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Effect of Reinforcement Pattern on the Behaviour of Skew Slab

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Abstract – *Slab is an extensively used structural element which usually carries uniformly distributed gravity loads. Out of different shapes of slabs, rectangular and skew slabs have quite a good number of applications in modern civil engineering structures. Depending on the shape and the behavior of simply supported skew slabs it can be divided into two types. i) Skew slab with short diagonal to span ratio less than unity and ii) Skew slab with short diagonal to span ratio greater than unity. The use of FEA has been a preferred method to study the behavior of concrete structures as it is much faster than the experimental method and is cost effective. In this study finite element modeling of skew slab by using commercially available Finite Element software, ANSYS, has been carried out. Finite Element modeling of the skew slab (with short diagonal to span ratio less than unity) specimens with different reinforcement pattern has been done and the results obtained are compared. After the analysis it was found that minimum deflection and more load capacity was found on slab with reinforcement pattern of main bar parallel to the free edge and distribution bar perpendicular to the free edge.*

Key Words**: Reinforced concrete skew slab, skew angle, Reinforcement pattern, Finite Element Analysis, ultimate load of skew slab**

1. INTRODUCTION

In a reinforced concrete structure, slabs are used to forming roof covering and floors of buildings. Normally, slab is perpendicular to the supports whereas skew slab is a four-sided slab having equal opposite angles other than 90^0. This shape of the slab facilitates a large variety of options for an engineer in terms of alignment opportunities in case of obstructions.

The behavior of a simply supported skew slab applied by point load at the centre depends on the ratio of short diagonal to its span. Skew slabs with short diagonal to span ratio less than unity show lifting of acute corners whereas skew slabs with short diagonal to span ratio greater than unity do not.

For rectangular slabs, a typical reinforcement pattern is parallel to the edges. Depending on the geometry and boundary conditions of the slab, this may not be the best reinforcement orientation, especially so in case of skew slabs. For skew slabs, the sides of the slab are not orthogonal and so it is a matter of interest to study the effect of different types of reinforcement schemes to arrive at the best arrangement.

Finite Element Analysis (FEA) is a method used for the evaluation of structures, and providing an accurate prediction of the component's response subjected to various structural loads. The use of FEA has been a preferred method to study the behaviour of concrete structures as it is much faster than the experimental method. With the invention of sophisticated numerical tools for analysis like the finite element method (FEM), it has become possible to model the complex behaviour of reinforced concrete structures using Finite Element modeling. In this study finite element modeling of skew slab by using commercially available Finite Element software, ANSYS, has been carried out and compared the results with the available experimental results to validate the software. The study on effect of reinforcement pattern on the behaviour of skew slab is examined here by varying the pattern for different skew angle.

2. GEOMETRIC PROPERTIES OF CONTROL SPECIMEN

In order to validate the analytical results of proposed approach, an experimentally tested skew slab (Flexural Behaviour of Reinforced Cement Concrete Skew Slabs by B.R Sharma) have been modeled in ANSYS with skew angle of 16.49^0. M 25 concrete have been used along with reinforcement pattern of 8 mm diameter bars @100 mm c/c is perpendicular to the support and distribution steel of 8 mm diameter bars @125 mm c/c laid over main reinforcement at right angles to it or parallel to the supports. Thicknesses of slabs have been kept 70 mm with clear cover 10 mm. The dimensions of the specimen and reinforcement pattern are shown in figure 1 and figure 2 respectively.

