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ANALYSIS OF SIMPLY SUPPORTED REINFORCED CONCRETE SKEW SLABS

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ABSTRACT

Reinforced concrete skew slabs are widely used in bridge construction when the roads cross the water streams and canals at angles other than 90 degrees. They are also used in floor systems of reinforced concrete buildings as well as load bearing buildings where the floors and roofs are skewed for architectural reasons or space limitations. In the present work, the load-deflection behaviour of simply supported reinforced concrete skew slabs was analysed using experimental and analytical methods. Finite element modelling of eighteen numbers of simply supported reinforced concrete skew slabs were made and non-linear analysis carried out on all skew slabs to obtain the load-deflection relationship under the action of uniformly distributed load. To carry out this analysis, a commercial Finite Element (FE) software ANSYS version 15 was used. Also, a method is proposed to predict the theoretical load-deflection curves. A comparison has been made between the experimental load deflection curves and using theoretical method, with the results of ANSYS.

Key words: analysis, concrete, deflections, simply supported, skew slabs, skew plates, slabs.

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1. INTRODUCTION

There is a growing demand for skew bridges as the needs for complex intersections and the problem with space constraint in urban areas arise. The presence of skew angle makes the analysis and design of skew slab intricate. For slabs with small skew angle, it is frequently considered safe to ignore the angle of skew and analyze the skew slab as right slab with the span equal to the skew span. However, slabs with large angle of skew can have a considerable effect on the behaviour of slab especially in the short to medium range of spans. Several parameters affect the response of skewed slabs which makes their behaviour complex. Therefore, there is a need for more research to study on the load-deflection behaviour of skew slabs.

To model the complex behaviour of reinforced concrete analytically in its non-linear zone is difficult. This has led engineers in the past to rely heavily on empirical formulae which were derived from numerous experiments for the design of reinforced concrete structures. The Finite Element Method (FEM) is an analytical tool which is able to model reinforced concrete structure and is able to calculate the nonlinear behaviour of the structural members. For structural design and assessment of reinforce concrete members, the nonlinear finite element analysis has become an important tool.

In the present work, finite element modelling of eighteen numbers of simply supported reinforced concrete skew slabs are made and non-linear analysis carried out on all skew slabs to obtain the load-deflection relationship under the action of uniformly distributed load. To carry this analysis, ANSYS v15 is used. And also for all eighteen simply supported reinforced concrete skew slabs a theoretical yield line analysis has done manually and obtained the results. A theoretical method is proposed using the thin plate elastic equation with a suitable effective moment of inertia function. A comparison has been made between the experimental, ANSYS and Proposed method.

2. LITERATURE REVIEW

Menassa et al. [1] compared the effect of skew angle with reference to straight bridge and reported that the bridges with skew angle less than 20 degree can be designed as non-skew as the moments are almost same for both.

University of Illinois [2] reported tables and curves for "Studies of highway skew slab-bridges with curbs" which show the variation of design moments with the bridge dimensions. These moments are compared with the corresponding moments in right slab-bridges with curbs.

Vikash Khatri et al. [3] have compared grillage method and finite element method of analysis of skew bridge and recommended the use of FEM because of close agreement with the exact solution and its capability to represent the complex geometry of the structure more realistically.

B. V. Sindhu et al., [4] carried out FEM analysis on RC slab bridge decks with and without edge beams to study the influence of aspect ratio, skew angle and type of load. The finite element analysis results for skewed bridges are compared to the reference straight bridges for dead load, IRC Class A loading and IRC 70R loading for with and without edge beam, A total of 90 bridge models were analyzed.

C. Deepak et al., [5] study deals with the finite element modelling of simply supported skew slab with varying skew angles using ANSYS software. Skew slab specimen with ratio of short diagonal to span less than unity is considered for studying the effect of skew angle on the behaviour of skew slab. It is revealed that when skew increases the uplift at both the acute corners also increases. The results also suggest that the load carrying capacity increases with increase in skew angle.

The above literature review points out the theoretical investigations on skew plates. However, a comparison between theoretical and experimental load-deflection behaviour on simply supported slabs has not been come across. Hence, a suitable method is required to analyse the same.

3. EXPERIMENTAL PROGRAMME [6]

The test data has been used to study the load-deflection behaviour of the simply supported skew slab with a view of the following.

