ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

EFFECT OF SKEW ANGLE ON STRUCTURAL BEHAVIOR OF RC RIBBED SKEW SLAB

M. S. Hora
Department of Civil Engineering, MANIT Bhopal, Madhya Pradesh, India
E-Mail: hora1961@gmail.com

ABSTRACT

The present research deals with parametric study of RC un-stiffened and ribbed skew slabs (stiffened by rib beams) with skew angles ranging from 20° to 50° in interval of 5°. The analyses are carried out for un-stiffened and ribbed skew slabs having two short edges simply supported and two long edges free. Total 14 cases are analyzed for un-stiffened and ribbed skew slabs by creating models in ANSYS software. The comparison of results is made with respect to displacements, bending moments, twisting moments, von-Mises stress, bending stresses and shear stresses.

Keywords: parametric study, finite element analysis, skew angle, ribbed skew slab, ANSYS.

INTRODUCTION

While designing a road project, it is not always possible to cross a river or an obstacle at right angle. In such situations, skew bridges are planned without disturbing the geometry and alignment of the road. The skew bridges are also necessitated due to site considerations such as alignment constraints, land acquisition problems etc. The behaviour of such a skew slab is complicated in view of analysis, design and detailing. Because of apprehensions, there is always a tendency to avoid or at least reduce the skew effects by choice of orientation of supports.

The bridge deck slabs are normally supported on two edges across the traffic direction and the remaining two edges are kept free which are usually orthogonal to the traffic direction. But sometimes they may not be orthogonal for the traffic direction necessitated by many reasons. Such bridge decks are defined as skew bridge decks. The inclination of the centre line of traffic to the centre line of the river/obstruction is called the skew angle.

The analysis of skew slab is quite complicated than those of a conventional rectangular slab. With increase in the skew angle, the deflection and stresses in the skew slab are significantly different from those of a straight slab. In the present research work, parametric study is performed using ANSYS software for un-stiffened and ribbed skew slabs to investigate the effect of skew angle on structural behaviour in view of deflection, bending moments and stresses.

PROBLEM FOR ANALYSIS

A ribbed skew slab of size 10 m x 5 m and thickness 200 mm is analyzed in ANSYS. The ribbed slab has 5 longitudinal beams of size 250 mm x 400 mm equally spaced with c/c distance of 1.1875 m. Two short edges are simply supported while other two edges are kept free. The modulus of elasticity of 3.0 x 10^4 N/mm^2 and Poisson's ratio of 0.2 are considered in the analysis. The transverse load on entire surface is taken 4 kN/m^2. The un-stiffened skew slab and ribbed slab are analyzed by varying skew angle from 20° to 50° in step of 5°. The FE model of skew slab is generated using ANSYS software with shell 181 element. Total 28 cases are analyzed for both types of skew slab considering two different boundary conditions. The comparison of results is made with respect to displacements, von-Mises stress, shear stress, bending moments and twisting moments. Figure-1 shows FE model of skew slab prepared using ANSYS software.

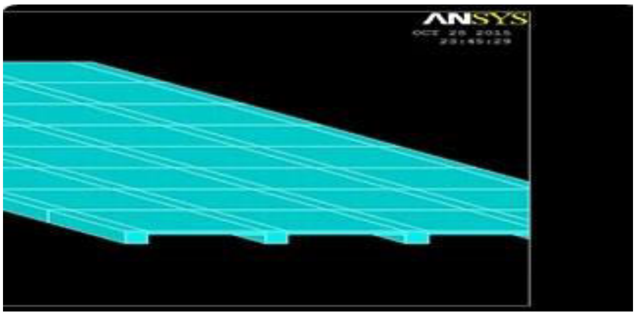


Figure-1. FE model generated in ANSYS.

FINITE ELEMENT MODELLING

ANSYS is commercial software most commonly used for finite element analysis. Its element library contains variety of plate bending elements. These elements have different functional use and capabilities. SHELL63 has elastic analysis capability. SHELL181 and SHELL l43 are capable of analyzing problems involving plastic deformations. SHELL281 is higher order element for more refined analysis. SHELL181 element is usually preferred because it is suitable for analyzing thin to moderately thick shell structure. It is a 4 node element with six degrees of freedom at each node (translations in the x, y, and z axes and rotations about x, y, and z axes). SHELL 181 is also well suited for linear, large rotation, and/or large strain nonlinear applications involving change in shell thickness and hence adopted in present analysis. Figure 2 shows details of finite strain SHELL 181 element.

ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

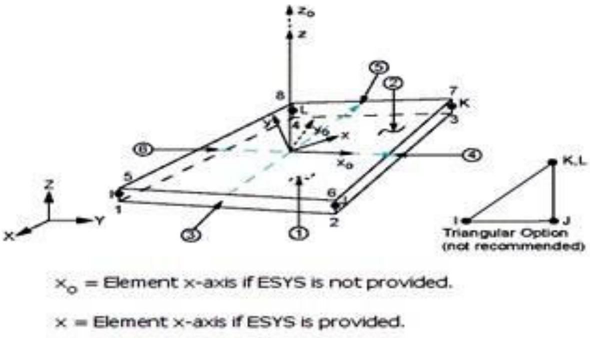


Figure-2. SHELL 181 finite strain element.

CONVERGENCE STUDY

The convergence study is made for finalizing the appropriate mesh size. Different mesh sizes are considered ranging from 2000 mm to 100 mm. The maximum deflection is evaluated using these mesh sizes as shown in Table-1.The mesh size of 100 mm is found satisfactory and therefore is adopted for analysis of all 28 cases. Figure-3 and Figure-4 shows FE mesh and deflection profile of skew slab respectively for skew angle of 45^0.

Table-1. Convergence study.

Mesh size (mm)	**Maximum value of deflection** (mm)
2000	09.356
1000	10.166
500	10.515
250	10.648
100	10.648

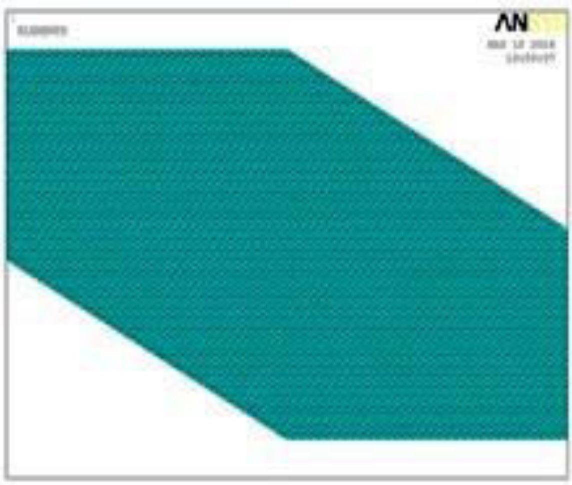


Figure-3. FE mesh for un-stiffened skew slab having skew angle of 45^0.

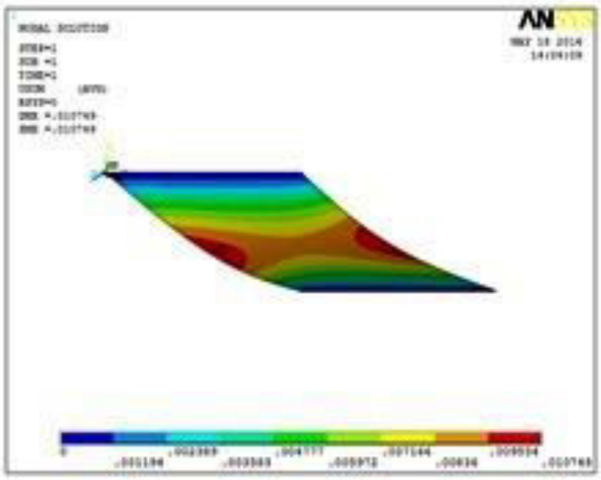


Figure-4. Deflection profile for un-stiffened skew slab having skew angle of 45^0.

Validation of FE Results

The results obtained by ANSYS are compared with theoretical formulas available in the literature [6]. The following problem is considered for validation by comparing maximum deflection in un-stiffened skew slab.

