

Analysis of Skewed 3-Lane Slab Bridge Deck

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ABSTRACT: The FEA is carried out to analyze the skewed RC and PC single-span slab bridge decks and also explored how the skew angle influences with respect to aspect ratio and live load i.e. IRC class A wheel load. The FEA results of 15 RC and 15 PC skew bridge deck models are compared with right bridge for dead load and live load combination and variations in structure response parameters such as longitudinal B.M, transverse B.M, torsional B.M, and longitudinal stresses are observed with various skew angles and aspect ratios. The results show that with increase in skew angle, maximum longitudinal B.M decreases, maximum transverse B.M increase, maximum torsional moment increases, and the maximum longitudinal stresses decrease with skew angle up to 30°, but increase thereafter. The advantage of pre-stressing shows significant decrease in longitudinal and transverse B.M and longitudinal stresses.

KEYWORDS: RC and PC slab bridge decks, Skew angle, IRC loading, Finite Element Analysis.

I. INTRODUCTION

A skew bridge deck is one whose flow of forces due to loads on deck is not at right angle to the reaction lines from abutment or pier cap. The skewed bridges are often necessary due to natural or manmade obstacles, complex intersections, space limitations, or mountainous terrain. When the loads are applied on slab, it's difficult to analysis its response due to its skewness. For small skew angle (α), the structural responsive parameters like bending moments, shear force, and support reactions are same for both skewed and non-skewed slabs. With higher α , the stresses in the slab and reactions on the abutment or pier will vary considerably from those in normal slab (Fig 1).

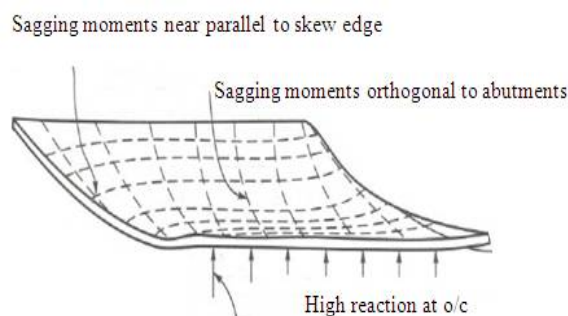


Fig 1: General flexural behaviour of skew deck

In right bridge, the load from the deck slab gets transfer to the nearest supports which are placed orthogonal to slab, whereas the load distribution from skewed slab to the supports is complicated issue due to uncertainty in finding the path (Fig 2). Hence, due to unequal flow of load to the supports in skewed bridges, there will be high reaction at obtuse angled corners (o/c), possible uplift at acute angled corners (a/c), negative moment along support lines, and high shear and high torsion near o/c.

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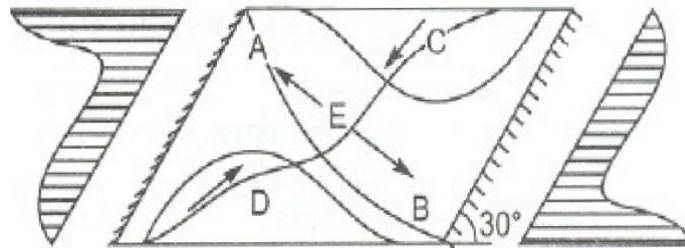


