure of slab is generally due to impact loading, so analysis for punching shear helps to assess the behavior of slab. In order to avoid punching shear, shear reinforcement is installed around the slab-column connections to increase the punching shear capacity of the flat slabs. Here punching shear reinforcement such as truss, stirrups and stud is used. Each type have different performance, largely depending on the anchorage condition of the shear reinforcement system and the distribution of the shear reinforcement. Amount and the arrangement of the shear reinforcement influence the performance and failure mode. Suitable amount of these studs, stirrups and truss that can resist the punching shear. Detailed study about this structure is necessary for the safety construction. Construction of flat slab with truss, studs or stirrups will helps to optimize the punching shear and also helps to reduce height of structure.

II. METHODOLOGY

The research work was done after reviewing the previous studies. It helps to understand the enhancement and fixing the objectives. Ansys16.1 software is used for the analysis. It can manage the individual applications and pass data between them, it is easy to automatically perform design studies for design optimization. Finite Element Model of flat slab with columns and shear reinforcement such as truss, stirrups and studs are used for the analysis. Size of the flat slab was 5800mm x 4800mm x 150mm. Support was fixed. Material properties and load was assigned as per previous studies. Flat slab without shear reinforcement was analysed first. Later slab with each shear reinforcement was analysed, also combination of stud stirrup and truss was also used for the analysis. Rectangular, angular and radial arrangement of shear reinforcement was used. Then the result obtained from each arrangement was compared and choose better model.

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III. MODELLING AND ANALYSIS

Slab size 5800mm x 4800mm x 150mm. Column size is 500mm x 500mm.Diametre of truss , stirrup and stud is 16mm. Height of column is 150mm above the slab and 200mm below the slab. Fixed support condition used for the analysis.

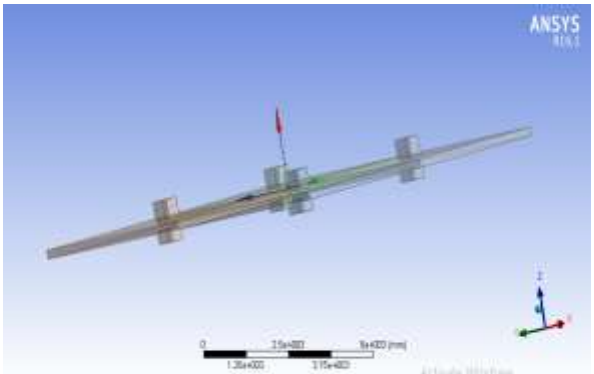

Fig. 1. Full model flat slab.

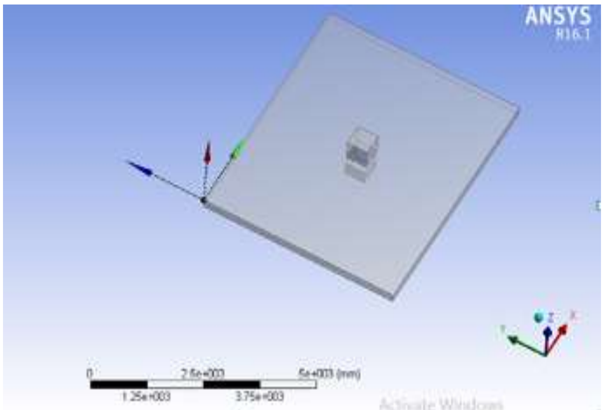

Fig. 2. Section of flat slab.

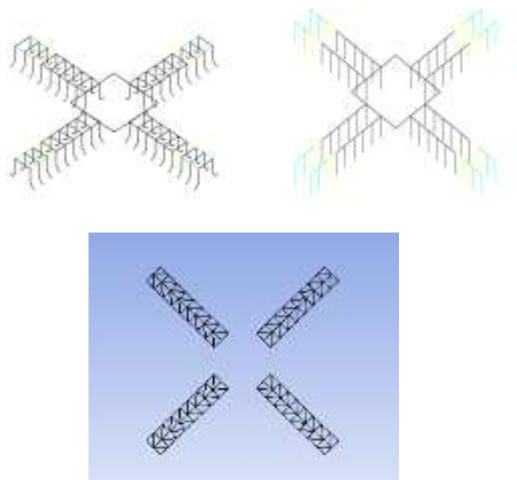

Fig. 3. Stirrup, stud and truss.

