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Load Deflection Behaviour of Restrained RC Skew Slabs Using FEM Technique

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Abstract

In this paper, a technique is suggested for finding out the complete load deflection behaviour of RCC skew slabs fixed at the edges, which is subjected to consistently distributed load. The investigation is considered in two phases. In the first phase, the load deflection behaviour up to cracking load is considered. The behaviour between the cracking load and the yield line load is considered in the second stage. A skew angle of 15º, 30º and 45º are used to study the behavior of slabs. The results obtained by using FEM technique (software tool ANSYS) are compared with experimental and theoretical results.

Keywords: analysis, deflections, fixed support, skew slabs, skew plates, slabs.

INTRODUCTION

In strengthened concrete construction, the slab is a widely used basic component shaping floors, street asphalt bridges and the rooftops. A concrete slab is the plane component having the profundity much littler than its range and width. It might be bolstered by strengthened concrete bars, by masonry walls and straight forwardly by columns. It ordinarily conveys consistently circulated gravity loads acting typical to its surface and exchanges same to the backings by flexure, shear and torsion. It is a direct result of this mind-boggling conduct that it is hard to choose whether the slab is a basic component, segment or basic framework.

In the event that a road arrangement crosses a river or other block at an alignment not the same as 90o, a skew intersection might be vital. In prior days of moderate traffic, endeavours were made to have a square intersection for the scaffold segment and appropriate bends were presented in the methodologies. With the present day quick traffic, safety prerequisites request sensibly straight arrangement for the road, requiring skew scaffolds. The alignment of the middle line of traffic to the ordinary to the inside line of the river if there should be an occurrence of river extension or other block is known as the skew edge. The investigation and configuration of skew slab is very confounded than those for a right slab. With increment in the skew edge, the stresses in the skew slab are contrast essentially from those in the straight slab.

While designing a road project, it is unrealistic to cross every one of the rivers and channels at right angle. Along these lines skew bridges are arranged at such destinations keeping in mind the end goal to cross the rivers or channels at a point other than ordinary without exasperating the geometry and arrangement of the road. Utilization of finite element technique to decide the ultimate loads of slabs and deflections of slabs are of late starting point. The upside part of ANSYS is that nonlinear examination can be done by characterizing the nonlinear properties of materials. As of late the studies utilizing ANSYS finite element bundle demonstrate that it can reproduce the conduct of reinforced concrete elements and results acquired from ANSYS are closer to experimental values.

LITERATURE REVIEW

Prakash Desayi & A Prabhakara [1] had investigated load deflection behaviour of restrained RC skew slabs subjected to uniformly distributed load. The experimental program consisted of casting, curing and testing of 12 skew slabs which having an aspect ratio of 1.5. In those 12 slabs 4 slabs are of 15º, 30º and 45º each with different reinforcement spacing. Mild steel rods of 4mm diameter, having 0.2% of proof stress were used as reinforcement. Slabs were casted for 50mm thick with a 10 mm cover. The testing procedure was carried out in a loading frame of capacity 50 tonnes. For avoiding any local damage to any of the 16-point loading, loading is transfer at each of these points through a bearing plate. The experimental test result showed that load enhancement decreases with increase in percentage of reinforcement skew angles [1].

Kanhaiya Lal Pandey [3] had investigated a simplified approach for the behaviour of reinforced concrete slab under different loading conditions (Four-point load) with reference to IRC class B loading. The test slabs were cast using ordinary Portland cement. Three modelled concrete skew slabs were tested in concrete and structure lab. The tests slabs were designated as SS01, SS02, SS03 with skew angle 30o. In first stage the skew slabs were tested with uniformly distributed load up to elastic limit and in next stage slabs were tested with 4-point loading arrangement with eccentric as well as eccentric. And they concluded that, for the same aspect ratio and skew angle, the ultimate load carrying capacity of skew slabs are higher in the case of uniformly distributed across the width and like that of four-point centric loads when it is compared with four-point eccentric loading [3].