Geometry

Size of skew slab 10 m x 5 m
Skew angle =45°
Thickness of slab= 200 mm

Material properties

Modulus of elasticity (E) = 3.0×10^4 N/mm^2
Poisson's ratio, μ = 0.2
Uniform transverse pressure (q) = 4 kN/m^2
Boundary conditions:

Two short edges simply supported and long edges free

Theoretical calculations

Maximum deflection in the free edge= $\alpha_1 qb^4/Et^3$
Maximum deflection in the centre = $\alpha_2 qb^4/Et^3$
Where, α_1=1.0 and α_2=0.82
Maximum deflection at the free edge=10.42 mm
Maximum deflection at the centre =8.54 mm

Values obtained from ANSYS

Maximum deflection at Edge (Theoretical) = 10.41 mm

Maximum deflection at Edge (ANSYS Software) = 10.75 mm

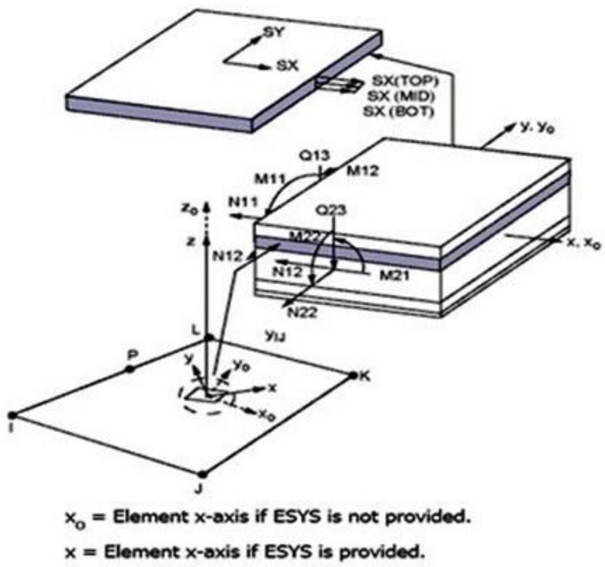
Maximum deflection at centre (Theoretical) = 8.54 mm

Maximum deflection at centre (ANSYS Software) = 8.55 mm

RESULTS AND DISCUSSIONS

Figure-5 shows the various output parameters for the SHELL 181 element.

 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences



Description	Notations
In-plane force	N11 (Fx)
In-plane force	N22 (Fz)
In-plane force	N12 (Fxz)
Average transverse shear stress	Q13 (τ_{xy})
Average transverse shear stress	Q23 (τ_{zy})
Bending Moment about x-axis	M11 (M_x)
Bending Moment about y-axis	M22 (M_z)
Twisting Moment	M12 (M_{xz})

Figure-5. Notations for forces.

The analyses are performed by varying skew angles from 20° to 50° in interval of 5°. The following quantities are evaluated:

a) Displacements

b) Von-Mises stress

c) Average transverse shear stresses (τ_{xy} and τ_{zy})

d) Bending stress (σ_x)

e) Bending moments (M_x and M_z)

f) Twisting moment (M_{xz})

Total-14 cases are analyzed for un-stiffened and ribbed skew slabs and results are compared.

Table-2 shows the maximum values of vertical deflection in skew slab for un-stiffened and ribbed slabs for various skew angles. It is found that maximum deflection in skew slab decreases with increase in skew angle. The decrease of nearly 9 to 20% is found in case of un-stiffened skew slab, when skew angle is varied from 20° to 50° in an interval of 5°. The decrease of nearly 3 to 7% is found in case of ribbed skew slab. The comparison between un-stiffened and ribbed skew slabs reveals that a significant decrease of nearly 19 times is found in case of ribbed skew slab having skew angle of 20°. Figure-6 shows effect of skew angle on vertical deflection for un-stiffened and ribbed skew slabs.

Table-2. Maximum values of vertical deflection (mm).