- The values of constant k_s is obtained from the experimental programme. This constant k_s is used to modify the flexural rigidity of the simply supported skew slabs under service loads.
- To study and to obtain the actual load-deflection behavior up to the yield line load and to compare with that obtained from the software ANSYS and Proposed method of analysis.
- To compare Experimental values at working load as well as at yield line load and corresponding deflection values with the values obtained at yield line load from software ANSYS and Proposed method of analysis.

Fig. 1 shows the geometry of RC simply supported skew slabs and Tables 1 and 2 give the details of the tested slabs. All slabs were of thickness 50mm and bars used were of 4mm dia.

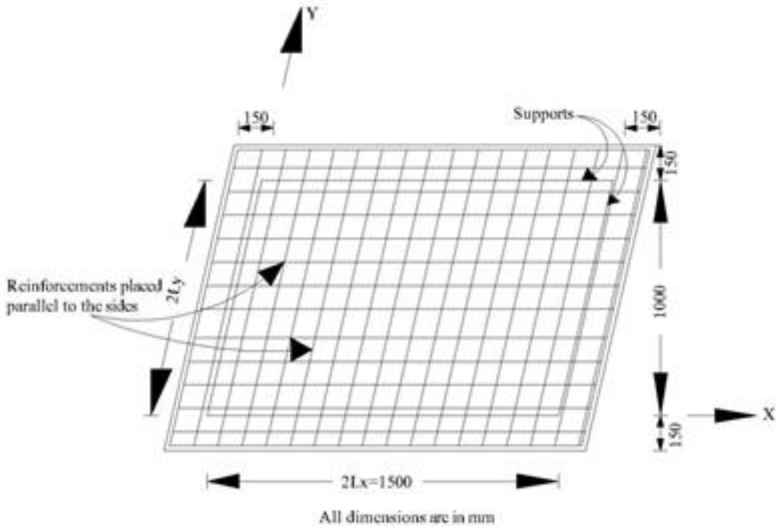

Figure 1 Geometry of a RC simply supported skew slab

Table 1 Details of simply supported RC skew slabs tested [6]

Sl. No.	Slab designation	Cube strength of concrete (N/mm^2)	Modulus of rupture of concrete (N/mm^2)	k_s
1	S1-15	24.1	4.32	0.400
2	S2-15	24.2	4.42	0.617
3	S3-15	24.0	4.42	0.389
4	S4-15	22.4	3.53	0.450
5	S5-15	19.8	3.53	0.482
6	S6-15	18.0	2.36	0.426
7	S1-30	31.8	4.51	0.448
8	S2-30	32.5	4.42	0.381
9	S3-30	28.0	3.92	0.355
10	S4-30	30.2	3.92	0.290
11	S5-30	35.4	4.32	0.173
12	S6-30	33.0	3.53	0.209
13	S1-45	28.5	3.24	0.257
14	S2-45	30.3	3.14	0.258
15	S3-45	34.5	3.43	0.210
16	S4-45	28.3	3.43	0.218
17	S5-45	32.0	3.53	0.151
18	S6-45	29.7	3.14	0.222

Table 2 Details of simply supported RC skew slabs tested [6]

Sl. No.	Slab designation	Skew angle (degs.)	Spacing of bars (mm)		Percentage of reinforcement		Coefficient of orthotropy
			along X direction	along Y direction	X-direction	Y-direction	
1	S1-15	15	50	50	0.630	0.700	1.13
2	S2-15	15	50	75	0.420	0.700	1.62
3	S3-15	15	50	100	0.315	0.700	2.11
4	S4-15	15	75	75	0.420	0.467	1.12
5	S5-15	15	75	100	0.315	0.467	1.46
6	S6-15	15	100	100	0.315	0.350	1.12
7	S1-30	30	50	50	0.630	0.700	1.12
8	S2-30	30	50	75	0.420	0.700	1.63
9	S3-30	30	50	100	0.315	0.700	2.12
10	S4-30	30	75	75	0.420	0.467	1.12
11	S5-30	30	75	100	0.315	0.467	1.47
12	S6-30	30	100	100	0.315	0.350	1.12
13	S1-45	45	50	50	0.630	0.700	1.12
14	S2-45	45	50	75	0.420	0.700	1.63
15	S3-45	45	50	100	0.315	0.700	2.14
16	S4-45	45	75	75	0.420	0.467	1.12
17	S5-45	45	75	100	0.315	0.467	1.47
18	S6-45	45	100	100	0.315	0.350	1.12

4. THEORETICAL PREDICTION OF LOAD-DEFLECTION CURVES

4.1. ANSYS

Finite Element Method (FEM) is an analytical tool which is able to model RCC structure and is able to calculate the nonlinear behaviour of the structural members. ANSYS v15 has been used to analyse the simply supported RC skew slabs. Three elements types PLANE 182, SOLID65 and LINK180 are used for meshing purpose, modelling concrete and reinforcing bars respectively. Subsequently, material properties have been assigned and loads are applied. The post processing results are reviewed and load deflection plots are generated for comparison.