Abozaid. L.A et al. [5] have published a paper on non-linear behaviour of a skew slab bridge under traffic loads. The main aim of his work is to present the typical experimental and non-linear finite element analysis which is design using direct design method. The skew angles 15º, 30º and 45º were chosen to study its behaviour and the result is compared with those of straight slabs. The 6 different grades of strength are used in slabs such as 400, 500, 600, 700, 800 and 900 kg/cm². And according to the Abozaid he concluded that skew slabs exhibit larger displacements for same loading and boundary conditions compared to rectangular slabs and also as the skew angle increased the deflection increased and the failure load is decreased [5].

Nizamud-Doulah.S.M et al [6] studied the behaviour of RC skew slabs to obtain the load deflection response and the ultimate strength of slabs. For precise prediction of the response of reinforced concrete structure under load, materials models of both, concrete and steel are used. He used M30 grade concrete on 4 test slabs and results obtained from this experiment is compared with the numerical method. Based on the results obtained the experimental failure loads is well in agreement with the numerical results. The average experimental ultimate load to the numerical is 1.0 and the experimental load deflection curve well matches with slight under estimation of deflection [6].

EXPERIMENTAL DATA

This experiment on load deflection behaviour of restrained R/C skew slabs was conducted by Prakash Desayi and A Prabhakara [1]. The main intention of this experiment is to know the cracking behaviour, strength and to compare the deflections with those determined by proposed method for R/C skew slabs. This experimental work includes casting, testing of all 12 slabs with various skew angle with various reinforcement spacings. This experimental data is extracted and the analysis is carried out for the experimental data in ANSYS. The details of experimental data are indicated in Table 1.

Table 1: Details of Skew Slabs with Fixed Edges

Sl. No.	Slab Designation	Skew Angle (degrees)	Spacing of Bars (mm)		Percentage of Bars	
			along X direction	along Y direction	in X direction	in Y direction
1	FS1-15	15	50	50	0.63	0.70
2	FS2-15	15	75	50	0.63	0.47
3	FS3-15	15	100	50	0.63	0.35
4	FS4-15	15	100	75	0.42	0.35
5	FS1-30	30	50	50	0.63	0.70
6	FS2-30	30	75	50	0.63	0.47
7	FS3-30	30	100	50	0.63	0.35
8	FS4-30	30	100	75	0.42	0.35
9	FS1-45	45	50	50	0.63	0.70
10	FS2-45	45	75	50	0.63	0.47
11	FS3-45	45	100	50	0.63	0.35
12	FS4-45	45	100	75	0.42	0.35

Slab Thickness = 50mm, Diameter of bars = 4mm,

Cover = 10mm

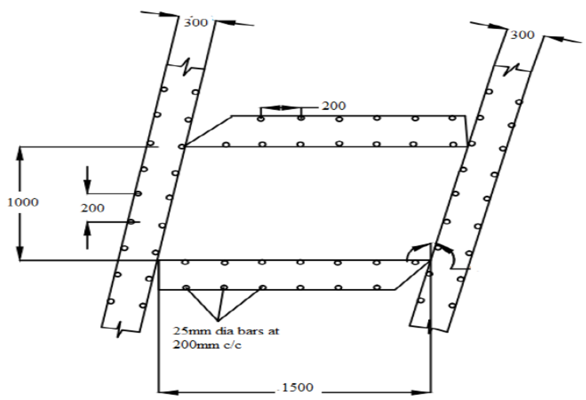

Figure 1: Experimental skew slab with fixity at the edges

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Load-Deflection Curves

The typical Load Vs Deflection curves for the experimental skew slabs are shown in Figure 2, Figure 3 and Figure 4.