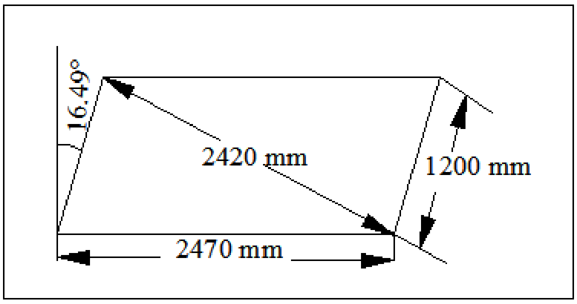


Fig -1: Dimensions of skew slab

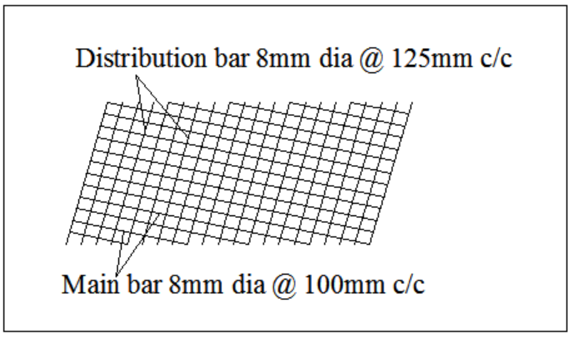
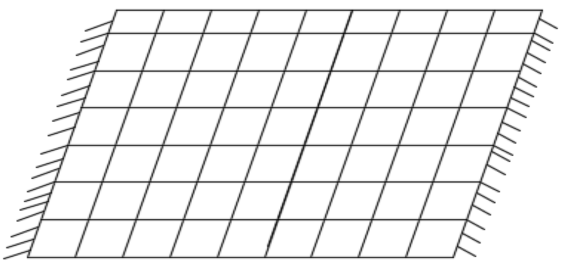


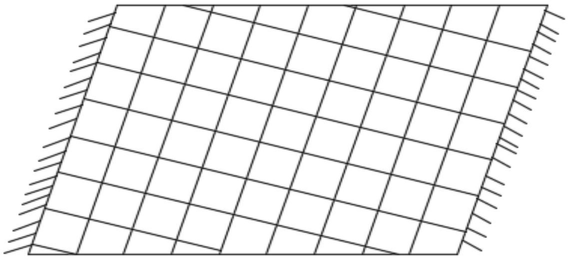
Fig -2: Reinforcement arrangement in skew slab

To understand the effect of reinforcement pattern on the behavior of skew slab, a study was conducted on skew slabs with three different reinforcement patterns as shown in figure3 under different angles:

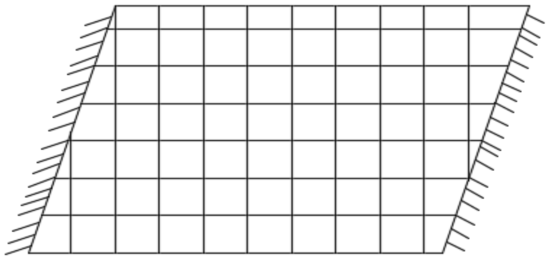
Pattern1: Main reinforcement is parallel to the free edge and the transverse reinforcement is parallel to the supported edge.
Pattern2: Main reinforcement is perpendicular to the supported edge and the transverse is parallel to the supported edge
Pattern3: Main reinforcement is parallel to the free edge and the transverse is perpendicular to the free edge



pattern-1



pattern-2



pattern-3

Fig -3: Types of arrangement of reinforcement

3. FINITE ELEMENT METHOD

The Finite Element Method (FEM) is a numerical analysis for obtaining approximate solutions to a wide variety of engineering problems. The basic concept behind FEM is that a body or structure is divided into smaller elements of finite dimensions called 'finite elements'. The original structure is then considered as an assemblage of these elements at a finite number of joints called 'nodes'. A commercially available FEM Software called ANSYS of version 15 is used for the finite element modeling.

3.1 Modelling

Selection of proper element types is an important criterion in Finite Element Analysis. For reinforced concrete slab the Concrete portion was modeled by using a special element available in the package particularly for Concrete namely SOLID 65 element. The element may be used to analyze cracking in tension and crushing in compression. This element has eight nodes, with each node having three translational degrees of the nodal X, Y & Z directions as shown in Figure 4.