4.2. Theoretical Method

The deflections at working load are computed using two stages. For the first stage the deflection corresponds to that in which the slab can be assumed as linear elastic load-deflection behaviour upto first cracking stage. The next stage, that is in the second stage, the cracked reinforced concrete slab load-deflection behaviour is considered upto yield line load.

4.2.1. Load-deflection behaviour of simply supported RC skew slabs upto cracking load

The load deflection behaviour of the reinforced concrete slab can be calculated using elastic skew plate theory. The central deflection of the simply supported reinforced concrete skew slab is given by the equation

$$\delta = \frac{\alpha_2 q L_y^4}{E_C I_g} \quad (1)$$

Equation 1 holds good for $0 < q < q_{cr}$. Then the cracking load, q_{cr}, is given by equation

$$q_{cr} = \frac{M}{\beta_2 H^2}. \quad (2)$$

Where

$$M_{cr} = \frac{f_r I_g}{h_t} \qquad (3)$$

And M_{cr} is the maximum moment which occurs at the centre of the slab. Appropriate values of α_2 and β_2 are obtained by the elastic analysis of skew plates using Table-3, Fig. 2 and Fig. 3 as given. For different skew angles the skew slab geometrical properties varies accordingly so the values of L_x/L_y and k_6 (it is a parameter which defines the skew angle), are calculated. Table-3, gives the value of θ_1 (it is the parameter of the skew slab for the combination of L_x/L_y and k_6). After getting values of θ_1 and k_6, the value for α_2 is obtained from the Fig. 2 and the value for β_2 is obtained from the Fig. 3.

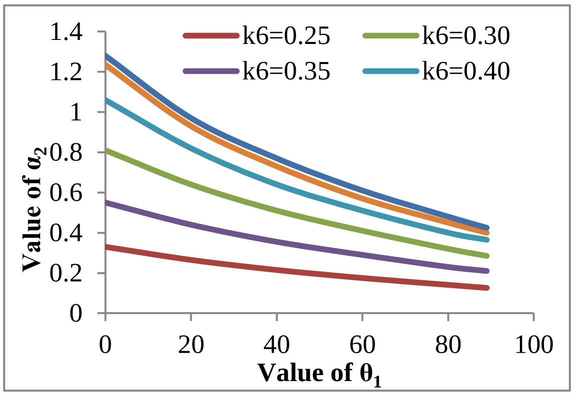

Figure 2 Variation of central deflection of a uniformly loaded simply supported skew

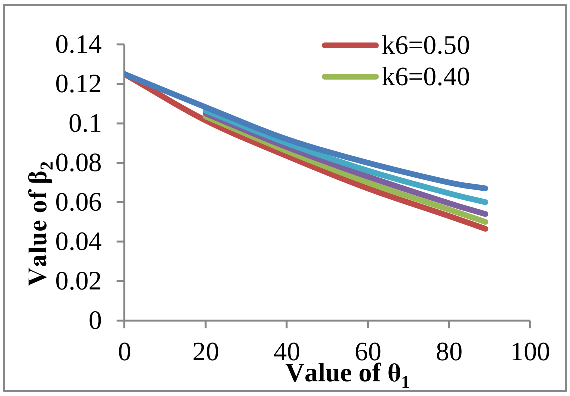

Figure 3 Variation of maximum bending moment of a uniformly loaded simply

Table 3 Values of θ_1, L_x/L_y and k_6

θ_1 / k_6	90°	80°	70°	60°	50°	40°	30°	20°	10°	5°
Values of 10^3 (L_x/L_y)										
0.50	1000	1083	1175	1279	1400	1546	1732	1992	2405	∞
0.45	1000	1082	1174	1276	1396	1540	1724	1981	2389	∞
0.40	1000	1080	1168	1268	1383	1523	1700	1947	2340	∞
0.35	1000	1076	1160	1254	1363	1493	1660	1892	2260	∞
0.30	1000	1071	1148	1234	1334	1453	1605	1816	2150	∞
0.25	1000	1063	1132	1209	1297	1402	1535	1720	2012	∞

