INFLUENCE OF SKEW ANGLE ON STATIC BEHAVIOUR OF RCC AND PSC SLAB BRIDGE DECKS

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ABSTRACT

The effect of a skew angle on single-span reinforced concrete bridges and PSC bridges are analyzed using the finite-element method and the results are presented in this paper. Investigations are carried out on RC slab bridge decks and PSC bridge decks 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. Also comparative analysis of response of skewed RCC and PSC slab bridge decks with that of equivalent right bridge deck is made. A total of 120 bridge models are analyzed. The variation of maximum longitudinal bending moment, maximum transverse moment, maximum torsional moment and maximum longitudinal stresses with skew angle is studied for all 120 bridge deck models. The FEA results of Dead load and Live load longitudinal bending moments decreases with increase in skew angle, where as maximum transverse moment increase with increase in skew angle and also maximum torsional moment increases with increase in skew angle and the maximum longitudinal stresses decrease with skew angle up to 30 degrees and there after increases. The benefit of pre-stressing is reflected in significant decrease in longitudinal bending moment and transverse moment and longitudinal stresses.

KEYWORDS: Bridges, Concrete slabs; Dead load; Skew angle; Finite element method; span length; IRC Class A loading.

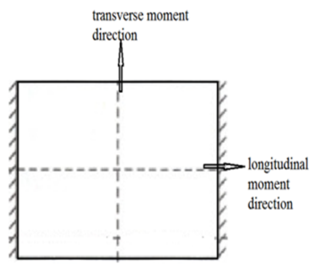
1. INTRODUCTION

Skewed bridges are often encountered in highway design when the geometry cannot accommodate straight bridges. The skew angle can be defined as the angle between the normal to the centreline of the bridge and the centreline of the abutment or pier cap, as described in Fig. 2. Skew bridges have become a necessity due to site considerations such as alignment constraints, land acquisition problems, etc. The presence of skew in a bridge makes the analysis and design of bridge decks intricate. For the Slab bridge decks with small skew angle, it is considered safe to analyze the bridge as a right bridge with a span equal to the skew span.

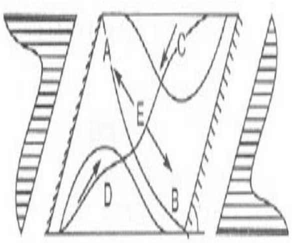
In non skewed bridges, the load path is straight toward the support (Fig 1a). In skewed bridges, the load tends to take a shortest path to the nearest support i.e. to the obtuse corners of the bridge here the maximum moments occurs at obtuse angled corner (Fig 1b).

Menassa et al. (2007) compared the effect o 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. Khaleel et al., (1990) presented a method for determining moments in continuous normal and skew slab-and-girder bridges due to live loads. Vikash Khatri et al. (2012) compared grillage method and finite element method of analysis and recommended the use of FEM because of closes agreement with the exact solution. Patrick Theoret et al., (2012) studied the bending moments and shear forces, required to design skewed concrete slab bridges.



(a)



(b)

Figure 1. Direction of moment flow in straight and skewed bridge decks.

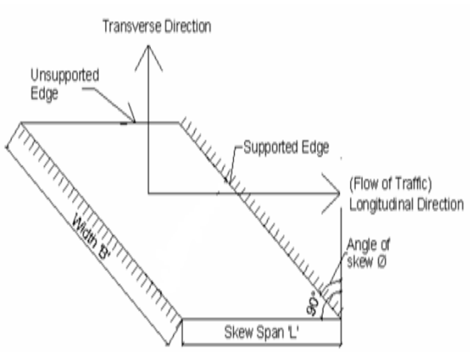


Fig2: Skew Bridge

2. PARAMETRIC STUDY

A simply supported, single span, two lane RCC and PSC slab bridge deck is considered. The span is varied from 7.5, 9 and 10.5m, and skew angle is varied from 0° to 60° at 15° interval is considered with the depth of the slab 450mm for all spans. The bridge deck is analyzed for Dead load as well as one class of live load i.e. IRC Class A and also for combination (LL+DL) of loads. Comparison of critical structural response parameter of above cases is presented in the following for RCC and PSC slabs. A total of 120 slab deck models have been analyzed

Table 1: Geometric parameters of slab bridge decks

No	**Span (m)**	**Width (m)**	**Aspect ratio (span/width)**
1	7.5	7.5	1
2	9	7.5	1.2
3	10.5	7.5	1.4

3. LOAD ON BRIDGE DECK MODELS

The vehicular live load consist of a set wheel loads and are treated as concentrated loads acting at centres of contact areas, one class of load i.e. IRC Class A is considered for analysis. The peak values of critical structural response parameter such as longitudinal bending moment, transverse moment, torsional moment and longitudinal stresses are analyzed. Different positions of loading systems are considered from table 2 of IRC 6:2010

4. FINITE ELEMENT MODELING

The analysis is carried out using finite element method. The concrete slabs are modelled using shell elements. Simple support condition is provided.