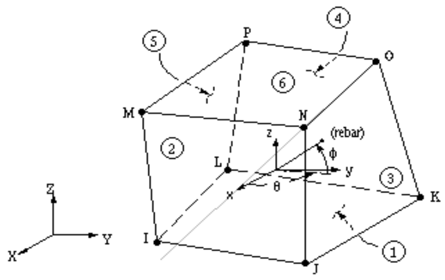


Fig -4: SOLID 65 Element

Table -1: Material properties of solid 65 element

Element Type	Material Properties	
SOLID65	Linear Isotropic	
	E_c	25000 MPa
	PRXY	0.2
	Concrete	
	Open Shear Transfer Coefficient (β_0)	0.2
	Closed Shear Transfer Coefficient (β_c)	0.9
	Uniaxial Cracking stress(ft)	3.5MPa
	Uniaxial Crushing Stress (fc')	25 MPa

The reinforcement was modeled by using LINK 180 element. Depending upon the applications, the element may be thought of as a truss element, a cable element, a reinforcing bar and a bolt. The three-dimensional spar element is having two nodes and each node having three translational degrees of freedom as shown in Figure 5. The material properties provided are given in table 2.

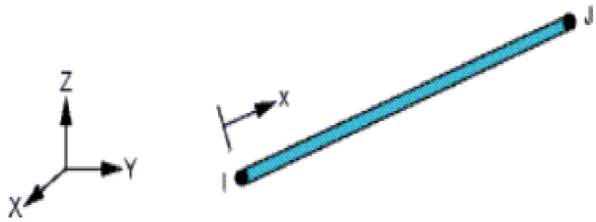
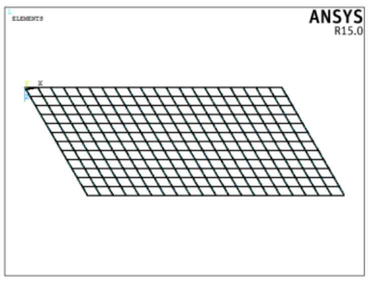


Fig -5: LINK 180 Element

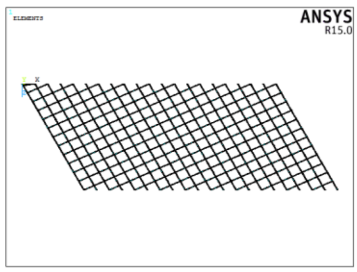
Table -2: Material properties of Link180 element

Element Type	Material Properties	
LINK180	Linear Isotropic	
	Ec	200000 MPa
	PRXY (v)	0.3
	Bilinear Isotropic	
	Yield Stress (f_y)	415 MPa

This element is capable of plasticity, creep, swelling and stress stiffening effects. The cross sectional area can be given as the real constant.



(a) pattern-1



(b) pattern-2

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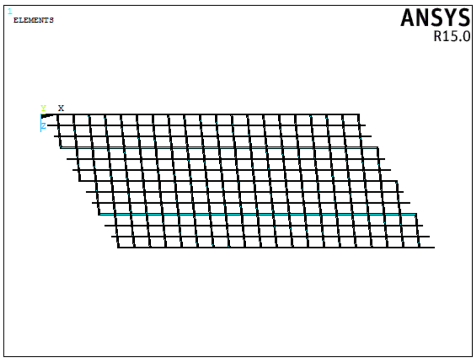

(c) pattern-3

Fig -6: Different reinforcement pattern on slab with skew angle 30^0

3.2 Analysis

Displacement boundary conditions are needed to constrain the model to get a unique solution. To achieve this, the translations at the nodes UX, UY and UZ are restrained in order to obtain a hinged joint and translations at the nodes UY, UZ are restrained in right side in order to obtain the roller joint. The force or a gradually increasing load in the downward direction is applied at the centre of the slab. The Static analysis type is utilized in this study. The Newton-Raphson method of analysis is used to compute the nonlinear response.