Skew angle (1)	Un-stiffened skew slab (2)	% Variation due to change in skew angle (3)	Ribbed skew slab (4)	% Variation due to change in skew angle (5)	Ratio (6)=(2/4)
20^0	22.387	----	1.147	----	19.518
25^0	20.298	-9.331	1.116	-2.703	18.188
30^0	17.983	-11.405	1.083	-2.957	16.605
35^0	15.550	-13.529	1.059	-2.216	14.684
40^0	13.102	-15.743	1.024	-3.305	12.795
45^0	10.749	-17.959	0.977	-4.590	11.002
50^0	8.594	-20.048	0.910	-6.858	9.444

ARPN Journal of Engineering and Applied Sciences

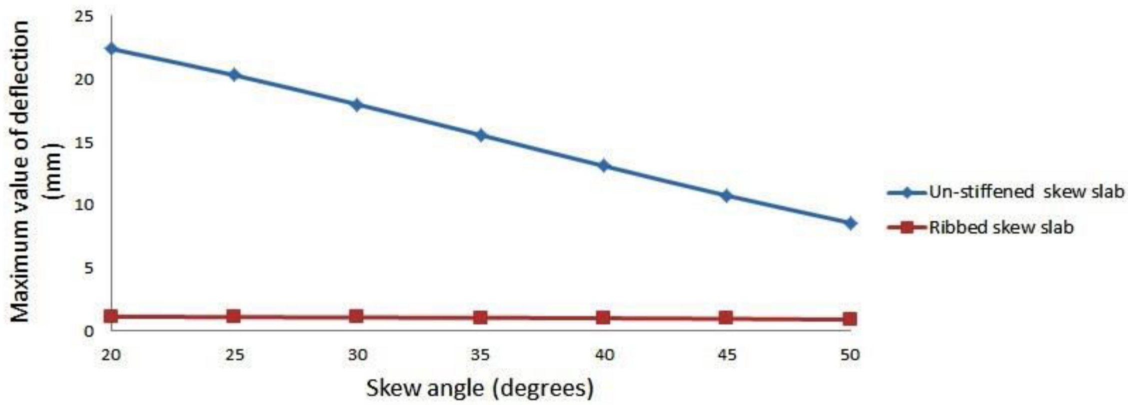


Figure-6. Effect of skew angle on vertical deflection.

Table-3 shows the maximum values of von-Mises stress in un-stiffened and ribbed for various skew angles. It is found that maximum von-Mises stress in un-stiffened skew slab occurs at 20° and whereas it occurs at 50° in case of ribbed skew slab. The insignificant variation of nearly -5 to 5% is found when skew angle is increased in case of un-stiffened skew slab. The variation of nearly -2 to 14% is found in case of ribbed skew slab. The comparison reveals that there is significant decrease of nearly 4 times in case of ribbed skew slab having skew angle of 20°. Figure-7 and Figure-8 shows von-Mises stress distribution for un-stiffened and ribbed skew slabs.

Table-3. Maximum values of von-Mises stress (N/mm^2).

Skew angle (1)	Un-stiffened skew slab (2)	% Variation due to change in skew angle (3)	Ribbed skew slab (4)	% Variation due to change in skew angle (5)	Ratio (6)=(2/4)
20^0	7.04	----	1.81	----	3.890
25^0	6.76	-3.977	1.77	-2.210	3.819
30^0	6.43	-4.882	1.73	-2.260	3.717
35^0	6.08	-5.443	1.98	14.451	3.071
40^0	6.37	4.770	2.21	11.616	2.882
45^0	6.45	1.256	2.46	11.312	2.622
50^0	6.33	-1.860	2.69	9.350	2.353