4.2.2. Load-deflection behaviour of simply supported RC skew slabs between cracking load and yield line load

The load q on the slab when it exceeds the cracking load, the reinforced concrete skew slab starts to crack. The load-deflection behaviour for $q > q_{cr}$ is not same and is influenced by the reinforcement percentages in both the directions, the material properties of concrete as well as steel and the decreased flexural rigidity due to cracking at first stage. Hence in this stage, the deflection δ, of the simply supported reinforced concrete skew slab is determined by the following equation

$$\delta = \frac{\alpha_2 q L_y^4}{k_s E_C I_e} \qquad (4)$$

Where,

$$I_e = \left(\frac{q_{cr}}{q}\right)^3 I_g + \left[1 - \left(\frac{q_{cr}}{q}\right)^3\right] I_{cr} \quad (5)$$

And here the constant k_s is determined based on the test results obtained by experiments [viz. Table 1]. Test results of 18 simply supported RC skew slabs were used in determination of constant k_s.

4.2.3. Determination of the multiplier constant ($1/k_s$)

The value of ks is found using linear regression analysis as

$$k_s = 0.2009 + 0.0163\lambda_2 \quad (6)$$

Where,

$$\lambda_2 = \left[\frac{P_x P_y}{P_x + P_y}\right]\left[\frac{f_y}{f_c}\right]\left[\frac{h}{L_y}\right]\left[\frac{10000}{(1+6\tan\theta)}\right] \quad (7)$$

$$P_x = \frac{A'_{sx}}{d_x}; \quad P_y = \frac{A'_{sy}}{d_y} \quad (8)$$

5. RESULTS AND COMPARISON

Table 4 Comparison of experimental, computed and ANSYS deflection of simply supported skew slabs

Sl. No.	Slab designation	Deflection at working load (mm)			Deflection at yield line load (mm)		
		Experimental δ_{we}	Computed δ_{wc}	ANSYS δ_{wa}	Experimental δ_{ye}	Computed δ_{yc}	ANSYS δ_{ya}
1	S1-15	11.0	8.50	2.83	25.5	14.50	5.92
2	S2-15	9.4	8.00	2.50	17.9	14.50	4.70
3	S3-15	14.0	7.75	2.20	23.5	14.70	3.75
4	S4-15	9.7	8.25	1.63	19.5	16.60	3.13
5	S5-15	7.0	7.33	1.88	17.5	14.50	3.00
6	S6-15	13.0	9.00	2.38	24.0	16.50	3.80
7	S1-30	12.3	10.33	1.83	22.5	20.40	3.16
8	S2-30	11.0	9.00	1.80	21.7	18.75	2.63
9	S3-30	9.7	8.75	1.50	20.3	17.70	2.63
10	S4-30	8.7	7.00	1.25	19.2	17.50	2.10
11	S5-30	10.5	4.50	1.00	23.0	14.12	1.69
12	S6-30	7.5	4.75	0.85	20.5	14.60	1.48
13	S1-45	13.0	9.00	1.18	24.8	17.50	2.00
14	S2-45	10.0	7.25	0.98	21.5	15.30	1.68
15	S3-45	7.0	5.50	0.75	22.0	13.60	1.35
16	S4-45	7.5	4.00	0.75	16.5	12.30	1.25
17	S5-45	5.4	1.83	0.58	17.0	9.44	1.00
18	S6-45	2.1	2.10	0.54	8.7	8.14	0.80

Average (δ_{we} / δ_{wc}) = 1.46   Average (δ_{we} / δ_{wa}) = 7.09   Average (δ_{wc} / δ_{wa}) = 4.96

Average (δ_{ye} / δ_{yc}) = 1.36   Average (δ_{ye} / δ_{ya}) = 9.72   Average (δ_{yc} / δ_{ya}) = 7.12

The typical curves for comparison of experimental, ANSYS and computed load-deflection are presented in Fig. 4, Fig. 5 and Fig. 6.