TABLE I. Material properties.

Material	Input Parameters	Slab
Concrete	Young's modulus Poison's ratio	25000MPa 0.15
Bottom and top reinforcement	Density Young's modulus Poisson's ratio Yield strength	7750 kg/m3 200000 M Pa 0.3
Column reinforcement	Density Young's modulus Poisson's ratio Yield strength	7750 kg/m3 200000 M Pa 0.3 415MPa
Stud	Density Young's modulus Poisson's ratio Yield strength	7750 kg/m3 200000 M Pa 0.3 345MPa
Stirrup	Density Young's modulus Poisson's ratio Yield strength	7750 kg/m3 200000 M Pa 0.3 415MPa
Truss	Density Young's modulus Poisson's ratio Yield strength	7750 kg/m3 200000 M Pa 0.3 415MPa

IV. RESULT AND DESCUSSION

In order to find best model having high punching shear resistance different arrangements of truss, stirrup and studs were used. Among this for rectangular arrangement different intensity of shear reinforcement is used. That is two times length of column as maximum intensity and length of column as minimum intensity. Values obtained for the analysis of slab without shear reinforcement is used for the comparison. Result obtained from each arrangement is as follows:

TABLE II. For rectangular arrangement.

Slab	Shear Connector	Failure load	Total deformation	Stress	Percentage Increase In Load
SB1	Null	4.90 x10^5	13.2	5.95	
SB2	Stud Maximum	5.66x10^5	13.215	4.57	15.2
SB3	Stud Minimum	5.56 x10^5	13.305	4.75	13.4
SB4	Stirrup Maximum	5.59x10^5	12.601	4.57	14
SB5	Stirrup Minimum	5.56x10^5	13.05	4.75	13.4
SB6	Truss Maximum	5.63x10^5	12.793	5.09	14.9
SB7	Truss Minimum	5.58x10^5	12.962	5.40	13.8

Table shows that stud of maximum intensity shows better performance. Slab with maximum stud intensity have a load carrying capacity of 15.2% more than conventional slab. With truss also have load carrying capacity 14.9% .From this also conclude that shear reinforcement of maximum intensity shows better performance, irrespective of the type

TABLE III. For angular arrangement.

Slab	Shear Connector	Failure load	Total deformation	Stress	Percentage
SB1	Null	4.9 x10^5	13.21	5.95	
SB2	Stud	5.51x10^5	13.11	4.65	12.4
SB3	Stirrup	5.565x10^5	13.164	6.123	13.5
SB4	Truss	5.6x10^5	12.73	4.7	14.2

Table shows that truss have better performance. Slab with truss have a load carrying capacity of 14.2% more than conventional slab. Rectangular arrangement of truss also shows better performance.

TABLE IV. For radial arrangement.

Slab	Shear Connector	Failure load	Total deformation	Stress	Percentage
SB1	Null	4.9 x10^5	13.21	5.95	
SB2	Stud	5.63 x10^5	13.45	4.65	14.8
SB3	Stirrup	5.62x10^5	13.71	4.63	14.7
SB4	Truss	5.73x10^5	12.8	4.34	17

Table shows that truss have better performance. Slab with truss have a load carrying capacity of 17% more than conventional slab. Value of stress is also reduced for radially arranged truss. Among all the three arrangements truss with radial arrangement have less equivalent stress.

After this three individual arrangement of truss or stirrup or stud, slab with combination of this shear reinforcement with radial arrangement is also analysed and the result is as follows

TABLE V. For radial (combination) arrangement.