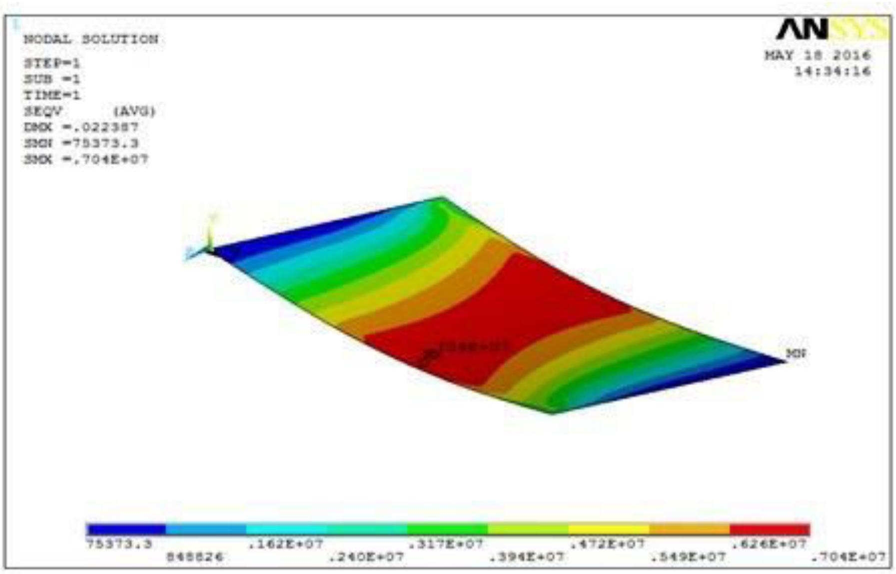


Figure-7. Von-Mises stress distribution in un-stiffened skew slab for 20° skew angle.

ARPN Journal of Engineering and Applied Sciences

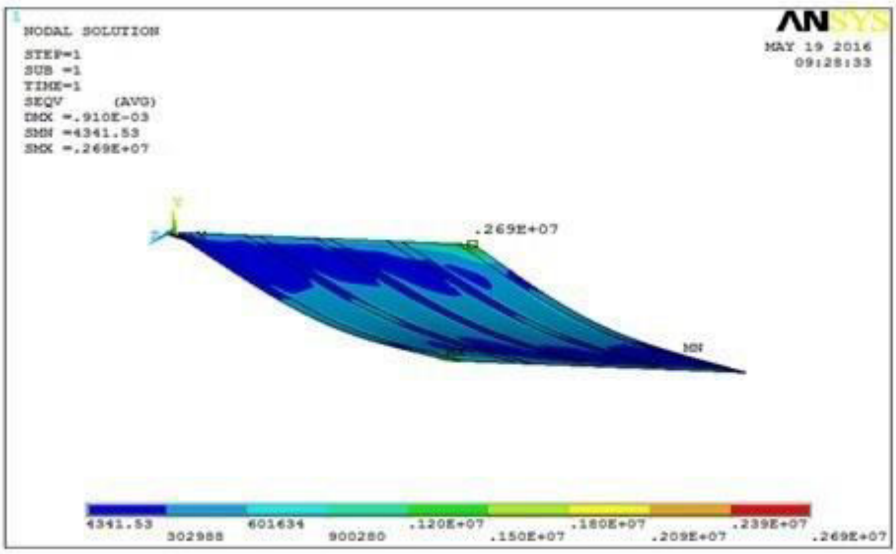


Figure-8. Von-Mises stress distribution in ribbed skew slab for skew angle of 50°.

Table-4 shows the maximum values of average transverse shear stress τ_{xy} in un-stiffened skew slab and ribbed skew slab for various skew angles. It is found that the maximum values of τ_{xy} increases with increase in skew angle up to 45° for both types of skew slabs. It then decreases in case of un-stiffened skew slab. The variation of nearly 12 to -1% is found in case of un-stiffened skew slab and nearly 17 to 2% in case of ribbed skew slab. The comparison reveals that there is significant decrease of nearly 8 times in case of ribbed skew slab having skew angle of 20°.

Table-4. Maximum values of average transverse shear stress τ_{xy} (N/mm^2).

Skew angle (1)	Un-stiffened skew slab (2)	% Variation due to change in skew angle (3)	Ribbed skew slab (4)	% Variation due to change in skew angle (5)	Ratio (6)=(2/4)
20^0	1.01	-	0.128	-	7.863
25^0	1.13	11.881	0.149	16.641	7.542
30^0	1.21	7.080	0.174	16.145	6.953
35^0	1.36	12.397	0.193	11.090	7.035
40^0	1.45	6.618	0.206	6.963	7.012
45^0	1.48	2.069	0.211	2.483	6.984
50^0	1.46	-1.351	0.224	6.130	6.492

Table-5 shows the maximum values of average transverse shear stress τ_{zy} in skew slab for un-stiffened and ribbed skew slabs for various skew angles. It is found that the maximum values of τ_{zy} increases with increase in skew angle for un-stiffened skew slab. It decreases with increase in skew angle up to 30° and then increases in case of ribbed skew slab. The variation of nearly 31 to 7% is found in case of un-stiffened skew slab whereas variation of nearly -8 to 9% is found in case of ribbed skew slab. The comparison reveals that there is significant decrease of nearly 22 times in case of ribbed skew slab having skew angle of 50°

VOL. 13, NO. 3, FEBRUARY 2018 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

Table-5. Maximum values of average transverse shear stress τ_{zy} (N/mm^2).

