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Numerical Examination of Reinforced Concrete Skew Slabs

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Abstract*: Skew slab structures are frequently investigation used in modern construction in the form of non-orthogonal reinforced concrete slabs supported by skew grid of beams. Skew bridges allow roadway alignments to a huge selection of solutions. Skew slabs contribute to a minimal environmental impact for recent road construction projects. Thus, it is difficult to analyse the skew slab bridges than the right angled bridges. The primary objective of this project is "Numerical Examination of Reinforced Concrete Skew Slab", is to determine the effect of different arrangement of steel reinforcement in the reinforced concrete skew slabs. For skew slabs, the sides 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. ANSYS (R.18.1) software was used for the analysis of skew slabs. Except the reinforcement alignment, dimensions are similar in all the skew slabs. For identifying the effective reinforcement pattern in skew slabs, deformation, stress, strain behaviour were studied. By comparing the datas for three types of reinforcement pattern in skew slab, the effective pattern will be observed in pattern having least values in solution. On analysis, the behaviour of different reinforcement pattern for the designed skew slab is studied using ANSYS (R.18.1) and the effective reinforcement pattern is suggested.

Keywords*: ANSYS, Numerical investigation, Reinforcement pattern, Skew slabs.

I. INTRODUCTION

Newly designed bridges are often skew owing to space constraints in urban areas. Skew bridges allow roadway alignments to a huge selection of solutions. Skew slabs contribute to a minimal environmental impact for recent road construction projects. It is also needed due to geographical constraints such as mountainous terrains. While comparing the right angled bridges, force flow is more complicated in skew bridges. For making the skew slab structures effective, numerical calculations alone is not sufficient. By performing the numerical analysis of skew bridge are modelled by varying the features and degrees of angles. In right angle bridges the load path goes straight towards the support in the direction of the span. In skew bridges this is not the case. For a solid slab skew bridge, the load tends to take a shortcut to the obtuse corners of the bridge. In bridge decks supported by longitudinal girders this effect occurs too, although less pronounced. The load path direction change in every skew bridge brings the subsequent characteristics such as increase of transverse moment, decrease of longitudinal moments, obtuse corner will be having negative reaction and acute corner will be having uplift reaction forces. These special characteristics of skew bridges make their analysis and design more intricate than right angled bridges. Skew slab structures are frequently used in modern construction in the form of non-orthogonal reinforced concrete slabs supported by skew grid of beams. Such structures find possible applications as floors in bridges and buildings. Hence a proper method of analysis of skew slabs is essential for their safe and efficient design and the investigations on reinforced concrete slabs in respect of stress, deformation and strain mainly with respect to rectangular slab is necessary in formulating pattern arrangement and the effect of skew angle. The primary objectives of this report are the following: To design the safe and efficient reinforced concrete skew slab with simply supported; To compare the computed values of reinforced concrete skew slabs with simply supported by using ANSYS (R18.1) software; To analyze the structure by applying point load for various reinforcement pattern for a skew angle of 25°; To determine the effect of reinforcement pattern and skew angles on a designed skew slab. The information presented in this report provides a computational investigation on the simply supported reinforced concrete skew slab with different patterns, skew angles and materials by using ANSYS (R18.1). It is expected that the reader will be able to use this information directly to design a skew slab. It is intended as an introduction to a broader understanding of the fundamental approached to risk in skew bridges. It provides a safe reinforcement pattern for skew angle greater than 20°.

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II. REVIEW OF LITERATURES

Anagha Manoharan et. al (2016) conducted investigation by varying skew angle and span length of skew slab along with different carriage widths. They found that the shear force of skew slab having loading condition of knife edge is increasing steadily and nearly increment of 30%. As the skew angle gradually increasing to 60°, bending moment of skew slab having concentrated loading and knife edge loading decreases as 65% and 75% respectively. S. K. Anusreebai et. al (2016) studied the effect of skew slab with three different patterns of reinforcement. Deepak et. al (2015) conducted investigation for identifying the deflection of reinforced concrete skew slab and skew angle uplift and concluded that uplift at acute corners increases if the skew angle increases.