Fig 2: Force flow in a skew deck

II. LITERATURE REVIEW

- Menassa et al. (2007):** using FEA, the parameters like span length, slab width, and α were investigated for skewed and normal slab decks and results are found in conformity with standard AASHTO and LFRD load procedures. Recommended that the analysis is same for both normal and skewed slab decks when $\alpha \leq 20^\circ$.
- Ibrahim Harba S.I (2011):** using FEM, an analytical study was made, with span length and α as parameters, on how α influences the behavior of simply supported RC T-beam bridge decks and confirmed that the deck geometries and loading are complied with AASHTO standards. LL B.M and deflection decreases in skewed T-beam bridges, while maximum shear, torsion and support reactions increases in some skewed T-beam bridges for all considered span lengths (12, 16, 20 and 24m). This study is in disagreement with the AASHTO and LRFD standard procedures in recommending that bridges with $\alpha \leq 20^\circ$ be designed as straight bridges.
- Patrick Theoret et al., (2012):** using the equivalent-beam method, investigation is made on skewed and straight concrete bridge deck slabs for determining B.M and S.F. Studied parametrically with different geometrics of slab deck and α for AASHTO loading and shown that non-orthogonal grillages for skewed slab for M_x and S.F has predicted satisfactorily. The parametric study results indicated that M_y , M_{xy} , and S.F will increase with increase of α , while M_x diminishes. Equations are proposed for calculating B.M and S.F for α up to 60° .
- Gholamreza Nouri et al., (2012):** using has 3D FEM analysis, investigated about the influence of α on two span composite girder continuous bridge models. The parameters varied are α , span ratio, and intermediate transverse diaphragm arrangements. AASHTO HS20-44 LL is applied on the slab decks. The results are compared, between skewed and right slabs, with AASHTO standard specifications. It is found that as α increases, the interior and exterior support moments are decreases and S.F of exterior girders increases whereas interior girder decreases. This investigation has confirmed that the provision of cross diaphragms is mandatory for better load distribution.

III. PARAMETRIC STUDY

3-lane single span reinforced concrete (RC) and pre-stressed concrete (PC) slab decks are considered for analysis. The slab length is varied from 7.5 m to 10.5 at 1.5 m interval and α is varied at 15° interval from 0° to 60° . The overall depth of concrete slab is 500 mm for all spans with M50 grade concrete. Analysis is done by applying IRC class 'A' wheel load (LL) on the slab. Comparison of critical structural response parameters with combination of LL and dead load (DL) is carried out for RC and PC slabs for various α .

Span, L (m)	Width, B (m)	Aspect Ratio ($\beta = L/B$)
7.50	12.00	0.625
9.00	12.00	0.750
10.50	12.00	0.875

Table 1: Geometric parameters of slab bridge deck

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IV. LOAD ON BRIDGE DECK MODELS

The LL i.e. vehicular load of IRC class A, which weighs 554kN through 8 axles and 18.8 m in length, is considered for analysis. This load is applied as per IRC 6: 2010 stipulations over 3-lane slab width either in forward/backward direction. Load for number of lanes and different positions of loading systems are considered from table 2 of IRC 6: 2010 and peak values of structural response parameters such as longitudinal B.M (M_x), transverse B.M (M_y), torsional moment (M_{xy}) and longitudinal stresses (S_x) are analysed.

V. FE MODELING

FEA is carried out using SAP2000 software for modelling of the deck slab. The concrete deck is treated as shell element for analysis with supports treated as simply supported.

Property of concrete	Value
Young's Modulus of elasticity (E)	: 35 x 10 ⁶ kPa
Poisson's ratio (μ)	: 0.2
Unit weight	: 25 kN/m ³

VI. RESULTS AND DISCUSSION

The results of analysis i.e. M_x , M_y , M_{xy} , and S_x due to (LL+DL) with various α are investigated and comparison is made between RC & PC slab decks.

1. RC SLAB BRIDGE DECK:

- **M_x (kN-m):** Unlike right slab, when α increases, M_x for skewed slab diminishes due to (DL+LL) for all the β s as shown in fig 3. It's due to unequal lengths of diagonals connecting o/c and a/c. The load path in the form of strip finds the shortest route to reach supporting lines. As the length between o/c decrease with increase in α , the value of M_x which is aligned along this strip reduces.

