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Experimental Investigation of Simply Supported Skew Slabs Subjected to Uniformly Distributed Loading

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Abstract
Reinforced concrete slab is one of the important structural elements in building construction. Early methods of slab design were based on elastic theory. The design based on elastic theory could not indicate a true margin of safety against failure and hence necessity of predicting the ultimate load was felt. With the advent of ultimate load methods, yield line analysis of slabs gained popularity and was considered as an accepted method for predicting the ultimate load of slabs. But tests conducted on reinforced concrete slabs show that the slabs have a capacity to carry more load than that predicted by yield line analysis. This load-enhancement beyond the yield line load was attributed to the inducement of in-plane (membrane) forces in the slab at finite deflections the effect of which was not considered in yield line analysis. Some investigations have proposed method of analysis to determine the ultimate loads of rectangular, square and circular slabs taking into account the effect of membrane forces. But similar studies on skew slabs have not been reported in literature. As reinforced concrete skew slabs supported on all edges find possible application in buildings wherein the slab is supported by a skew grid of beams due to architectural considerations or space limitations, the present work reports the experimental investigation of the load-deflection behaviour and cracking pattern of four reinforced concrete skew slabs with all edges simply supported and subjected to uniformly distributed load.

Keywords: skew slabs, skew angle, simply supported, concrete, slabs, and deflections.

Introduction

In this research paper, an attempt is made to investigate the load deflection behaviour and yield pattern of skew slabs which were subjected to uniformly distributed loading and simply supported on all edges. Four skew slabs with a skew angle of 15º with varying reinforcement were cast and tested. The grade of concrete used was M30.

Experimental Program

The experimental programme was intended to study the load-deflection behaviour, cracking pattern and flexural behaviour of concrete skew slabs. The experimental programme was conducted to,

1) Study the ultimate strength of concrete skew slabs.
2) Obtain the actual load deflection plots upto ultimate load (under short-term loading).
3) Study the cracking behaviour.

The experimental programme consisted of casting and testing of four numbers of skew slabs of dimensions 1035.27x1500x50 mm, with a skew angle of 15º with varying percentage of reinforcement. The slabs were tested under UDL and with all edges simply supported.

Mix Design

Mix design was done for M30 grade concrete with conventional materials, shown in Figure 1. The fine aggregates, coarse aggregates and cement were tested for their quality and properties prior to mix design. Mix design was done as per IS 10262: 2009 and the quantity of materials are tabulated in Table 1.

Figure 1: Materials used

Table 1: Quantity of Materials for M30

Materials	Quantity for 1m^3 Concrete
Cement	358 Kgs
Course aggregates	1055.62 Kgs
Fine sand	775 Kgs
Water – Cement ratio	0.45
Water	161 liters
Super plasticizer	1% of Weight of Cement
Ratio	**1: 2.16 : 2.94**

Details of Slab Specimens

Four skew slabs of M30 grade concrete with a skew angle of 15º and with varying spacing of reinforcement were cast and cured for 28 days. The geometrical details of the skew slabs are shown in Figure 2 and the details of span and reinforcement are tabulated in Table 2 and Table 3.

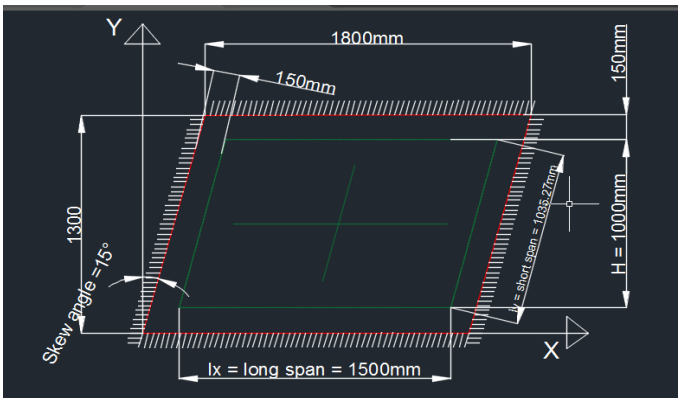

Figure 2: Geometrical Details of a Typical Skew Slab

Table 2: Geometrical Details of Skew Slabs

Slab ID	Skew Angle	Overall Size mm	Long Span l_X mm	Short Span l_Y mm	Aspect Ratio l_X/l_Y
SS-1	15º	1300 x 1800	1500	1035.27	1.45
SS-2	15º	1300 x 1800	1500	1035.27	1.45
SS-3	15º	1300 x 1800	1500	1035.27	1.45
SS-4	15º	1300 x 1800	1500	1035.27	1.45