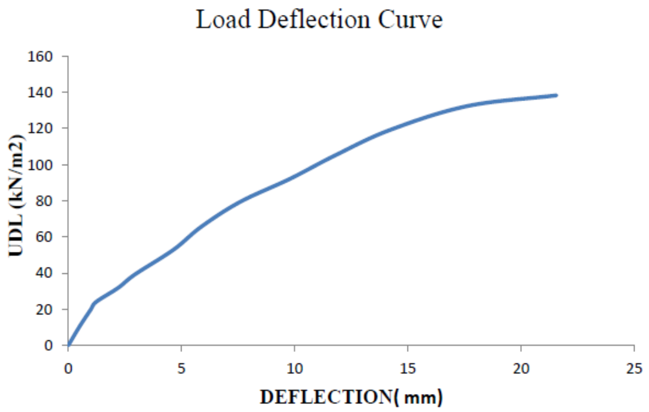

Figure 2: Experimental load-deflection curve for FS1-15

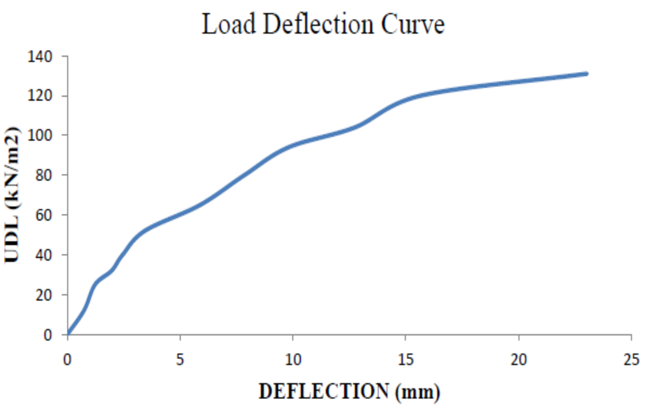

Figure 3: Experimental load-deflection curve for FS1-30

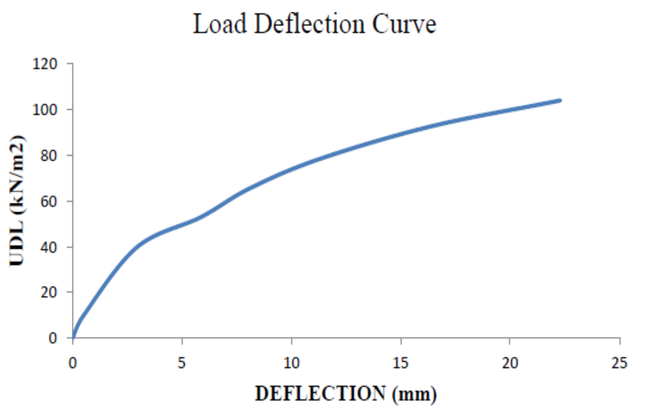

Figure 4: Experimental load-deflection curve for FS1-45

Desayi & Prabhakara Method [1]

This method has been developed in 2 stages. The first stage deals with the behaviour of the slab upto cracking load. The second stage deals with the behaviour between cracking load and yield line load and third stage deals with behaviour after yield line load. The assumptions made are,

1) The compressive membrane forces are formed, in the slab after the development of yield line mechanism at yield line load
2) At yield line load the +ve yield lines developing through the obtuse and acute corners are imagined to lay on the bisector of the angle.
3) As in yield line theory it is presumed that the deformation of the slab, appear along yield lines and the portions of the slab between yield lines are rigid.
4) The tensile strength of concrete of concrete is ignored
5) The ordinates are taken parallel to the sides and the bars are kept, parallel to the sides and at equal spacing. The base reinforcement is provided all-round the slab where as the top bars are extended for a distance of 1/4th of the length of the edge.
6) The slab is formed of strips running, parallel to its sides. Yield sections of the strips are normal to the direction of bars.

Stages in Analysis

Stage-1: Load-Deflection Behavior upto Cracking Load

In this stage, the behaviour upto cracking load is considered. It is phase in which concrete slabs forms the first major crack at the maximum bending moment point, the corresponding load is called as cracking load. The deflection of the slab for this stage is computed based on elastic skew plate theory. Thus, the deflection at the middle of the skew slab is given by

$$\delta_{cr} = \frac{\alpha_1 q_{cr} L_x^4}{E_c I_g}$$

In which the $\alpha_1$is taken from Table 2 (Extracted from table 1 of reference [2]).