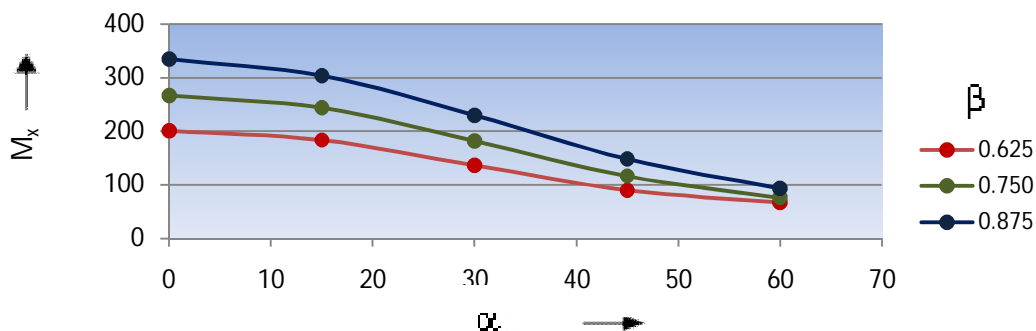


Fig 3. Variation of M_x due to (DL+LL) combination on Deck Slab

- **M_y (kN-m):** Unlike M_x , M_y increases with increase of α for all β s as shown in fig 4. The DL moments are positive i.e. sagging along o/c and negative i.e. hogging along a/c. Whereas, the LL moments are only positive along o/c.

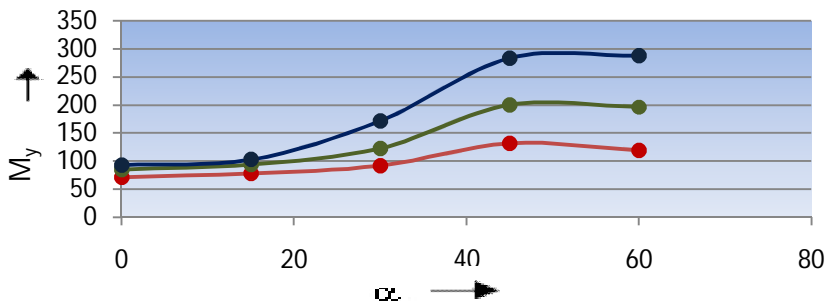


Fig 4. Variation of M_y due to (LL+DL) combination on deck slab

- M_{xy} (kN-m): for increase in values of α for all the β , it is found that due to (DL+LL) over skewed slab, M_{xy} decreases up to 30° and then increases further increase in α as shown in fig 5.

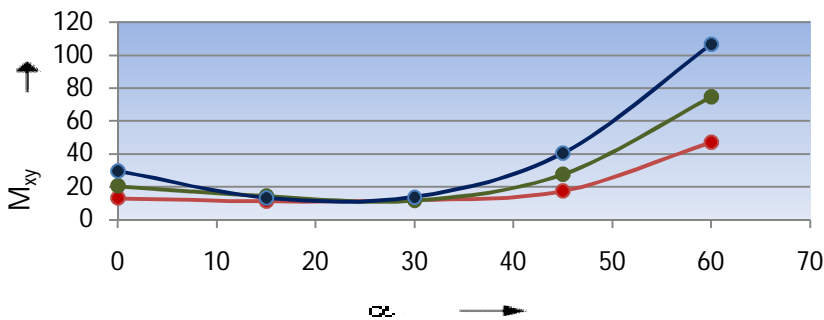


Fig 5. Variation of M_{xy} due to (DL+LL) combination on deck slab

- S_x (MPa): the structural response of S_x is same as M_{xy} i.e. with the increase in α for all β s up to 30° , the value decreases for the (DL+LL) combination and thereafter increases with increase in α as shown in fig 6.