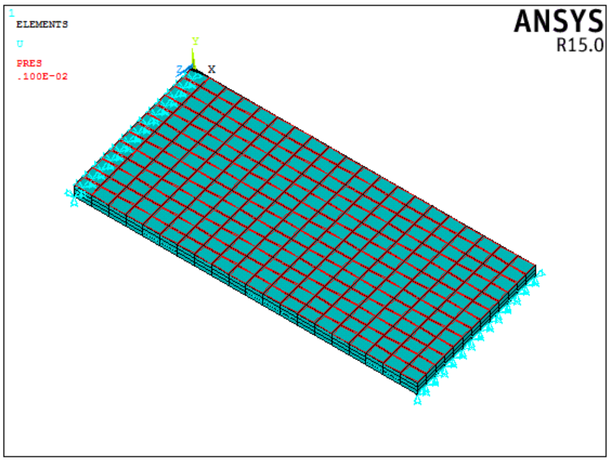

Fig -7: Boundary condition of skew slab

4. RESULTS AND DISCUSSIONS

The results of this study can be mainly included under 2 part such as the result of comparison of experiment and finite element analysis study and study of effect of reinforcement pattern on the behavior of skew slab.

4.1 Comparison of experimental and analytical results

To validate the obtained FEA results, comparison with experimental results are necessary. In the case of experiment, the load was applied gradually at the centre of the test specimen and deflections at the centre of the slab at different load are recorded. In FE Model of skew slab specimen, loads have been applied at the centre of the slabs as done in case of experiment. The load on the structure has been gradually increased in the steps till failure. The load-deflection values at every step have been recorded as in table 3

Table -3: Load and deflection from experiment and FE model

Load (kN)	Deflection (mm)	
	Experimental	Fe model
5	5.5	5.067
10	7.7	8.47
15	17	13.3875
20	24.7	20.67
25	29.3	25.75
26.4	-	29.1942

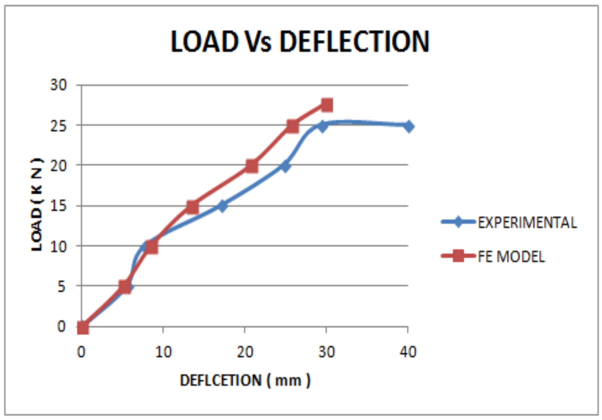

Chart-1 : Load v/s Deflection comparison graph

From the plotted graphs in chart-1, the FE model and Experimental results shows almost same results. It can be seen that the structure behaved linearly elastic up to the

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value of load 10kN. At this point minor cracks started to get generated. After this point there is slight variation in curvature in the plot and deflection started increasing. The ultimate load and corresponding deflection for FE model are 26.4kN and 29.1942mm respectively whereas the ultimate load and corresponding deflection came from experimental result was 25kN and 29.3mm respectively.