Overall thickness of slabs = 50mm

Table 3: Reinforcement Details of Skew Slabs

Slab ID	Spacing of bars mm		Percentage of Reinforcement mm		Coefficient of Orthotropy
	Short span	Long span	Short span	Long span	
SS-1	50	50	0.630	0.700	1.126
SS-2	100	100	0.315	0.350	1.121
SS-3	75	100	0.315	0.467	1.458
SS-4	75	75	0.420	0.467	1.122

Casting of Skew Slab

All the materials were weighed and kept ready before mixing and required quantity of water was added and slabs were cast in 2 layers with hand compaction. The slabs were cured for 28 days and then tested on a loading frame of 2000kN capacity. A typical layout of reinforcement cage, casting of the slabs and a typical testing arrangement of slab are shown in Figure 3, Figure 4 and Figure 5.

Figure 3: Typical Layout of Reinforcement Cage

Figure 4: Casting of a Typical Skew Slab

Figure 5: Testing of a Skew Slab under UDL

Experimental Results

The load and deflection data of all skew slabs have been tabulated in Table 4. It gives the cracking load and ultimate load of all skew slabs and their respective deflections.

Table 4: Cracking & Ultimate Loads with Corresponding Deflections of Skew Slabs

Slab ID	Compressive Strength, f_{ck} N/mm^2	P_{cr} kN	P_U kN	δ_{cr} mm	δ_U mm
SS-1	34.66	34.5	138.6	5.89	36.46
SS-2	30.88	27.5	114	3.74	40.03
SS-3	31.11	29.5	131	3.79	41.56
SS-4	30.22	32.5	142	2.41	34.16

Cracking Pattern of Skew Slabs

The typical cracking pattern of skew slabs on tension and compression side are shown in Figure 6 and Figure 7.

Figure 6: Typical Cracking Pattern of Skew Slabs on Tension Side

Figure 7: Typical Cracking Pattern of Skew Slabs on Compression Side

Load-Deflection Plots

The load deflection plots were developed for all the four skew slabs from the experimental data. The load-deflection plots are shown in Figure 8 and Figure 9.

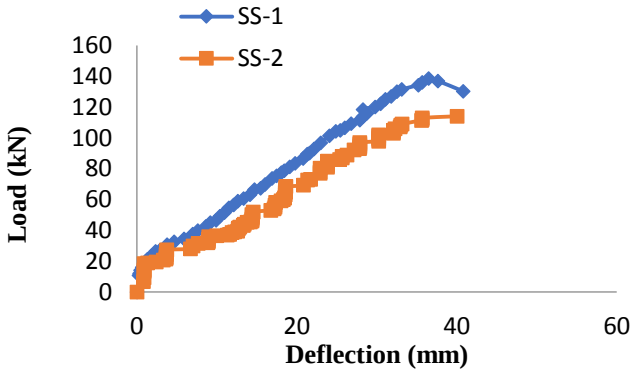

Figure 8: Load-Deflection Plots of SS-1 & SS-2

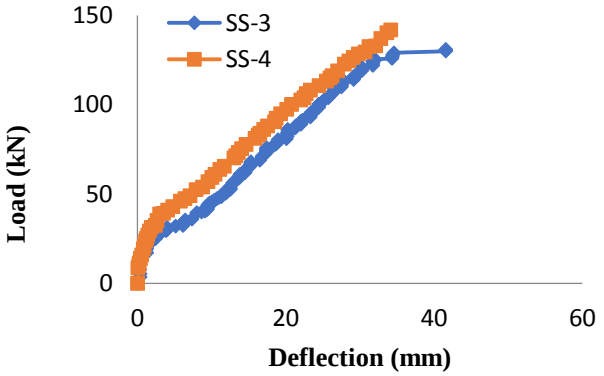

Figure 9: Load-Deflection Plots of SS-3 & SS-4

Comparison of Theoretical and Experimental Cracking Load

The cracking load for all skew slabs was recorded from experimental data and also theoretical cracking load was calculated. Table 5 gives the comparison of the same.

Table 5: Comparison of Theoretical and Experimental Cracking Load

Slab ID	Experimental (P_{cr}) kN	Calculated (P_{cr}) kN	$\frac{(Pcr)calculated}{(Pcr)experimental}$
SS-1	34.5	38.09	1.10
SS-2	27.5	35.96	1.30
SS-3	29.5	36.09	1.22
SS-4	32.5	35.57	1.09
		Average	1.18
		Standard Deviation	0.1
		Coefficient of Variation	8.47%

Comparison of Theoretical and Experimental Deflection at Cracking Load

The deflection at cracking load for all skew slabs was recorded from experimental data and also theoretical deflection at cracking load was calculated. Table 6 gives the comparison of theoretical and experimental deflection at cracking load for all skew slabs.