ELASTIC MODULUS	25000 Mpa
POISSON'S RATIO	0.2
DENSITY OF CONCRETE	25kN/m^2

5. RESULTS AND DISCUSSION

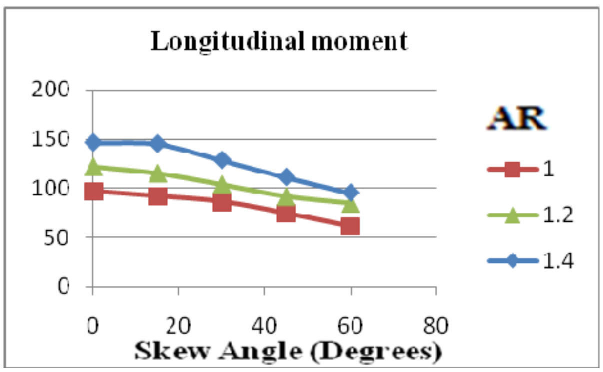
The FEA results are obtained and presented in terms of critical structural response parameter such a longitudinal bending moment, transverse moment, torsional moment, and longitudinal stresses in the bridge deck models due to the applied wheel load.

The variations of the critical structural response parameter due to changes in skew angle are presented in the following.

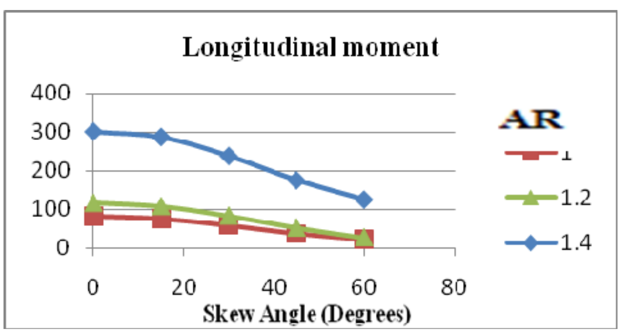
5.1. RCC Deck

5.1.1 Longitudinal Bending Moment (kNm)

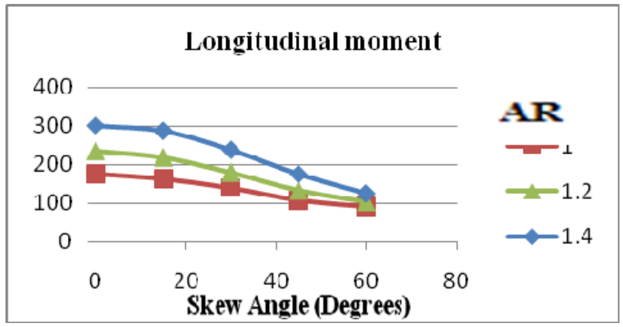
It is observed that the maximum dead load longitudinal bending moment and wheel load longitudinal bending moment for skewed deck slabs compared to that of straight deck slab decreases with the increase in skew angle for all aspect ratios as shown in fig 3. This is because the force flow between the support lines is through the strip area connecting the obtuse angled corners, as skew increases the length of strip area decreases therefore the moment decreases.