They also concluded that skew angle increases with load carrying capacity of skew slab.

Mallikarjun et. al (2015) studied the influence of skew angle, aspect ratio and type of load in single span RCC bridges and Prestressed concrete bridges using finite element method. From their studies, they identified that there is a decrease in transverse moment, longitudinal stresses and bending moment. Sindhu et. al. (2013) investigated RCC single span bridges by varying skew angle, which resulted that there is a significant decrease in torsional moment and longitudinal bending moment. Abozaid et. al (2014) compared various investigations on RCC skew slab by nonlinear FEM analysis and concluded that overall behaviour of the skew slab is influenced by the concrete grade and skew angle. Menassa et. al studied the effect of skew angle in RCC concrete bridges and finally concluded that less than 20º skew angle may be designed as non skew slabs. Vikash Khatri et. al. have analysed the skew bridges by using FEM and grillage method and suggested that use of finite element methods had given the nearer solution and it was able to give complex geometry of the skew slab exactly. 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, suitable method is required to analyse the same.

III. METHODOLOGY

A. Reinforcement Pattern

Pattern 1 – The effect of skew in deck slabs having skew angles upto 20 degrees, is not so significant and in designing such bridges, the length parallel to the centre line of the roadway is taken as the span. The thickness of the slab and the reinforcement are calculated with this span lengths and the reinforcements are placed parallel to the centre line of the roadway. The distribution bars are, however placed parallel to the supports as usual. Pattern 2 – When the skew angle varies above 20 degree, the skew effect becomes significant and the slab tends to span normal to the supports. In such cases, the slab thickness is determined with shortest span but the reinforcement worked out on the basis of shortest span are multiplied by $Sec^2\theta$ (θ being the skew angle) and are placed parallel to the roadway as shown in Figure 1 and the distribution bars being placed parallel to the supports as usual. It is also a common practice to place the reinforcement perpendicular to the support when the skew angle lies between 20 degrees to 50 degrees. The thickness and the reinforcement are determined with span normal to the support but since in placing the reinforcement perpendicular to the supports. Pattern 3 – For skew bridges angles more than 50 degrees, girders should be used even though the spans are comparatively less. Where the width of the bridge is not much, the girders may be placed parallel to the roadway and the slab thickness and the reinforcement may be designed with the spacing of the girders as the span.

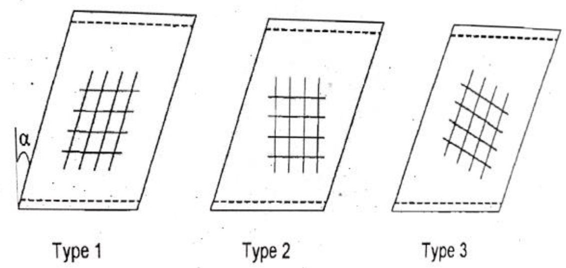

Figure 1 Reinforcement Pattern

B. Reaction at Supports

It has been observed that due to the effect of skew, the reaction at supports are not equal but the same is more at obtuse angle corners and less at acute angle corners depending on the angle of skew. For skews upto 20 degrees, the increase in the reaction on the obtuse angle corners is 0 to 50% and for skews from 20 to 50 degrees, the increase is from 50-90% of the average reaction. Zero pressure point was observed in acute angle corner due to obtuse angle corner reaction becoming double times the average reaction when the skew angle reaches about 60 degrees.

C. Slab Designation

The test sample slabs were represented as Pattern 1 - S1, Pattern 2-S2 and Pattern 3-S3. Except the reinforcement pattern arrangement, all the test sample slabs were in dimension. The test sample slab S1was reinforced with pattern type-1 reinforcement, S2 was reinforced with pattern type-2 and S3 was reinforced with pattern type-3 reinforcements. The reinforcement bars for test sample slabs S1, S2 and S3 were hooked at the ends. Skew angle is measured between the free edge and the line normal to the support. A single point load was applied from top at the centre point of the slabs. Two opposite edges of the test sample slabs had simple supports. The designed slab S1, S2 and S3 were analysed using ANSYS (R.18) – Static Structure. To analyse through the following steps: defining the geometry, defining the material, choosing the element type, create mesh, apply loads and define boundary conditions, solve the problem and process the results.