Table 2: Coefficient α_1 for maximum deflection at the centre for various skew angles and ratio of sides

Sl. No.	**Skew Angle**	**Values of Lx/Ly**			
		1.00	**1.25**	**1.50**	**2.00**
1	15^o	1.793	1.055	0.611	0.221
2	30^o	1.181	0.696	0.405	0.147
3	45^o	0.508	0.301	0.177	0.0656
4	60^o	0.120	0.0717	0.0426	0.0162
5	75^o	0.0082	0.00495	0.00296	0.00114

The load at the development of first crack q_{cr} is obtained from

$$q_{cr} = \frac{f_r I_g}{\beta_1 h_t L_x^2}$$

In which, suitable values for moment coefficient β_1 are based on the skew angle and Lx/Ly.

Stage-2: Load-Deflection Behaviour Between Cracking Load and Yield Line Load

When load increases on slab exceeding cracking load the slabs cracks. The deflection behaviour of RC skew slab for the load $q>q_{cr}$ differs and it is dependent on various factors such as percentage of reinforcement in the two directions, characteristics of concrete and steel, skew angle, Hence the formula is used to find the deflection at cracking load is altered as

$$\delta_y = \frac{\alpha_1 q L_x^4}{k_r E_c I_e}$$

$$I_e = \left(\frac{q_{cr}}{q}\right)^3 I_g + \left[1 - \left(\frac{q_{cr}}{q}\right)^3\right] I_{cr}$$

$$k_r = 0.2346 + 0.00305\lambda_1$$

$$\lambda_1 = \left(\frac{\rho_x \rho_y}{\rho_x + \rho_y}\right)\left(\frac{f_y}{f_c}\right)\left(\frac{h}{L_y}\right)\left(\frac{1}{1+6tan\theta}\right) 10000$$

The yield line load q_y is computed from,

$$q_y = \frac{6M'_{py}\frac{L_x}{L_y}\left(1+\frac{M''_{py}}{M'_{py}}\right) + \lambda\left(1+\frac{M''_{px}}{M'_{px}}\right)}{L_y^2\left(3\frac{L_x}{L_y} - 1\right)}$$

Analysis Using FEM Technique – ANSYS

The numerical analysis is performed using Finite Element package ANSYS 15. FEM is a numerical technique for determining relative solutions to wide collection of engineering problems. Nonlinear finite element method helps to perform analysis on behaviour of RC structural elements by separating the elements continuum into a mesh of finite discrete elements. In this work the RC skew slabs with all the edges restrained have been analysed using finite element model in ANSYS version 15. Elements used are

1) Concrete: A Solid65 is used for 3d modelling. The solid is capable of racking in tension and crushing in compression. This element is defined by eight nodes having three degrees of freedom at each node that is translations in the nodal x, y, and z directions.

2) Steel reinforcement: Link180 element is used, to model reinforcement bars, this element can be used to model various structural elements such as 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.

3) Meshing element: Plane182 element is used as a meshing element. PLANE182 is used for 2-D modelling of solid structures. This element can be used as either a plane element (plane stress, plane strain or generalized plane strain) or an axisymmetric element. It is defined by four nodes having two degrees of freedom at each node that is translations in the nodal x and y directions. The element has plasticity, hyper elasticity, stress stiffening, large deflection, and large strain capabilities.

Figure 5 and Figure 6 show the FEM model of skew slabs with fixed edges and the displacement of skew slabs.