a) Live Load



b) Dead Load

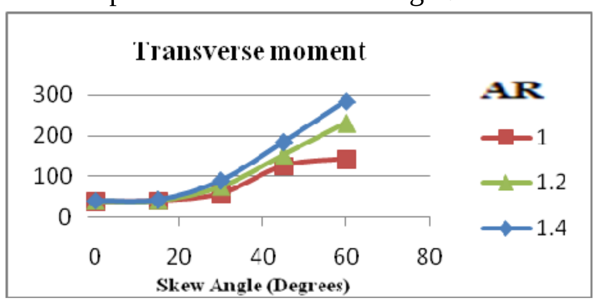


c)) (LL+DL) Load

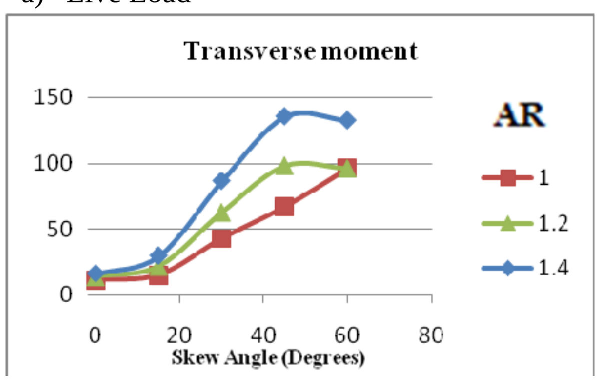
Fig 3 Variation of Longitudinal Moment Due To Dead Load and Live Load and the Combination (LL+DL) on Deck Slab

5.1.2 Transverse Bending Moment (kNm)

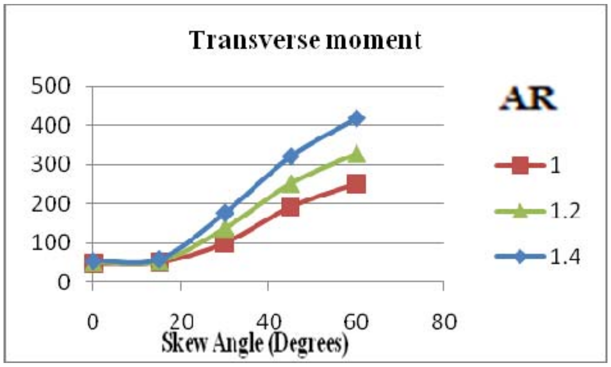
Unlike longitudinal bending moment it is observed that the maximum dead load transverse bending moment and wheel load transverse bending moment for skewed deck slabs compared to that of straight deck slab increases with the increase in skew angle for all aspect ratios as shown in fig 4.



a) Live Load



b) Dead Load

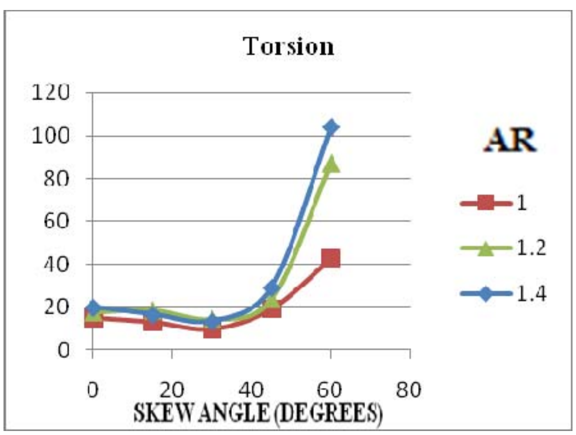


c) (LL+DL) Load

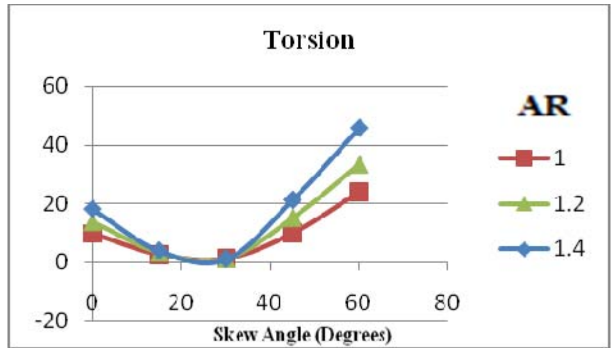
Fig 4 Variation of Transverse Bending Moment Due To Dead Load, Live Load and the Combination (LL+DL) on Deck Slab

5.1.3 Torsional Moment (kNm)

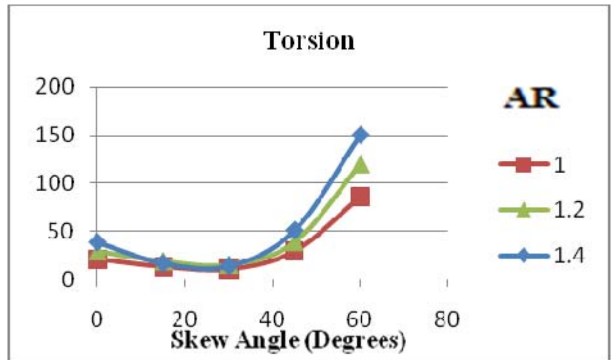
It is observed that the dead load and wheel load torsional moments for skewed deck slab decreases with the increase in skew angle for all aspect ratios up to 30 degrees and then increases for further increase in skew angle for aspect ratios as shown in fig 5.



