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Effect on Super Structure of Integral Abutment Bridge under Fixed and Pinned Pile Head Connections

Yamuna Bhagwat(corresponding author)
Post Graduate Student, Civil Engineering Department, KLEMSSCET Belgaum, Belgaum- 590008
Karnataka, India
Email : yamuna.bhagwat1@gmail.com

R.V. Raikar and Nikhil Jambhle
1Professor, Civil Engineering Department, KLEMSSCET Belgaum, Belgaum- 590008, Karnataka, India

Abstract

Integral bridges are recommended as one of the best alternative in the construction of bridges. They are constructed without joints in superstructure and these bridges can be of single span or multi span. Typically integral bridges have stub-type abutments supported on piles and a continuous bridge deck from one embankment to the other. Failure of proper functioning of the expansion joints and abutment bearings due to various reasons leads to highly critical and serious problems. Failure to move properly due to unanticipated movements results in overstress and subsequent structural damage to the bridge elements via split and rupture of abutment bearings, abutment-rotation and abutment-overturning.An attempt is being made in this study to analyse the effect of pile head connection with abutment on super structure under DL, LL and temperature effects on integral abutment bridge by FEM analysis using SAP 2000. The study considers integral abutment bridge with pile head having fixed and pinned connection with single, two and three spans. The variation of different design parameters such as BM, SF, axial force and longitudinal fibre stresses in deck slab and BM and SF in girder bridges have been analysed and compared. It is found that, in integral abutment bridge the design parameters are affected by the pile head to abutment connection. It is found that, in case of only DL, the negative maximum end BM is reduced by 10.5% in case of single span, 28.5% in two spans integral abutment bridge and no change in three spans integral abutment bridge. However the positive BM shows an increasing trend. It is also observed that the all design parameters are reduced with increase in span numbers. On the other hand, the temperature rise enhances negative BM and decreases positive BM. Furthermore, SF in deck slab is increased by 5.9% in two spans integral abutment bridge having pile head with pinned connection but there is no change in SF is observed in single and three spans, similarly in central girder decrease and in external girder increase in SF is observed in single and two spans bridge and there is no change in three spans bridge. Also DL + temperature and DL + LL+ temperature combination with different spans in comparison with single span and in comparison with DL is studied.

Keywords: Abutment, Deck, Integral Abutment Bridge, piles, pile head, Finite element method, Abutment pile head connection

Introduction

Bridges constructed without any expansion joint (between spans or between spans and abutments) and without any bearings are called integral bridges. Integral bridges are characterized by monolithic connection between the deck and the substructure (piers and abutments). This rigid connection allows integral bridges to act as a single unit in resisting thermal and brake loads. The need for jointless bridges evolved from the desire to eliminate the use of expansion joints and bearings. Leakage of water laden with salt, deicing chemicals and contaminants through the joints results in the corrosion of the reinforced concrete, girder ends, bearings and pier caps underneath. Failure to move properly due to unanticipated movements results in overstress and subsequent structural damage to the bridge elements via split and rupture of abutment bearings, abutment-rotation and abutment-overturning. In addition, expansion joints are very expensive to design, manufacture and install. The continuous maintenance and replacements costs are not meager either. Therefore integral bridges came to the forefront as a result of a need for a definite change in the design of highway bridges (Khodair and Hassiotis 2013).

The daily and seasonal temperature changes, the changing temperature conductivity between the different components of the bridge superstructure, and the non-uniformity of the temperatures within the bridge deck in both the horizontal and vertical directions result in cyclic bridge expansions and contractions (Khodair and Hassiotis 2013).

The integral abutment bridge concept is based on the theory that due to the flexibility of the piling, thermal stresses are transferred to the substructure by way of a rigid connection between the superstructure and substructure. They are generally designed with the stiffness and flexibilities spread throughout the structure/soil system so that all supports accommodate the thermal and braking loads. Integral bridges are single or multiple span bridges having their superstructure cast integrally with their substructure. Generally, these bridges include capped pile stub abutments. Piers for integral abutment bridges may be constructed either integrally with or independently of the superstructure. Typically single rows of piles provide foundation support for the abutments. Typical integral-abutment bridge details cause the heads of piles to be fixed, but this condition will cause relatively high pile bending stresses in longer bridges. To relieve bending stresses at the pile heads the connection may be detailed as a pinned-head condition or the abutment detailed to create a hinge (Dunker and Liu 2007).