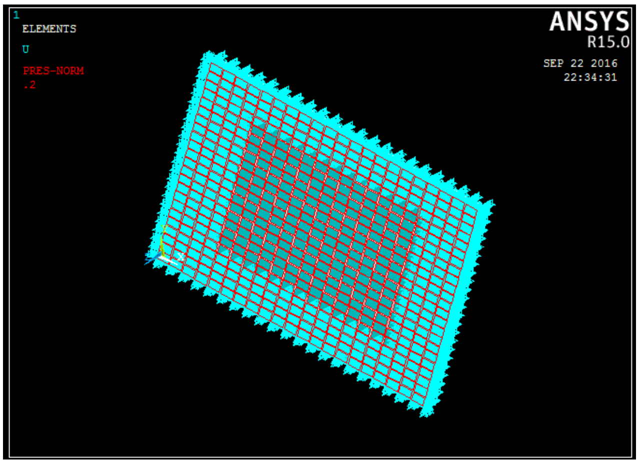

Figure 5: FEM model of skew slab

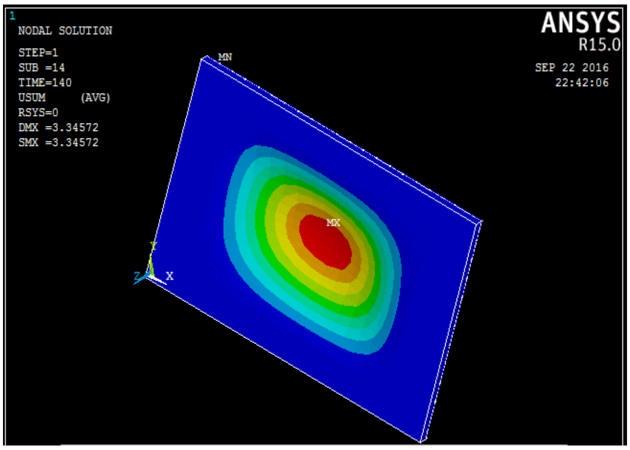

Figure 6: Displacement of skew slab

RESULTS AND COMPARISON

Load-Deflections upto Yield Line Load

The ratios of experimental deflection to theoretical deflection at working load and yield line load are computed and tabulated in Table 3 and Table 4.

Table 3: Deflections at working load

Sl. No.	Slab Designation	Working Load (kN)	Experimental Deflection (mm) δ_e	Theoretical Deflection (mm) δ_c	Ratio $\frac{\delta_e}{\delta_c}$
1	FS1-15	138.6	8.10	11.80	0.68
2	FS2-15	118.1	5.60	10.99	0.51
3	FS3-15	114.2	7.20	10.30	0.69
4	FS4-15	103.46	6.60	11.50	0.57
5	FS1-30	132.9	7.00	12.10	0.57
6	FS2-30	112.3	6.10	10.78	0.56
7	FS3-30	110.3	7.00	10.00	0.70
8	FS4-30	108.4	5.00	9.50	0.52
9	FS1-45	105.4	5.10	5.44	0.93
10	FS2-45	99.6	5.00	4.41	1.13
11	FS3-45	94.6	4.40	3.50	1.25
12	FS4-45	87.1	3.00	3.16	0.94
Average					**0.76**
Coefficient of variation					**0.31**

Table 4: Deflections at yield line load

Sl. No.	Slab Designation	Yield Line Load (kN)	Experimental Deflection (mm) δ_e	Theoretical Deflection (mm) δ_c	Ratio $\frac{\delta_e}{\delta_c}$
1	FS1-15	173.8	15.0	18.14	0.82
2	FS2-15	155.2	10.50	17.01	0.61
3	FS3-15	140.8	15.50	15.76	0.98
4	FS4-15	122.8	14.00	19.04	0.73
5	FS1-30	160.4	13.30	17.05	0.78
6	FS2-30	134.7	13.00	16.71	0.77
7	FS3-30	125.6	14.00	15.60	0.89
8	FS4-30	97.1	9.00	15.98	0.56
9	FS1-45	119.6	12.00	9.98	1.20
10	FS2-45	109.5	10.10	8.64	1.16
11	FS3-45	99.0	9.80	7.74	1.26
12	FS4-45	78.0	7.90	7.55	1.04
Average					**0.91**
Coefficient of variation					**0.25**

The load-deflection curves obtained by Prakash & Desayi Method and ANSYS are plotted against experimental curves and are shown in Figure 7, Figure 8 and Figure 9.