a) Live Load



b) Dead Load

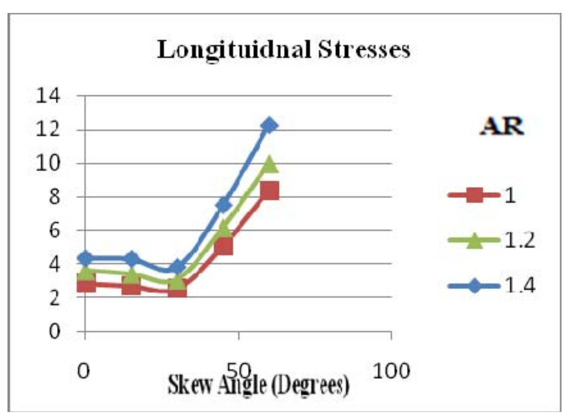


c) (LL+DL) Load

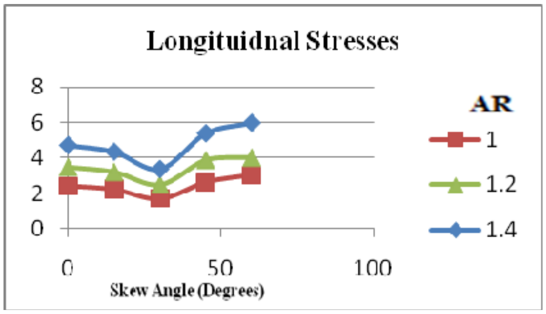
Fig 5 Variation of Trosional Moment Due To Dead Load and Live Load and the
Combination (LL+DL) on Deck Slab

5.1.4 Longitudinal Stresses (N/mm²)

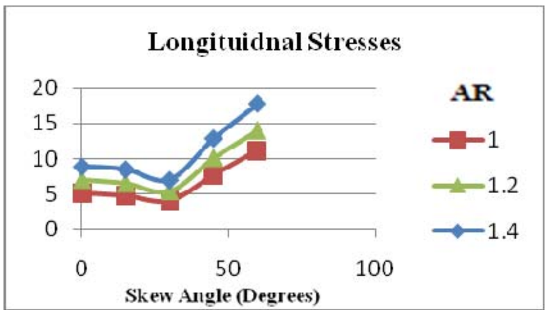
- The trend in longitudinal stresses is similar to torsional moment. It is observed that the dead load and wheel load longitudinal stresses for skewed deck slab decreases with the increase in skew angle for all aspect ratios up to 30 degrees and then increases for further increase in skew angle as shown in fig 6.



a) Live Load



b) Dead Load



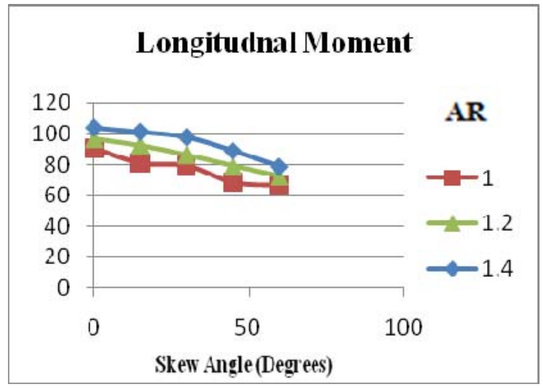
c) (LL+DL) Load

Fig 6 Variation of Longitudinal stresses Due To Dead Load, Live Load and the Combination (LL+DL) on Deck Slab