This paper describes the effect of pile head connection with abutment on deck slab. Using commercially available finite element software SAP 2000. The bridge models are prepared for pile head with fixed connection and pinned connection and analysed for dead load, live load and temperature load cases. Effect of pile head connections on deck slab is studied by observing variation of design parameters like bending moment, shear force, axial force and longitudinal stresses.

BRIDGE DETAILS CONSIDERED FOR STUDY

The bridge model with 60 m length having single (60 m), two (30 m each) and three spans (20 m each) is considered for the study with pile head having fixed connection and pinned connection. Width of the bridge taken for the study is 12 m. The thickness of the deck slab considered is 0.25 m, main girders are of size 0.35 m × 1.5 m placed at the distant of 2.4 m c/c. The height of the integral abutment from the bottom of the abutment to bottom of girder is 3m. And piles are of cast in situ having diameter 1.1 m and pier of diameter 1.2 m are used for the current study. Figure 1 shows the model of integral abutment bridge developed using SAP 2000.

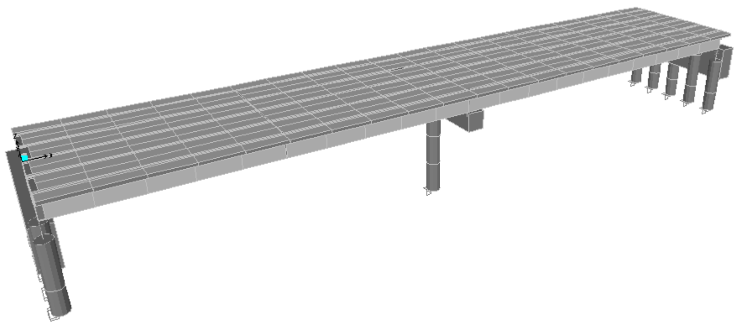


Fig.1. Two spans integral abutment bridge model developed using SAP 2000.

The live load is applied as per IRC 6-2000 and the positive change in temperature 10°C is considered in the analysis. And all the properties of M 30 concrete and Fe- 415 steel are taken from IRC21:2000.

METHOD OF MODELING OF BRIDGE

The bridge models are done in commercially available software SAP 2000v14 by using bridge wizard. The deck and the girder are accounted by rigid links. Deck slab is modeled by quadrilateral shell element, which couples bending with membrane action. Longitudinal girders diaphragm and piles are modeled as frame element. The deck and girder are placed at their vertical location of the centroid respectively. The composite action between the deck and girder is effected by the rigid links.

Six bridge models are developed having single span, two spans and three spans with pile head fixed connection and pinned connection. The intermediate piers constitute of one column, over which a pier cap is provided to rest the main longitudinal girders. The pile and pier column are assumed to be fixed at base and soil effect on pile is not considered in this study. The details of the bridge models developed are given in Table 1.

Table 1: Details of bridge models.

Bridge model	Bridge length (m)	Number of span	Each span length (m)	Connection of pile head
1	60	1	60	Fixed
2	60	1	60	Pinned
3	60	2	30	Fixed
4	60	2	30	Pinned
5	60	3	20	Fixed
6	60	3	20	Pinned

RESULTS AND DISCUSSION

The results are compared for the bending moments, shear forces and longitudinal stresses in the deck slab of integral abutment bridge having pile head with fixed and pinned connections and presented in the form of graphs.