Skew angle (1)	Un-stiffened skew slab (2)	% Variation due to change in skew angle (3)	Ribbed skew slab (4)	% Variation due to change in skew angle (5)	Ratio (6)=(2/4)
20^0	0.93	-	0.105	-	8.867
25^0	1.23	31.344	0.100	-4.452	12.189
30^0	1.54	25.203	0.092	-7.849	16.561
35^0	1.85	20.130	0.096	3.369	19.247
40^0	2.13	15.135	0.105	9.407	20.254
45^0	2.35	10.329	0.111	6.342	21.014
50^0	2.51	6.809	0.114	2.209	21.959

Table-6 shows the maximum values of bending stress σ_x in un-stiffened skew slab and ribbed slab for various skew angles. The maximum value of bending stress decreases with increase in skew angle up to 45° and then increases in case of un-stiffened skew slab. In case of ribbed skew slab, it increases with increase in skew angle. The variation of nearly -17 to 12% is found in case of un-stiffened skew slab whereas variation of nearly 3 to 11% is found in case of ribbed skew slab. The comparison reveals that there is significant decrease of nearly 6 times in case of ribbed skew slab having skew angle of 20°

Table-6. Maximum values of bending stress (σ_x) (N/mm^2).

Skew angle (1)	Un-stiffened skew slab (2)	% Variation due to change in skew angle (3)	Ribbed skew slab (4)	% Variation due to change in skew angle (5)	Ratio (6)=(2/4)
20^0	6.61	----	1.12	----	5.902
25^0	6.09	-7.867	1.15	2.679	5.296
30^0	5.50	-9.688	1.25	8.696	4.400
35^0	4.86	-11.636	1.39	11.200	3.496
40^0	4.18	-13.992	1.51	8.633	2.768
45^0	3.48	-16.746	1.61	6.623	2.161
50^0	3.91	12.356	1.68	4.348	2.327

Table-7 shows the maximum values of bending moment M_x in un-stiffened skew slab and ribbed slab for various skew angles. The maximum bending moment in un-stiffened skew slab decreases with increase in skew angle up to 45° and then increases. In case of ribbed skew slab, M_x decreases with increase in the skew angle. The variation of nearly -17 to 12% is found in case of un-stiffened skew slab whereas decrease of nearly 2 to 8% is found in case of ribbed skew slab. The comparison reveals that significant increase of nearly 7 times is found in case of ribbed skew slab having skew angle of 45°. Figure-7 shows the effect of skew angle on bending moment (M_x).

Table-7. Maximum values of bending moment M_x (kN-m).

Skew angle (1)	Un-stiffened skew slab (2)	% Variation due to change in skew angle (3)	Ribbed skew slab (4)	% Variation due to change in skew angle (5)	Ratio (6)=(4/2)
20^0	44.046	-	194.723	-	4.421
25^0	40.603	-7.817	190.247	-2.299	4.686
30^0	36.674	-9.677	184.247	-3.154	5.024
35^0	32.379	-11.709	176.399	-4.259	5.448
40^0	27.841	-14.015	167.899	-4.819	6.031
45^0	23.185	-16.724	156.772	-6.627	6.762
50^0	26.051	12.362	144.682	-7.712	5.554

ARPN Journal of Engineering and Applied Sciences

Table-8 shows the maximum values of bending moment M_z in un-stiffened skew slab and ribbed slab for various skew angles. It is found that the maximum bending moment in un-stiffened skew slab increases with the increase in skew angle up to 45° and then decreases. In case of ribbed skew slab, it decreases with increase in the skew angle up to 40° and then increases. The variation of nearly 45 to -0.5% is found when skew angle is varied in case of un-stiffened skew slab whereas it is nearly -0.5 to 9% in case of ribbed skew slab. The comparison reveals that there is significant decrease of nearly 1.5 times in case of ribbed skew slab having skew angle of 40°. Figure-9 shows the effect of skew angle on bending moment (M_z) for un-stiffened skew slab. Figure-10 shows the effect of skew angle on bending moment (M_z) for ribbed skew slab.