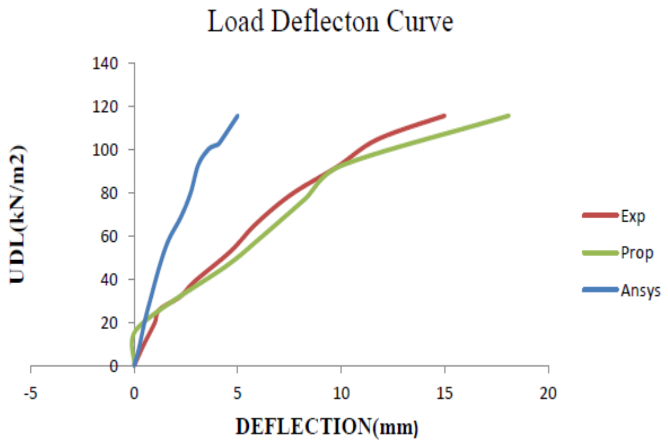

Figure 7: Comparative load-deflection curve for FS1-15

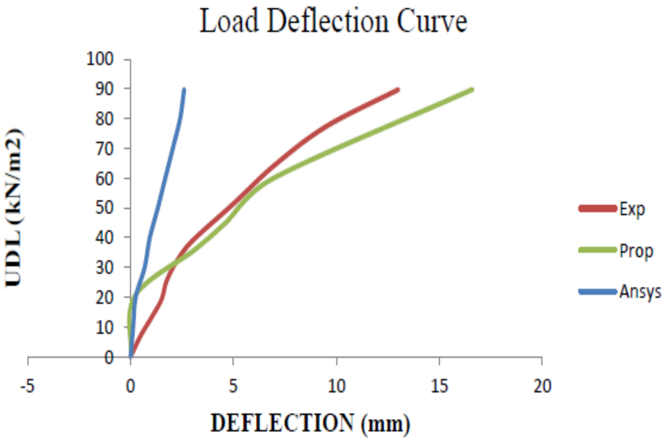

Figure 8: Comparative load-deflection curve for FS1-30

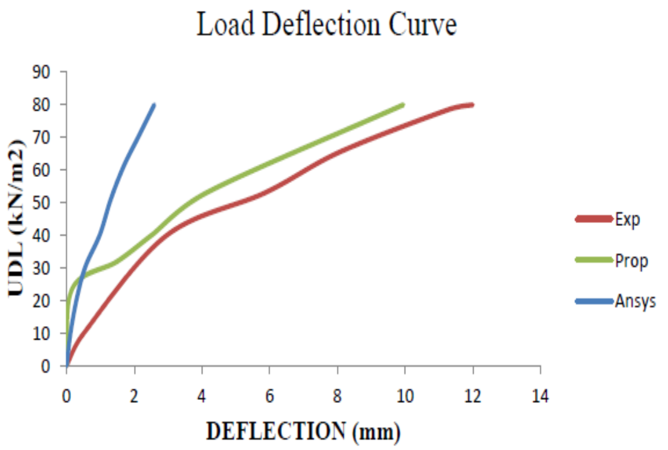

Figure 9: Comparative load-deflection curve for FS1-45

Comparison of deflections obtained using ANSYS are compared with experimental values at working load and tabulated in Table 5.