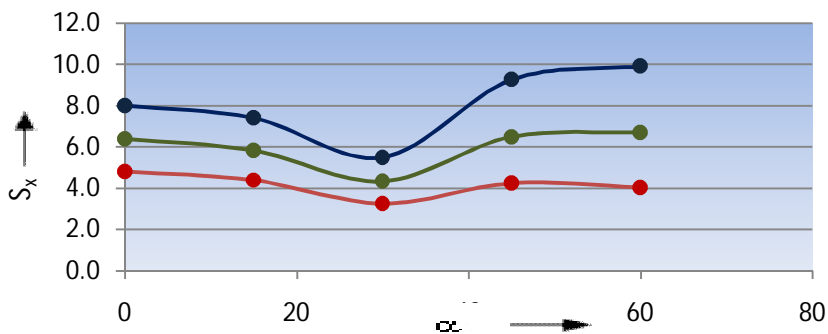


Fig 6. Variation of S_x due to (DL+LL) combination on deck slab

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2. PC SLAB BRIDGE DECK:

- M_x (kN-m): the moment distribution of PC skewed slab is same as RC skewed slab, except that the results of M_x of skewed PC are 20% to 30% lower than skewed RC slab due pre compression imparted to the concrete.

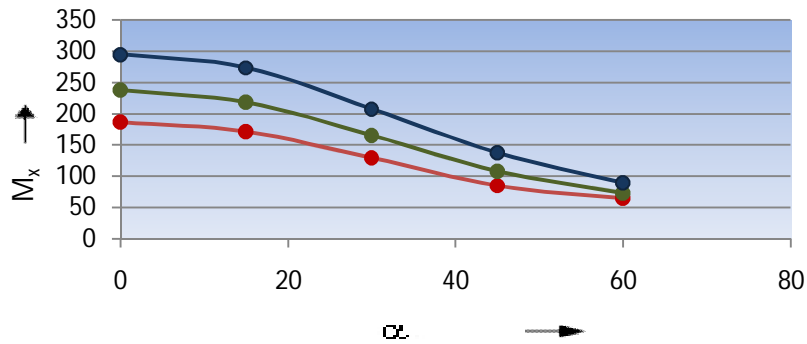


Fig 7. Variation of M_x due to (DL+LL) combination on PC slab deck

- M_y (kN-m): for all the β s and with α increases, the moment distribution of PC skewed slab is same as for RC skewed slab as shown in fig 8.

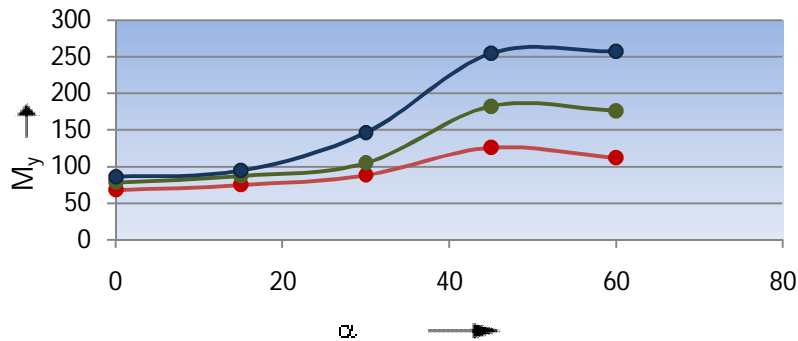


Fig 8. Variation of M_y due to (LL+DL) combination on deck slab

- M_{xy} (kN-m): for increase in values of α for all the β , it is found that due to (DL+LL) on skewed slab, M_{xy} slightly increases up to 30° and then increases further with further increase in α as shown in fig 9.

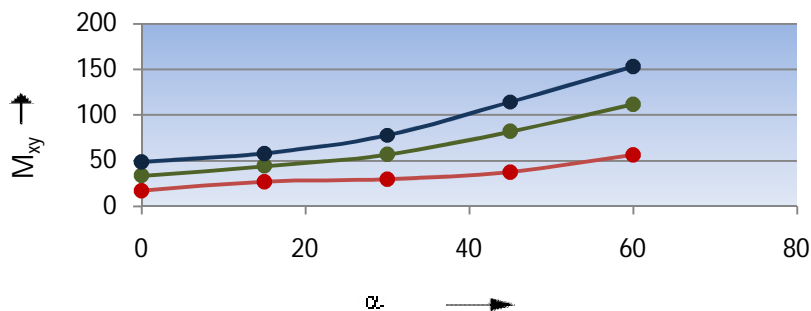


Fig 9. Variation of M_{xy} due to (DL+LL) combination on deck slab

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- S_x (kN-m): when slab skewness increases for all β_s , the trend in PC for S_x is similar to the RC skewed slab as shown in fig 10.