Table-8. Maximum values of bending moment M_z (kN-m).

Skew angle (1)	Un-stiffened skew slab (2)	% Variation due to change in skew angle (3)	Ribbed skew slab (4)	% Variation due to change in skew angle (5)	Ratio (6)=(2/4)
20^0	5.870	-	10.162	-	0.578
25^0	8.515	45.044	10.115	-0.456	0.842
30^0	11.192	31.436	9.720	-3.912	1.151
35^0	13.592	21.450	9.354	-3.762	1.453
40^0	15.340	12.858	9.209	-1.544	1.666
45^0	16.183	5.497	9.980	8.372	1.621
50^0	16.079	-0.643	10.903	9.239	1.475

Table-9 shows the maximum values of twisting moment M_{xz} in un-stiffened skew slab and ribbed slab for various skew angles. It is found that the maximum twisting moment in un-stiffened skew slab increases with the increase in skew angle up to 40° and then decreases. In case of ribbed skew slab, it increases with increase in the skew angle. The variation of nearly 15 to -6% is found when skew angle is varied in case of un-stiffened skew slab. The increase of nearly 26 to 9% is found in case of ribbed skew slab. The comparison reveals that there is significant decrease of nearly 3 times in case of ribbed skew slab having skew angle of 20°. Figure-9 and Figure-10 show the effect of skew angle on twisting moment (M_{xz}) for un-stiffened and ribbed skew slabs respectively.

Table-9. Maximum values of twisting moment M_{xz} (kN-m).

Skew angle (1)	Un-stiffened skew slab (2)	% Variation due to change in skew angle (3)	Ribbed skew slab (4)	% Variation due to change in skew angle (5)	Ratio (6)=(2/4)
20^0	17.030	-	6.467	-	2.633
25^0	19.644	15.350	8.155	26.109	2.409
30^0	21.375	8.813	9.914	21.569	2.156
35^0	22.379	4.698	11.330	14.285	1.975
40^0	22.799	1.876	13.055	15.223	1.746
45^0	22.272	-2.311	14.712	12.693	1.514
50^0	20.835	-6.451	16.094	9.393	1.295

ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

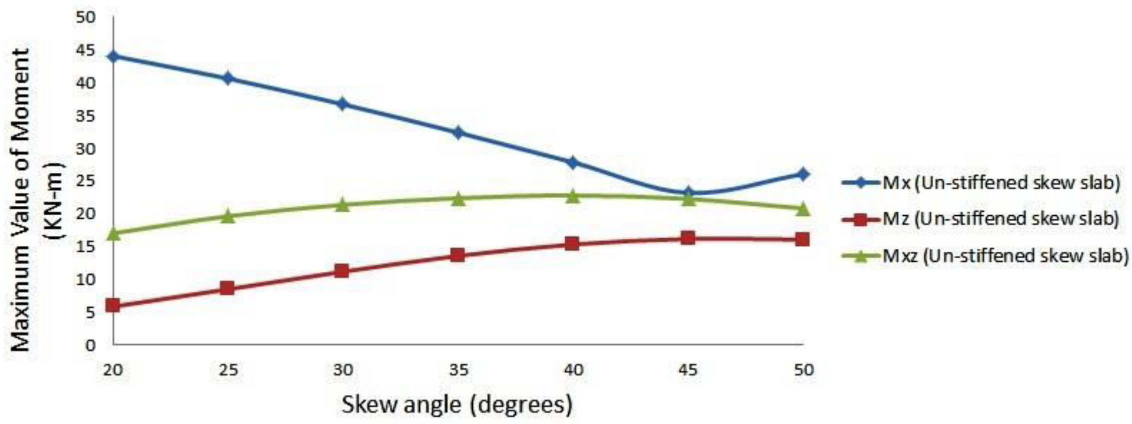


Figure-9. Effect of skew angle on bending moments and twisting moment for un-stiffened skew slab