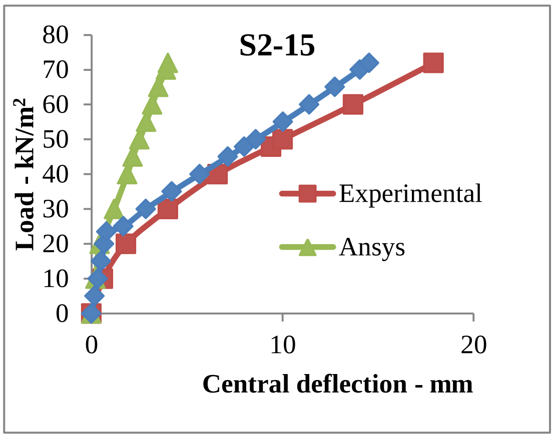

Figure 4 Comparison of experimental, ANSYS and computed load-deflection plots for S2-15

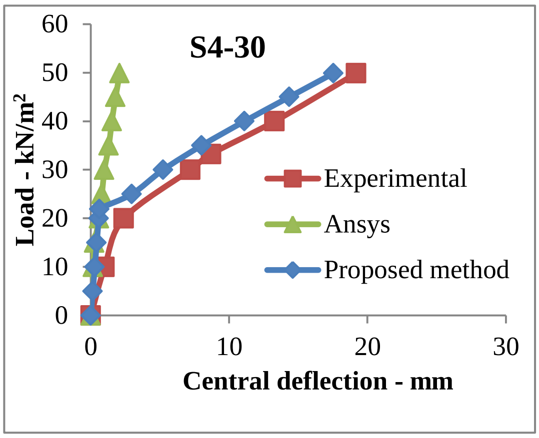

Figure 5 Comparison of experimental, ANSYS and computed load-deflection plots for S4-30

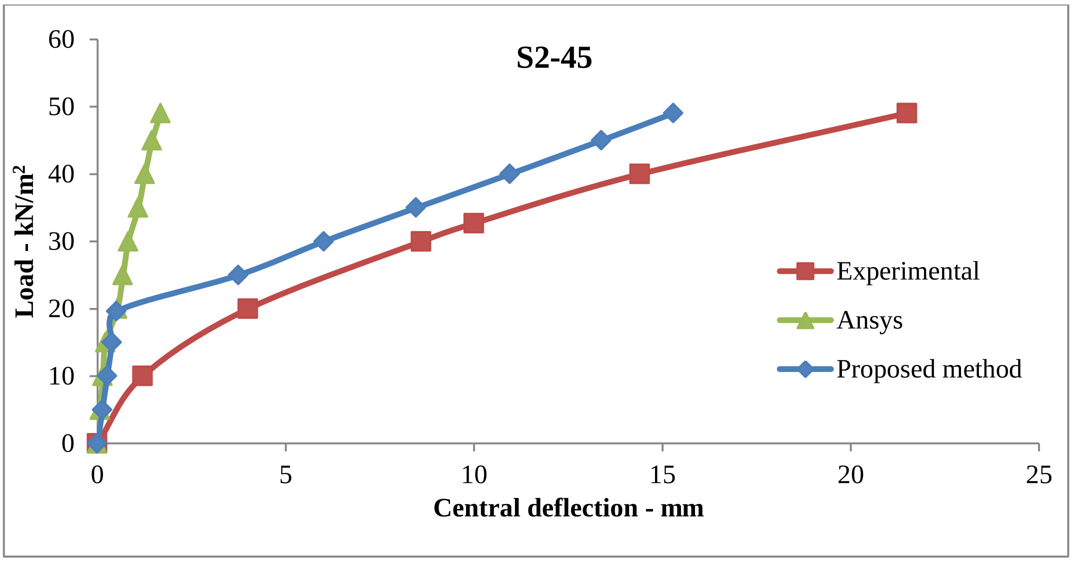

Figure 6 Comparison of experimental, ANSYS and computed load-deflection plots for S2-45

6. SUMMARY AND CONCLUSIONS

A method is proposed to study the load-deflection behaviour of simply supported RC skew slabs, experimental data of 18 simply supported skew slabs were used and the FE analysis of the same been done using ANSYS v15. The following conclusions are made.

- To take into account the decrease in flexural rigidity of the simply supported RC skew slabs with increase in load beyond the cracking load, a constant k_s given by the equation, $k_s = 0.2009 + 0.0163\lambda_2$ is used to determine the deflection between cracking load and the yield line load.
- Deflection at working load and yield line load are found to compare satisfactorily for the simply supported RC skew slabs, showing the ratio of experimental to computed values an average of 1.46 at working load while the corresponding values at yield line load is 1.36 respectively.

- The ratio of experimental to ANSYS values an average of 7.09 at working load while the corresponding values at yield line load is 9.72 respectively.
- The ratio of computed to ANSYS values an average of 4.96 at working load while the corresponding values at yield line load is 7.12 respectively
- In this work, an attempt is made to make a comparative study between experimental, computed and ANSYS results and it has been found that theoretical results closely concur with experimental results. However, attempts could be done to further improve the modelling and analysis technique using ANSYS.

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