Table 6: Comparison of Theoretical and Experimental Deflection at Cracking Load

Slab ID	Experimental Cracking Deflection, δcr (mm)	Calculated Cracking Deflection, δcr (mm)	$\frac{(\delta cr)calculated}{(\delta cr)experimental}$
SS-1	5.89	0.55	0.09
SS-2	3.74	0.55	0.147
SS-3	3.79	0.55	0.145
SS-4	2.41	0.55	0.228
		Average	0.153
		Standard Deviation	0.057
		Coefficient of Variation	37.25%

Comparison of Johansen's Yield Load and Experimental Ultimate Load

The ultimate load for all skew slabs was recorded from experimental data and also theoretical Johansen's yield line load was calculated. Table 7 gives the comparison of both the values for all skew slabs.

Table 7: Comparison of Johansen's Yield Load and Experimental Ultimate Load

Slab ID	(P_U) exp kN	(P_y) cal kN	$\frac{(P_y)\text{cal}}{(P_u)\text{ exp}}$
SS-1	138.6	426.76	3.08
SS-2	114	232.935	2.04
SS-3	131	232.935	1.78
SS-4	142	232.935	1.64
		Average	2.135
		Standard Deviation	0.651
		Coefficient of Variation	30.5%

Ratio of Experimental Ultimate Deflections and Overall Depth

The experimental deflections at ultimate load for all skew slabs were recorded and the ratio of the same with overall depth has been calculated. Table 8 gives the ratio of experimental ultimate deflections to overall depth.

Table 8: Ratio of Experimental Ultimate Deflections and Overall Depth

Slab ID	(δu) exp mm	$\frac{(\delta u)\text{exp}}{D}$
SS-1	36.46	0.73
SS-2	40.03	0.80
SS-3	41.56	0.83
SS-4	34.16	0.68

Partial Safety Factor with respect to Deflection

From the experimental data, it was possible to determine the load at which the limiting deflection had occurred. The limiting deflection has been calculated by considering short term deflection and long-term deflection (taken as twice of short term deflection) as prescribed in IS 456:2000. Table 9 shows Partial safety factor with respect to deflection.

Table 9: Partial Safety Factor with respect to Deflection

Slab ID	P_U kN	$P_{1.38}$ kN	$PSF = \frac{P_U}{P_{1.38}}$
SS-1	138.6	21.3	6.5
SS-2	114	19	5.08
SS-3	131	21.26	5.32
SS-4	142	27	5.61

Partial Safety Factor with respect to Cracking

From the experimental data, it was possible to determine the load at which the limiting crack width had occurred. The limiting crack width has been considered which is prescribed in IS 456:2000 as 0.3mm for concrete structures. Table 10 shows Partial Safety Factor with respect to Cracking.

Table 10: Partial Safety Factor with respect to Cracking

Slab ID	P_U kN	$P_{0.3}$ kN	$PSF = \frac{P_U}{P_{0.3}}$
SS-1	138.6	-	-
SS-2	114	103.5	1.1
SS-3	131	99.64	1.31
SS-4	142	-	-

Conclusions

The following conclusions were drawn from the study on four skew slabs:

1) A comparison between theoretical and experimental cracking load has been done and the co-efficient of variation is 8.47%.
2) A comparison between theoretical and experimental deflection at cracking load are been done and the co-efficient of variation is 37.25%. The crack width of the slabs was limited.
3) A comparison between Johansen's yield line load and experimental ultimate load has been done and the co-efficient of variation is 30.5%. It was noted that Johansen's yield line load is very high compared to experimental ultimate load due to high yield strength of pre-stress steel.
4) The ratio of ultimate deflections from experimental data with overall depth was calculated and it has been noted that the ratio is in the range of 0.68 to 0.83 times the overall depth.
5) Partial safety factors with respect to deflection and cracking have been determined as per the limiting values prescribed in IS-456:2000. It is noted that the partial safety factor with respect to deflection are greater than 1.5, but however the partial safety factor with respect to cracking are ranging between 1.1 to 1.31 because the reinforcement bars used did not allow for crack width to reach limiting values.
6) Lastly, a conclusion has been drawn that, by the use of high yield strength pre-stressed steel, the cracking width was well within the limiting values and also snapping of bars was not observed even when the slabs were loaded beyond ultimate loads till failure.

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