The Details of test slabs and reinforcement details are provided in Table I and II respectively.

TABLE I. Details of Test Slabs with Designation

Slab	Dimension (Span x Width) mm	Skew Angle (Degree)	Pattern Type	Skew Loading (kN)	Thickness (mm)
S1	7500 x 1500	25	Type - 1	252	600
S2	7500 x 1500	25	Type - 2	252	600
S3	7500 x 1500	25	Type - 3	252	600

Note: For all the slabs, clear cover is 50 mm

TABLE II. Reinforcement Details

Slab	Diameter	Spacing
S1 – Pattern 1	Main Bar: 25 mm	150 mm
	Distribution Bar: 16 mm	200 mm
S2 – Pattern 2	Main Bar: 25 mm	150 mm
	Distribution Bar: 16 mm	200 mm
S3 – Pattern 3	Main Bar: 25 mm	150 mm
	Distribution Bar: 16 mm	200 mm

D. ANSYS Workbench

Treatment of engineering problems basically contains three main parts: create a model, solve the problem and analyse the results.

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ANSYS, like many other finite element programs, is divided into three main parts (processors) which are called pre-processor, solution processor and post-processor. Other softwares may contain only the pre-processing part or only the post-processing part. During the analysis, you will communicate with ANSYS via a Graphical User Interface (GUI).

E. Materials Used

SOLID65 - It is used for the three – dimensional modelling of solids with or without reinforcing bars (rebars). The solid is capable of cracking and crushing in tension and compression respectively. Their material properties such as linearly isotropic, Ec value is 25000 MPa, open shear transfer coefficient is 0.2, closed shear transfer coefficient is 0.9, uniaxial cracking stress is 3.5 MPa and uniaxial crushing stress is 25 MPa. LINK180 – It is a 3-D spar that is useful in a variety of engineering applications. 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. Their material properties such as linearly isotropic, Ec value are 200000 MPa and yield stress is 415 MPa.

IV. RESULTS AND DISCUSSION

The skew slab and reinforcement pattern modelled in ANSYS software and the equivalent strain, equivalent stress and total deformation results are shown.

The skew slab pattern 1 reinforcement software analysis results are shown in Figure 2, 3 and 4.

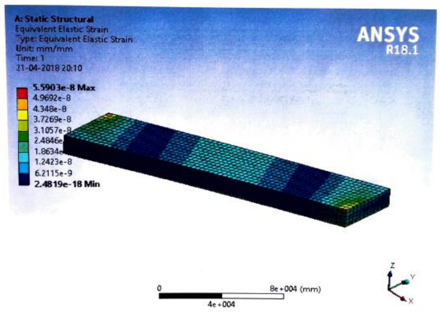

Figure 2 Pattern 1 Reinforcement Equivalent Elastic Strain

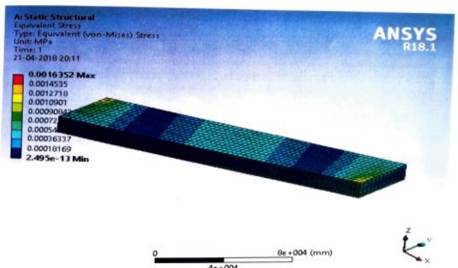

Figure 3 Pattern 1 Reinforcement Equivalent Stress

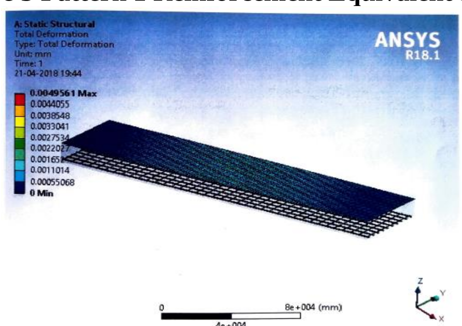

Figure 4 Pattern 1 Reinforcement Total Deformations

The skew slab pattern 2 reinforcement software analysis results are shown in Figure 5, 6 and 7.