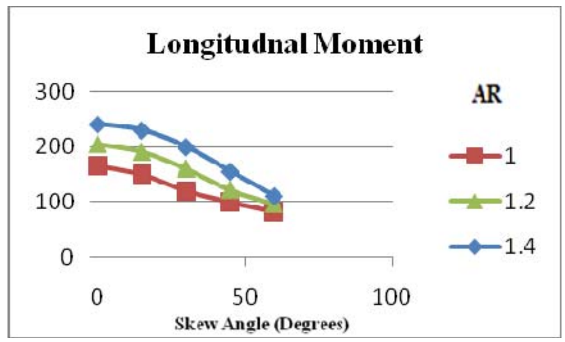
5.2 PSC Deck

5.2.1 Longitudinal Bending Moment

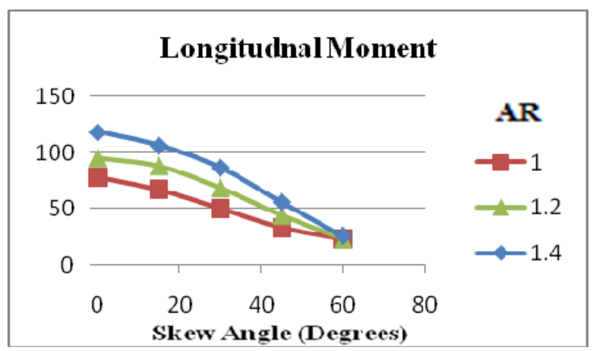
- It is observed that the maximum dead load longitudinal bending moment and wheel load longitudinal bending moment for skewed deck slabs compared to that of straight deck slab decreases with the increase in skew angle for all aspect ratios as shown in fig 7. This is because the force flow between the support lines is through the strip area connecting the obtuse angled corners, as skew increases the length of strip area decreases therefore the moment decreases.



a) Live Load



b) Dead load

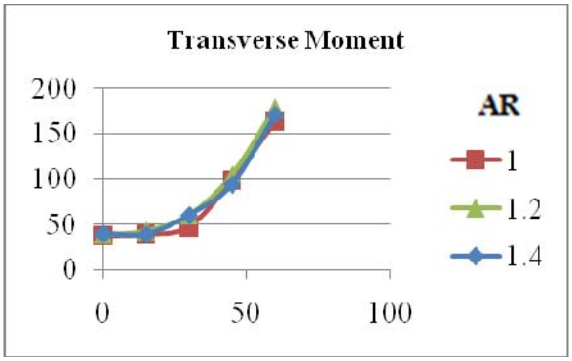


c) (LL+DL) Load

Fig 7 Variation of Longitudinal Moment Due To Dead Load and Live Load and the Combination (LL+DL) on PSC Deck Slab

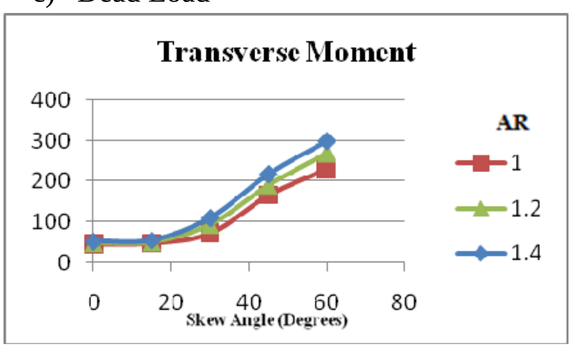
5.2.2 Transverse Moment

- Unlike longitudinal bending moment it is observed that the maximum dead load transverse bending moment and wheel load transverse bending moment for skewed PSC deck slabs compared to that of straight PSC deck slab increases with the increase in skew angle for all aspect ratios as shown in fig 8.



a) Live Load

c) Dead Load

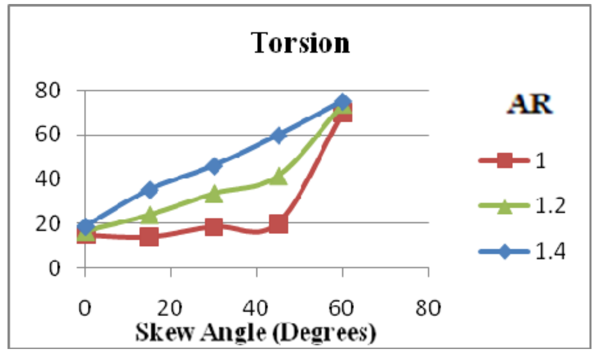


c) (LL+DL) Load

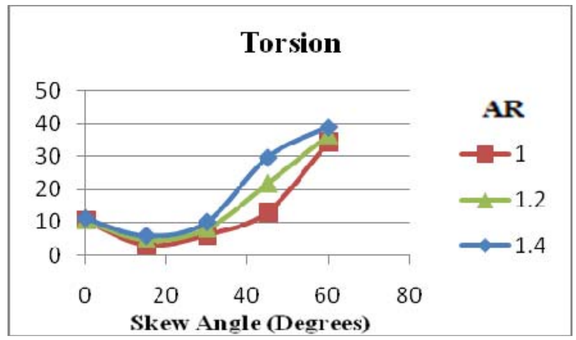
Fig 8 Variation of Transverse Bending Moment Due To Dead Load, Live Load and the Combination (LL+DL) on PSC Deck Slab