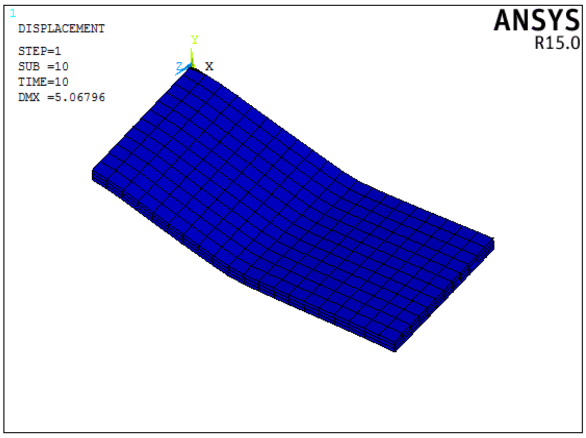

Fig -8: Deformed shape of slab at a load of 5kN

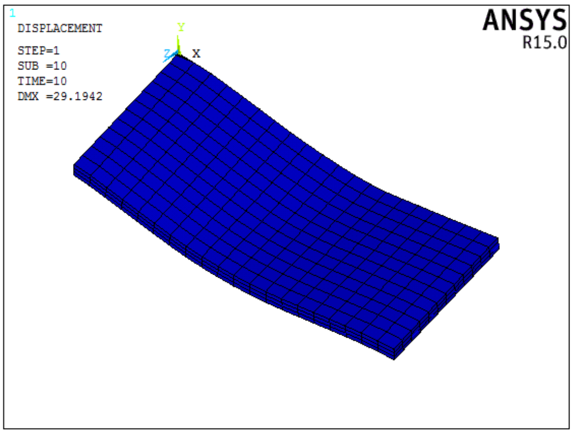

Fig -9: Deformed shape of slab at ultimate a load

4.2 Effect of reinforcement pattern on skew slab

For comparing the effect of reinforcement on skew slab (ratio of short diagonal to span less than one), slab with skew angles of 15^0, 30^0, 45^0, and 60^0 were modeled with pattern 1, pattern-2 and pattern 3 reinforcements and analyzed to get the crack load. Crack load is the load corresponding to the formation of first crack. The crack load in each case is tabulate in table 4. In the graph showing in the figure 12 x-axis represents the skew angles changing from 15^0 to 60^0 and y-axis represents the crack load for skew slab with three patterns of reinforcement

Table -3: Crack load of skew slabs with different pattern at different angle

Angle (in degree)	load (k N/m^2)		
	pattern - 1	pattern - 2	pattern - 3
15	8.2	9.3	10.2
30	10.3	12.1	13.3
45	24.9	26.1	27.5
60	46.7	48.8	51.9

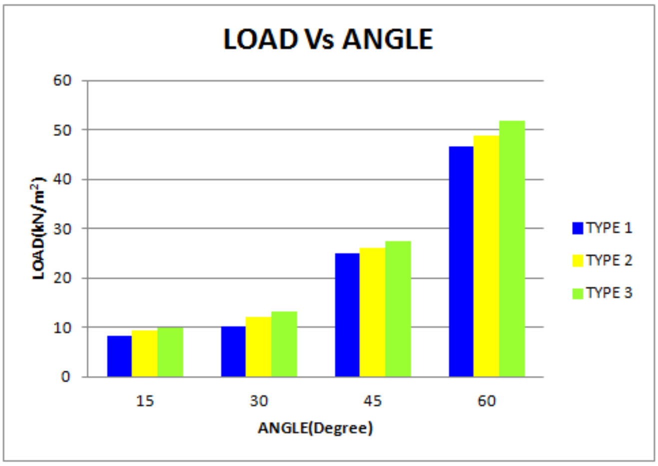

Chart-2: Load v/s Skew Angle graph of pattern-1, pattern-2, and pattern-3 reinforcement

From chart-2, it is clear that the slabs reinforced with pattern-3 (Main reinforcement is parallel to the free edge and the transverse reinforcement is perpendicular to the free edge) have higher load carrying capacity whereas Slab with pattern-1 reinforcement show less load carrying capacity.

4.2 Crack Patterns in skew slabs

The variations of crack pattern have been taken out from the post processer of ANSYS. The figure 11 and 12 represents the crack pattern of slab with skew angle 15^0 at its yielding load and at ultimate load respectively.

For the skew slab in general, at the early stages of loading, the behaviour was elastic until the appearance of the first crack. Invariably, the crack was initiated at the centre of the skew slab and the cracks gradually propagate

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towards the end of the free edge on the tension face side as the loading progressed and the crack propagation is parallel to the support edge.