Slab	Shear Connector	Failure load	Total deformation	Stress	Percentage
SB1	Null	4.9x10^5	13.21	5.95	
SB2	Truss Angular Stud Rectangular	5.68x10^5	13.13	4.7	15.9
SB3	Truss Angular Stirrup Rectangular	5.67x10^5	13.15	5.26	15.7
SB4	Stud Angular Stirrup Rectangular	5.62x10^5	13.75	4.60	14.6
SB5	Stirrup Angular Stud Rectangular	5.65x10^5	13.17	5.3	15.3
SB6	Stirrup Angular Truss Rectangular	5.63x10^5	13.36	4.61	14.8
SB7	Stud Angular Truss Rectangular	5.62x10^5	13.58	4.65	14.6

Table shows that combination of truss angular stirrup rectangular have better performance. Slab with combination of truss angular stirrup rectangular have a load carrying capacity of 15.9% more than conventional slab. Value of stress is also reduced.

Load carrying capacity and stress distribution pattern is considered for taking the best model. Model from each section having high load carrying capacity and better stress distribution pattern is considered for the result comparison.

Here maximum value obtained from each arrangement of shear reinforcement is compared. Each arrangement shows better performance, compared to flat slab without shear reinforcement. Among these flat slab with radially arranged truss have maximum load carrying capacity and minimum value of stress. Stress distribution pattern shows the intensity of crack on slab. Load carrying capacity of selected model is 17% more than conventional slab. It also shows better performance during the application of lateral loads. When a full flat slab model is analysed, slab with truss shows better stress distribution.

TABLE VI. Comparison of maximum value obtained for different arrangement.

Slab	Shear Connector	Arrangement	Failure load	Stress	Percentage Increase In Load
SB1	Null		4.90 x10^5	5.95	
SB2	Stud	Rectangular	5.66 x10^5	4.57	15.5
SB3	Truss	Angular	5.6 x10^5	4.7	14.2
SB4	Combination Of Truss And Stud	Radial	5.68x10^5	4.7	15.9
SB4	Truss	Radial	5.73 x10^5	4.34	17

TABLE VI. For lateral loading.

Angle of Loading (Degree)	Shear Connector	Failure load	Total deformation	Stress	%
45	Null	5.04x10^5	14.4	5.84	
90	Null	3.21x10^5	5.6	4.58	
45	Truss	5.6 x10^5	13.49	5.6	11.11
90	Truss	5.58x10^5	5.2	4.69	18

From all the results flat slab with radially arranged truss have high load carrying capacity, less deformation, less stress distribution value. It also have the capacity to resist lateral load acting on it along with the impact load. That is it has the capacity to resist the punching shear and lateral load.

V. CONCLUSION

In this analysis a flat slab of size 5800mm x 4800mm x 150mm and shear reinforcement such as truss, stirrup and stud was used to find the effect of impact load. Flat slabs with and without shear connectors are used for the analysis The FEA analysis software ANSYS16.1 is used for the analysis.

- Different type of shear connectors such as stud, stirrup and truss are used. Various placement and amount of these shear connectors are used for the analysis.
- The comparison between rectangular, angular and radial arrangement of shear connectors is done. Also combination of stud, stirrup and truss in radial arrangement is also compared with above.
- The comparative studies show that the radial arrangement of truss increases the load capacity of slab it also decreases the stress and deflection of the slab. The increase in load capacity is 17% when compared to conventional flat slab.
- Stress distribution the slab shows the crack developed on the slab during loading.
- Lateral load acting at an angle of 45 degree and 90 degree is also applied for analysing the slabs performance. And the result shows that truss which is used as a shear reinforcement have the capacity to resist lateral load acting on the slab along with the punching shear resistance.
- In both cases (Impact load and Lateral load) slab with truss as shear connector, stress distribution and deflection decreases, and the load carrying capacity increases compared to conventional slab. It also shows better performance during lateral loading.

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