5.2.3 Torsional Moment

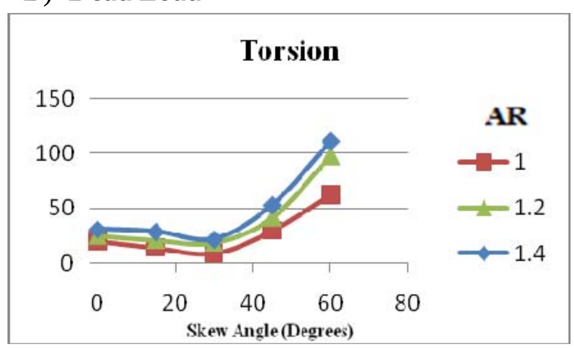
- It is observed that the dead load and wheel load torsional moments for skewed PSC deck slab increases with the increase in skew angle for all aspect ratios and for combination of loads is decreases up to 30 degree and then increase with further increase in skew angle as shown in fig 9.



a) Live Load



B) Dead Load

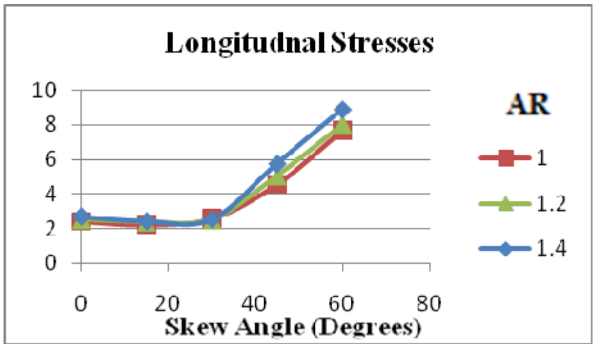


c) (LL+DL) Load

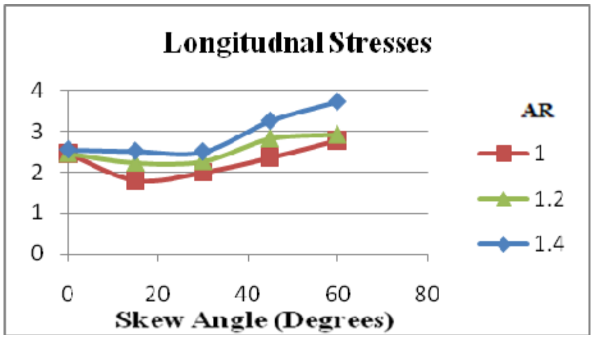
Fig 9 Variation of Trosional Moment Due To Dead Load and Live Load and the Combination (LL+DL) on PSC Deck Slab

5.2.4 Longitudinal Stresses

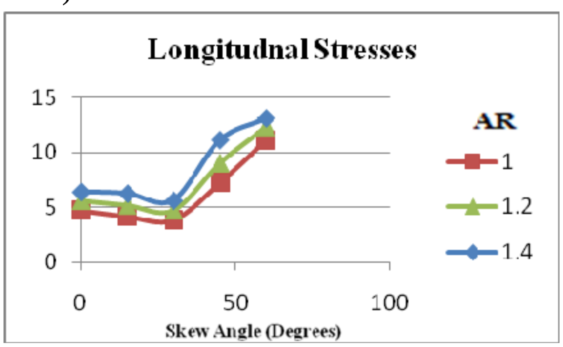
- The trend in longitudinal stresses is similar to combination of loads in torsional moment. It is observed that the dead load and wheel load longitudinal stresses for skewed PSC deck slab decreases with the increase in skew angle for all aspect ratios up to 30 degrees and then increases for further increase in skew angle as shown in fig 10.