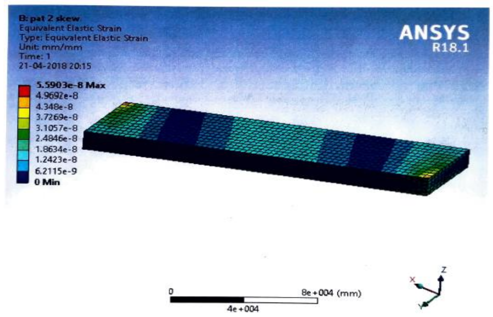

Figure 5 Pattern 2 Reinforcement Equivalent Elastic Strain

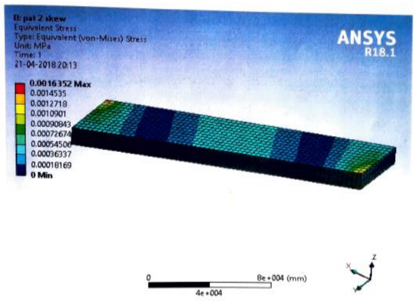

Figure 6 Pattern 2 Reinforcement Equivalent Stress

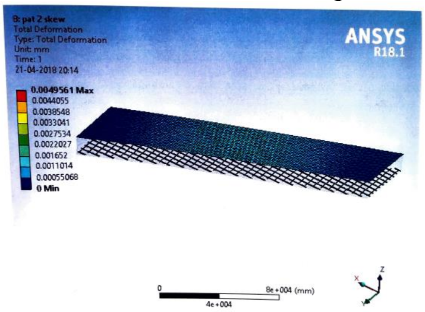

Figure 7 Pattern 2 Reinforcement Total Deformation

The skew slab pattern 2 reinforcement software analysis results are shown in Figure 8, 9 and 10.

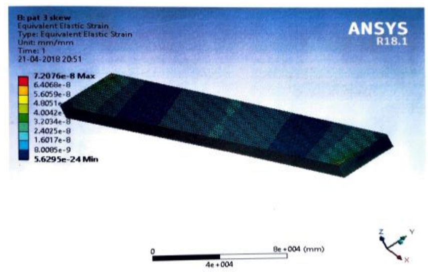

Figure 8 Pattern 2 Reinforcement Equivalent Elastic Strain

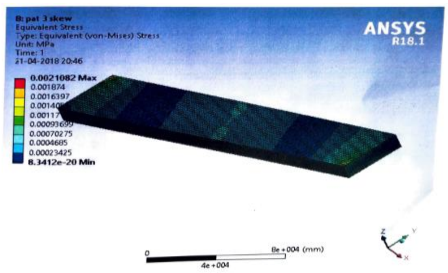

Figure 9 Pattern 2 Reinforcement Equivalent Stress

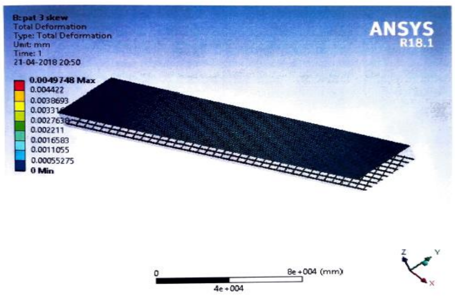

Figure 10 Pattern 2 Reinforcement Total Deformation

The skew slab of angle 25 degrees with different reinforcement patterns were analysed by ANSYS R.18. From the analysis, the solution for total deformation, equivalent strain and equivalent stress had compared by a bar chart preparation for minimum and maximum values of the following: total deformation and pattern type, equivalent strain and pattern type and equivalent stress and pattern type. By comparing the datas of three patterns, we conclude that the pattern 2 in which the longitudinal bars are perpendicular to the support is having the least minimum value and least maximum value while comparing with the solution of pattern 1and pattern 3. Here, solution represents the data's of total deformation, equivalent strain and equivalent stress of designed skew slab carrying a point load having a skew angle of 25 degrees. Though pattern 1 is easy in fabrication, pattern 2 has the safe the efficient performance for skew angle of 25 degrees. The analysis results of equivalent elastic strain, equivalent stress and total deformation were compared with the three pattern of reinforcement are shown in figure 11,12 and 13.