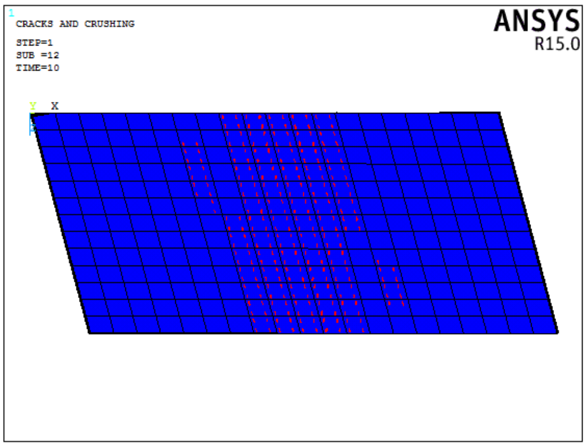

Fig -11: Crack pattern of skew slab with skew angle 15^0 at yielding

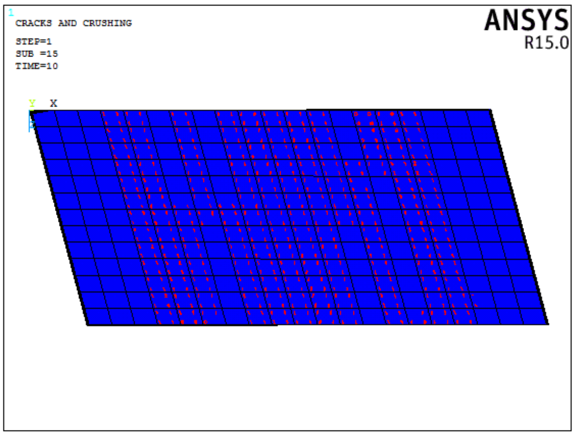

Fig -12: Crack pattern of skew slab with skew angle 15^0 at ultimate load

While varying the skew angle from $0\text{-}60^0$ the load carrying capacity increases. The behavior of load carrying capacity and skew angle of skew slab with pattern-3 reinforcement is graphically represented in chart-2.

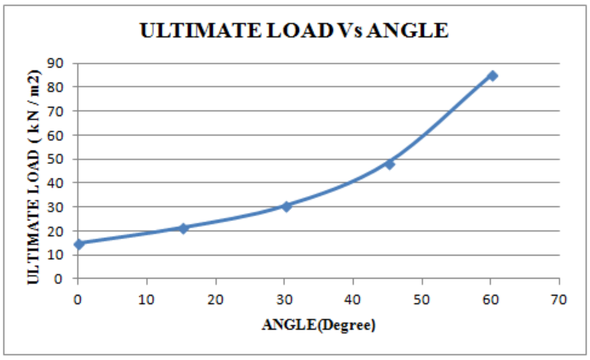

Chart-3: Ultimate load of skew slab with varying skew angle

This increase in load carrying capacity and decrease in deflection corresponding to increase in skew angle is because the maximum force flow between the support lines is through the strip area connecting the obtuse angled corners, as skew angle increases the length of strip area decreases.

5. CONCLUSIONS

In this study the behaviour of reinforced cement concrete skew slab with different reinforcement paatern having different skew angle under static load has been investigated. The following conclusions are obtained from the investigations

1. The general behavior of the finite element models represented by the load-deflection curves show good agreement with the experimental data. It is verified that the finite element analysis can accurately predict the load deformation similar to the experiment.
2. Slab with reinforcement pattern-3(main reinforcement parallel to the free edge and distribution reinforcement perpendicular to the free edge) has more cracking load and ultimate load capacity compare with the other patterns.
3. Also value of deflection is minimum for the type-3 reinforcement pattern
4. Micro cracks have been observed to appear even when the skew slab is in its elastic zone. The cracks have been found increasing with the increase in deflection.

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