a) Live Load



b) Dead Load

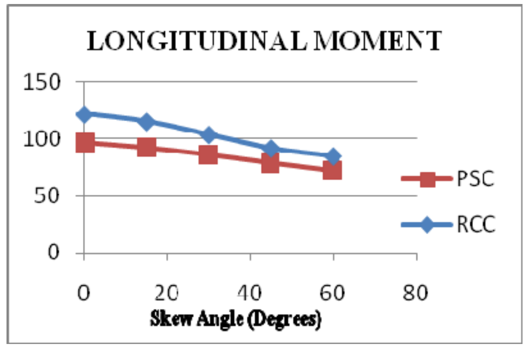


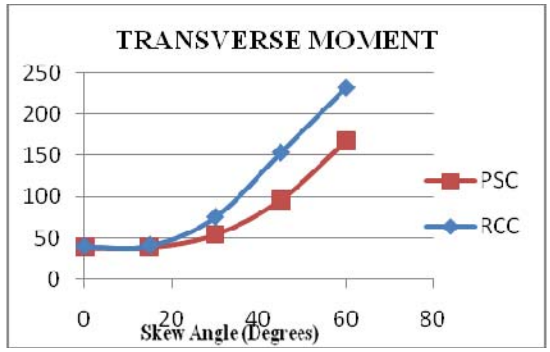
c) (LL+DL) Load

Fig 10 Variation of Longitudinal stresses Due To Dead Load, Live Load and the Combination (LL+DL) on PSC Deck Slab

5.3 COMPARISON OF RCC AND PSC SLAB BRIDGE DECK

It is observed that the maximum dead load and wheel load moments and stresses for skewed deck slabs reduces for PSC deck compared with that of RCC deck this is because by Prestressing the slab the deck becomes stiff and thus the moments and stresses are reduced as shown in fig 11,12 and 13.





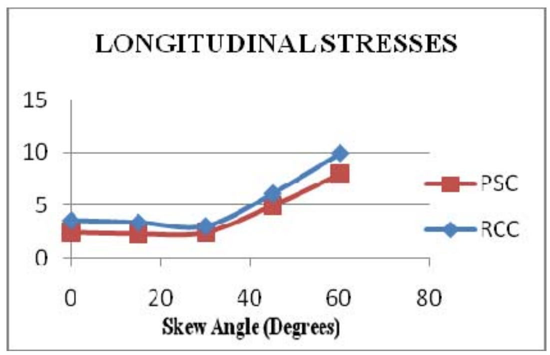
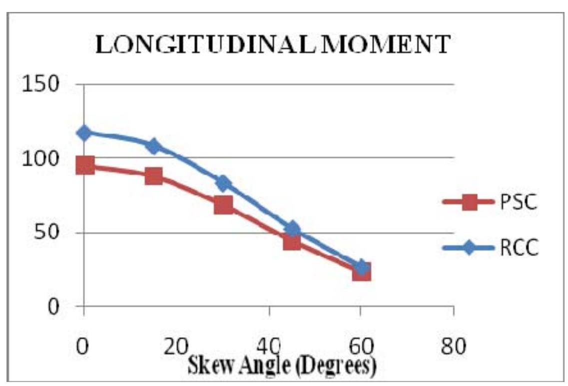


Fig 11 Comparison of RCC and PSC Deck Slab For Live Load Condition



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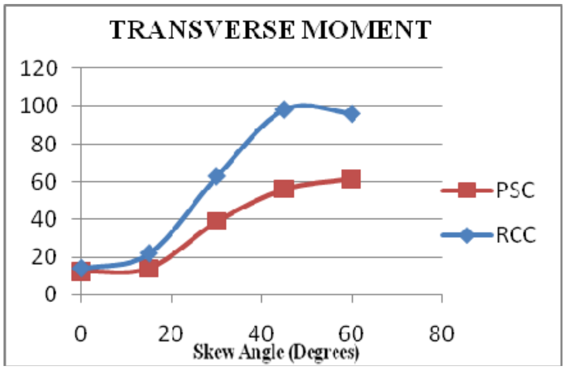