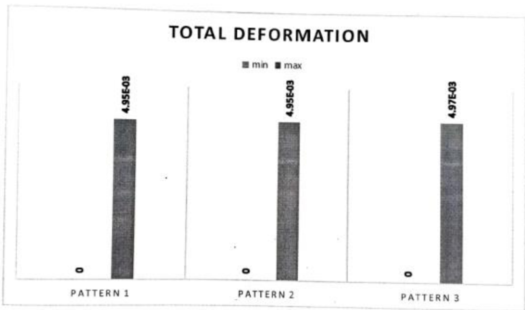

Figure 11 Comparisons of Total Deformation Values

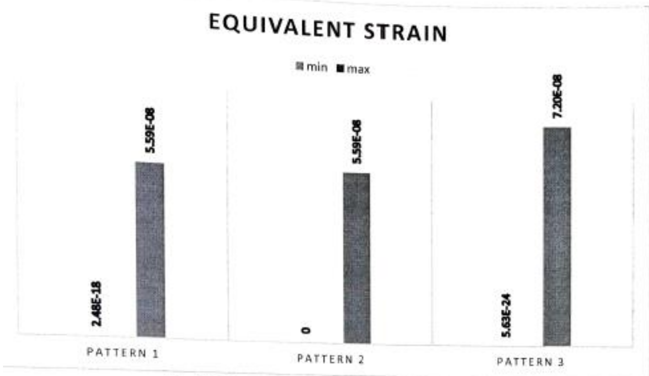

Figure 12 Comparisons of Equivalent Elastic Strain Values

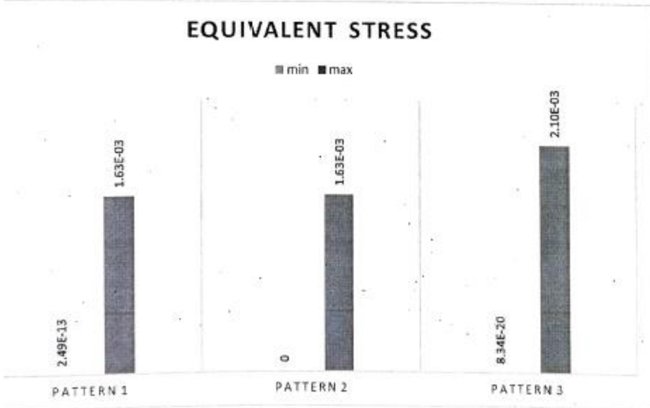

Figure 13 Comparisons of Equivalent Stress Values

V. CONCLUSION

From the present study of skew slabs with point loading for different types of pattern, the following conclusions may be drawn.

1) Type 1 reinforcement layout is the most common and widely used steel layout in practice even for skew slabs. Their preferences over the other two types are more because of its ease of fabrication than performance.
2) While considering the ultimate strength, all the three patterns of reinforcement performs equally almost for skew slabs. Although, slab with Type 3 pattern of reinforcement fails at somewhat higher load.
3) In serviceability and ultimate strength point of view, type 2 pattern of reinforcement with main reinforcement bar tip is welded to an extra reinforcement bar at the free edge will perhaps the most efficient and advantageous reinforcement layout pattern.
4) For achieving the best performance in skew slab with point load system along with 20º to 50º skew angle, reinforcement layout pattern type 2 should forever be used with provision for satisfactory end anchorage of the main bars.

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