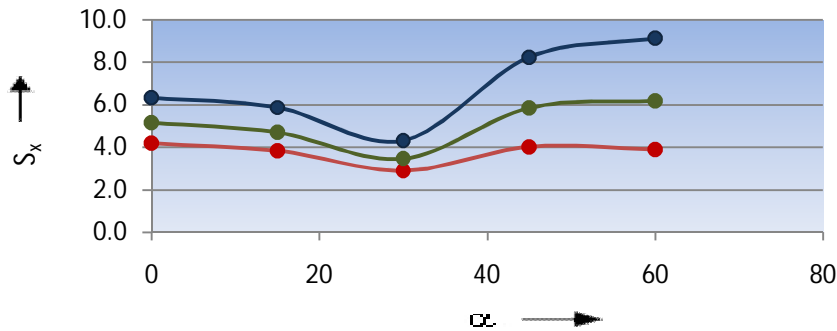
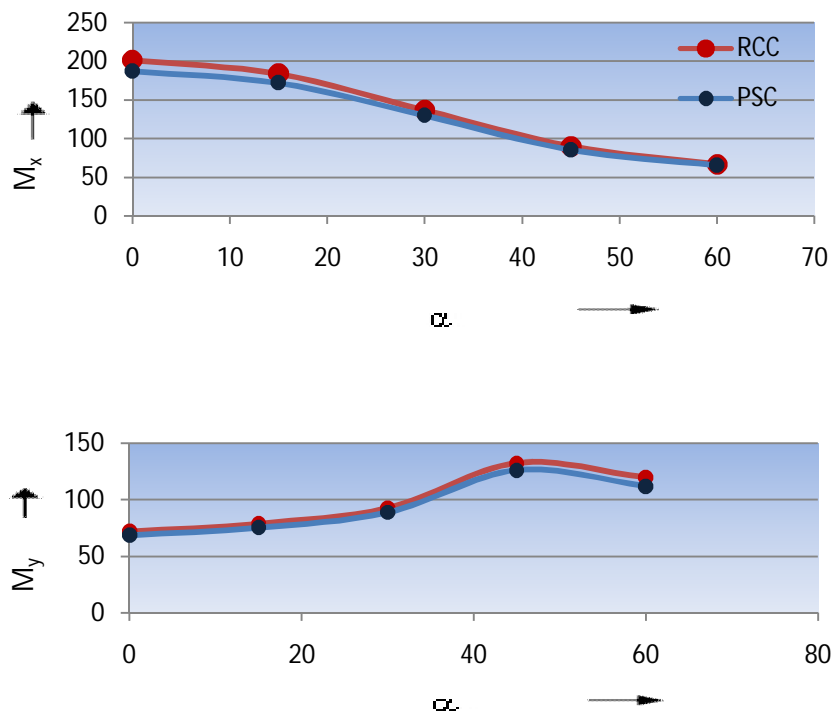


Fig 10. Variation of S_x due to (DL+LL) combination on PC slab deck

3. COMPARISON OF RC AND PC SLAB BRIDGE DECKS:

It is observed that by imparting pre-compression in concrete, the maximum DL and LL moments and stresses for skewed PC slab will reduce when compare with that of RC slab as shown in Fig 11.