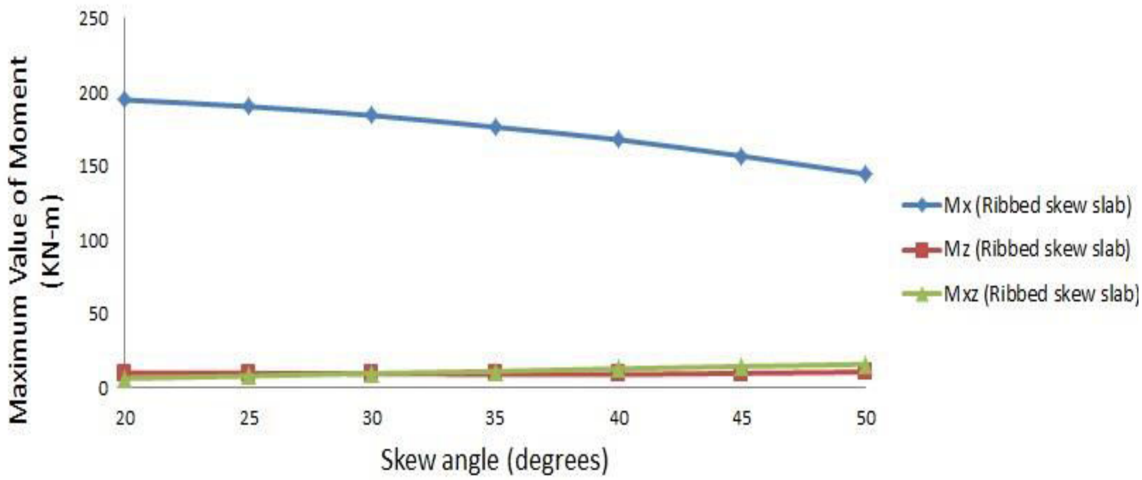


Figure-10. Effect of skew angle on bending moments and twisting moment for ribbed skew slab.

CONCLUSIONS

a) The value of maximum deflection in un-stiffened and ribbed skew slabs decreases significantly with increase in skew angle. The comparison between un-stiffened and ribbed skew slabs reveals that a significant decrease of nearly 19 times is found in case of ribbed skew slab having skew angle of 20°.

b) The maximum von-Mises stress decreases/increases with increase in skew angle. The comparison between un-stiffened and ribbed skew slab shows significant decrease of nearly 4 times in case of ribbed skew slab having skew angle of 20°.

c) The maximum value of transverse shear stress τ_{zy} increases with increase in skew angle for un-stiffened skew slabs. The comparison between two types of skew slab reveals significant decrease of nearly 22 times is found in case of ribbed skew slab having skew angle of 50°.

d) Significant increase of nearly 7 times is found in bending moment M_x in case of ribbed skew slab having skew angle of 45°.

e) A significant decrease of nearly 1.5 times is found in bending moment M_z in case of ribbed skew slab compared to un-stiffened skew slab having skew angle of 40°.

f) The maximum twisting moment increases with the increase in skew angle for ribbed skew slabs. The comparison between the two reveals that there is significant decrease of nearly 3 times in case of ribbed skew slab having skew angle of 20°.

REFERENCES

[1] Sharma Madhu. 2011. Finite element modelling of reinforced concrete skew slab. M.E. Thesis, Thapar University Patiala (Punjab).

[2] Mohan R. U., Bhupendra M.B., Nikhil J. 2015. Study of plate bending element in various analysis software. Vol. 3, S2. International Journal of Engineering Research-Online, ISSN: 2321-7758, pp. 255-259.

[3] Butalia T.S., Kant T. and Dixit V.D. 1990. Performance of heterosis element for bending of skew

rhombic plates. Computers and Structures. 34(1): 23-49.

[4] Wankhade R.L. 2011. Geometric nonlinear analysis of skew plates using finite element method. International Journal of Advanced Engineering Technology. 2(2): 154-163.

[5] Deepak C., Sabeena M.V. 2015. Effect of skew angle on uplift and deflection of RCC skew slab. International Journal of Research in Engineering and Technology. 4(5): 105-111.

[6] Richard G. B. and Warren C. Y. 2011. Roark's Formulas for stress and strain, 5th edition, McGraw-Hill Book Company.

[7] Bryan J. M. D. 2011. Practical Stress Analysis with Finite Elements, 2nd edition, Glasnevin Publishing.

[8] Timoshenko S. 2010. Theory of Plates and Shells. McGraw-Hill Book Publishing.

[9] ANSYS Manual.