Table 5: Comparison of deflections at working load

Sl. No.	Slab Designation	Deflection at working load (mm)		Ratio $\frac{\delta_{exp}}{\delta_{ANSYS}}$
		δ_{exp}	δ_{ANSYS}	
1	FS1-15	8.10	3.02	2.68
2	FS2-15	5.60	1.18	4.74
3	FS3-15	7.20	2.35	3.06
4	FS4-15	6.60	1.52	4.34
5	FS1-30	7.00	5.05	1.38
6	FS2-30	6.10	2.38	2.56
7	FS3-30	7.00	1.60	4.37
8	FS4-30	5.00	2.30	2.17
9	FS1-45	5.10	2.36	2.16
10	FS2-45	5.00	2.39	2.09
11	FS3-45	4.40	0.83	5.30
12	FS4-45	3.00	2.99	1.00
Average				**3.0**
Coefficient of variation				**0.44**

Comparison of deflections obtained using ANSYS are compared with experimental values at yield line load and tabulated in Table 6.

Table 6: Comparison of deflections at yield line load

Sl. No.	Slab Designation	Deflection at yield line load (mm)		Ratio $\frac{\delta_{exp}}{\delta_{ANSYS}}$
		δ_{exp}	δ_{ANSYS}	
1	FS1-15	15.00	5.0	3.00
2	FS2-15	10.50	1.4	7.50
3	FS3-15	15.50	3.2	4.84
4	FS4-15	14.00	2.0	7.00
5	FS1-30	13.30	7.0	1.90
6	FS2-30	13.00	2.6	5.00
7	FS3-30	14.00	2.0	7.00
8	FS4-30	9.00	6.2	1.45
9	FS1-45	12.00	2.59	4.63
10	FS2-45	10.10	2.5	4.04
11	FS3-45	9.80	0.89	9.20
12	FS4-45	15	3	5.00
Average				**5.05**
Coefficient of variation				**0.44**

CONCLUSIONS

The following conclusions are drawn from the present study

1) The deflections at working load have been estimated by Desayi & Prabhakara method. The average deflection ratio of experimental to computed is 0.76 with a coefficient of variation of 0.310 (Table 3) at working load.
2) Now considering the deflection at yield line load, it can be observed that the deflection ratio between experimental and yield line load is acceptable. The average is 0.91 and co efficient of variation is 0.25 (Table 4)
3) Regarding ANSYS analysis the values at working load, the deflection ratio between ANSYS and experimental value is not satisfactory.
4) A semi-empirical approach combined with ANSYS can be attempted for satisfactory prediction of experimental load-deflection curves of restrained skew slabs.

REFERENCES

[1] Desayi P and Prabhakara A, “Load-Deflection Behaviour of Restrained R/C Skew Slabs,” Journal of Structural Division, ASCE, Vol. 107. May 1981, pp. 873-888.

[2] Kennedy J B, “On the Bending of Clamped Skew Plates under Uniform Pressure,” Journal of Royal Aeronautical Society, Vol. 69, May 1965, pp. 352-359.

[3] K Lal Pandey, “Behaviour of Reinforced Concrete Skew Slab under Different Loading Conditions,” GJESR Research paper, Vol. 1, February 2014, pp. 21-30.

[4] Desayi P and Prabhakara A, “Determination of Maximum Crack Width in Reinforced Concrete Skew and Rectangular Slabs,” Proceedings of the Institution of Civil Engineers, London, England, Dec 1979.

[5] Abozaid L A, “Nonlinear Behaviour of s Skew Slab Bridge under Traffic Loads,” Journal of World Applied Sciences, 2014, pp. 1479-1493.

[6] Nizamud-Doulah S M, “Behaviour of RC Skew Slabs-Finite Element Model and Validation, 27th conference on Our World in Concrete and Structures, August 2002, pp. 413-419.

[7] Madhu Sharma, “Finite Element Modelling of Reinforced Cement Concrete Skew Slab,” Department of Civil Engineering, Thapar University, Patiala, June 2011.

[8] Prabhakara A, “Strength and Deformation of Reinforced Concrete Skew Slabs, Ph.D. Thesis, Indian Institute of Science, Bangalore, 1979, pp. 154-160.

[9] IS 456:2000, Plain and Reinforced Concrete -Code of Practice (Fourth Revision).