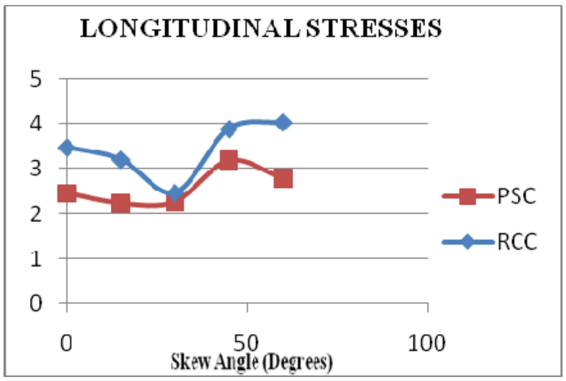
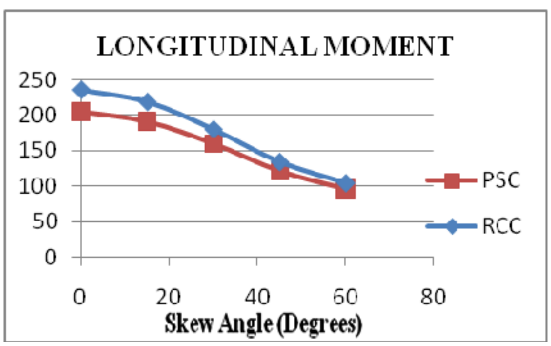
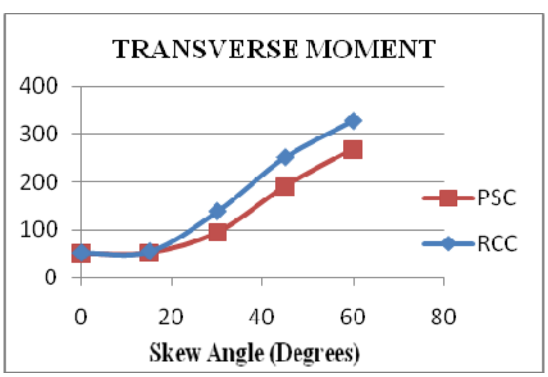


Fig 12 Comparison of RCC and PSC Deck Slab For Dead Load Condition





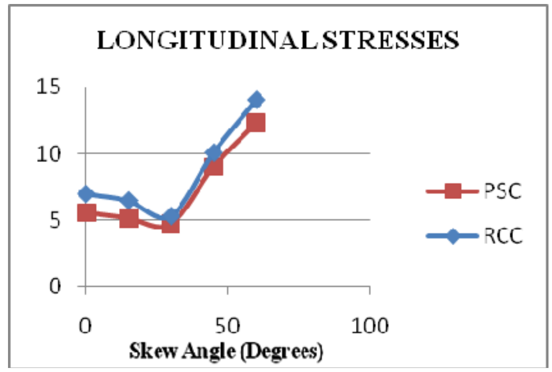


Fig 13 Comparison of RCC and PSC Deck Slab for (LL+DL) Load Condition

CONCLUSIONS

1. The maximum longitudinal bending moment shows pattern of reduction with increase in skew angle and maximum reduction due to dead load is found to be 70 % for a skew angle 60° compared to right bridge for both RCC and PSC deck for all aspect ratio.Maximum wheel load longitudinal bending moment decreases around 30 % to 35% for skew angle 60° compared to right bridge for RCC and PSC decks for all aspect ratio.

2. For right bridge deck slab (0° skew), maximum longitudinal moments are orthogonal to abutments in central region. As the skew angle increases maximum longitudinal moments gradually shifts towards obtuse corner.

3. The maximum transverse bending moment shows pattern of increment with increase in skew angle and maximum increment due to dead load is found to be 80 % for a skew angle 60° compared to right bridge for both RCC and PSC deck for all aspect ratio.Maximum wheel load longitudinal bending moment increases around 70 % to 75% for skew angle 60° compared to right bridge for both RCC and PSC decks for all aspect ratio.

4. It is observed that the dead load and wheel load torsional moments for skewed PSC

deck slab increases with the increase in skew angle for all aspect ratios. For RCC deck and for combination of loads in PSC deck it decreases up to 30 degree and then increase with further increase in skew angle. The peak value of torsional moment is two times more than corresponding value for a right bridge deck.

5. The increase in torsional moment is because the area on the either side of the strip do not transfer load to the support directly but transverse the load to the strip as cantilever, hence skew slabs are subjected to twisting moments. For right bridge deck slabs (0° skew), maximum torsional moments are located near all corner regions. As skew angle increases torsional moments gradually shifts towards obtuse angle.

6. It is observed that the dead load and wheel load longitudinal stresses for skewed deck slab decreases with the increase in skew angle for all aspect ratios up to 30 degrees and then increases for further increase in skew angle for all the aspect ratios for both RCC and PSC deck slabs.

7. It is observed that the maximum moments and stresses for dead load, wheel load and combination of loads for skewed deck slabs reduces for PSC deck compared with that of RCC deck this is because by Prestressing the slab the deck becomes stiff and thus the moments and stresses are reduced.

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Standard Codes

1. IRC 6:2000 “Standard Specifications and Code of Practice for Road Bridges, Section-II Loads and Stresses”, Indian Road Congress, New Delhi.
2. IRC 21:2000 “Standard Specifications and Code of Practice for Road Bridges, Section-III Cement Concrete (Plain and Reinforced)”, Indian Road Congress, New Delhi.