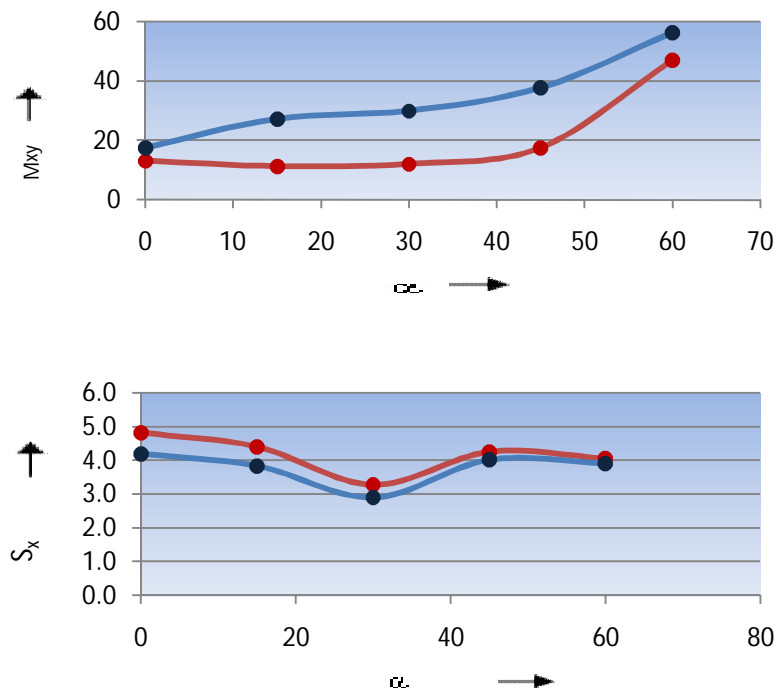


Fig 11. Comparison of RC and PC slab for (DL+LL) combination.

VII. CONCLUSION

1. The M_x shows a decreasing trend with increase in α and the maximum reduction in DL M_x is found to be 60% for α of 60° compared to right bridge for both RC and PC deck slabs for all β s. The maximum reduction in LL M_x is around 30% to 35% for α of 60° compared to right bridge for RC and PC decks for all β s.
2. For right slab, the maximum M_x is orthogonal to abutments in central region. As the α increases, maximum M_x gradually shifts towards o/c and there is uplift in a/c. Hence care should be taken in detailing the reinforcement properly at corners.
3. The maximum M_y shows an increasing trend with increase in α and the maximum increments in DL M_y is found to be 70% for a α of 60° compared to right bridge for both RC and PC decks for all β s. The maximum increment in LL M_y is around 70% to 80% for α of 60° compared to right bridge for both RC and PC decks for all β s.
4. It is observed that the DL and LL M_{xy} for RC deck slab decreases with the increase in α up to 30° and then increases with further increase in α for all β s. The peak value of M_{xy} is nearly two times more than corresponding value for a right bridge deck. However in case of PC bridge decks M_{xy} increases with the increases in α for all the β s.
5. Maximum M_{xy} for right bridge deck slabs (0° skew) is located near all corner regions. As α increases, M_{xy} gradually shifts towards o/c.
6. It is observed that the (DL+LL) S_x decreases with the increase in α for all β s up to 30° and then increases for further increase in α for all the β s for both RC and PC deck slabs.
7. It is observed that the maximum moments and stresses reduce for PC deck compared with that of RC deck for all load cases in skewed deck slabs.

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8. It is observed that the PC decks show 20% reduction in the M_x for α up to 30° and for $\alpha > 30^\circ$ it found that the percentage decrease is around 10 to 15% for all the β , which is not much significant.
9. The percentage decrease in M_x for PC bridge deck compared with that of RC bridge deck is found to be about 20 to 30% for all α & β .
10. When compare with RC slab, it is found that there is 30 to 35% increase in M_{xy} in PC slab for all the β and for all α except for 30° , it is found to be 80% increase for 30° for all the β .
11. When compare with RC slab, for all the α and β , there is 15 to 30% reduction in S_x for PC slab.
12. The advantage of providing pre-stressing is observed in reduction of the maximum M_x , M_y and S_x , more effectively up to 30° . For $\alpha > 30^\circ$, pre-stressing is not so effective. This is due to the fact that much of B.M is aligned towards the o/c. Hence there is a necessity for provision of higher amount of pre-stress there by arranging pre-stressing cables in the form of fan-shape.

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