Fig. 2 shows the comparison of variation of BM in deck slab of single span integral abutment bridge having pile head with fixed and pinned connection under only DL. It is found that the positive maximum BM is increased by 17.69% while negative maximum BM is reduced by 10.5% in pinned pile head connection as compared with fixed pile head connection. In SF it is observed that the SF values (both positive and negative) remain same in both cases. The variation of SF is shown in Fig.3

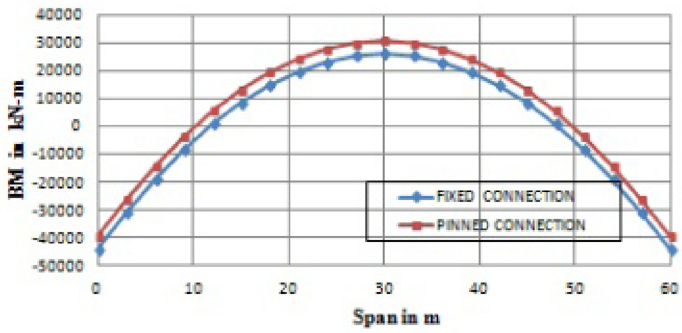


Fig.2. Comparison of BM variation in deck slab due to DL for pile head with fixed and pinned connection

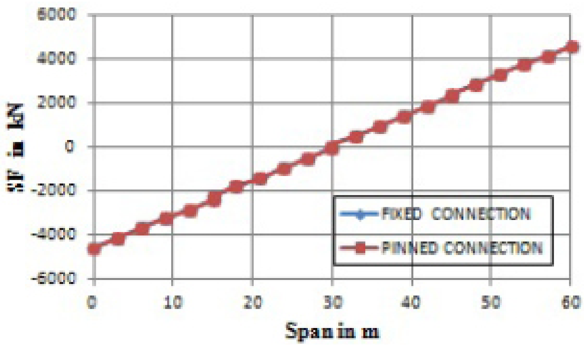
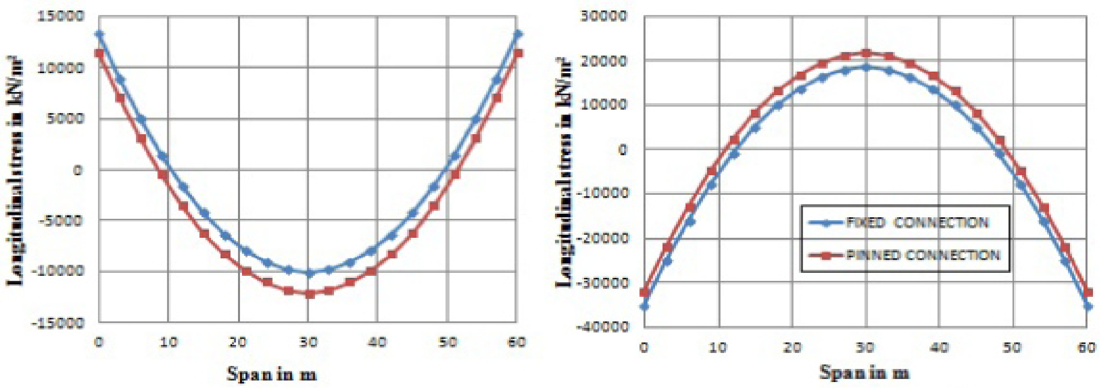


Fig.3. Comparison of SF variation in deck slab of single span integral abutment bridge due to DL for pile head with fixed and pinned connection

Fig. 4 (a) and (b) shows the variation of longitudinal stress under DL at top and bottom fibre of deck slab of single span integral abutment bridge with pile head having fixed and pinned connection. It is found that the positive maximum longitudinal stress is reduced by 14.6% at top and increased by 16.8% at bottom. This is due to respective increase in positive maximum BM by 17.69% and decrease in negative maximum BM by 10.5%. Correspondingly, the negative maximum longitudinal stresses are increased by 19.4% at top and decreased by 8.95% at bottom.



a) At top b) At bottom

Fig.4. Variation of longitudinal stress maximum envelope (a) at top, (b) at bottom in deck slab of single span integral abutment bridge due to DL for pile head with fixed and pinned connection

The comparison of variation of BM in the deck slab of two spans integral abutment bridge having pile head with fixed and pinned connection under only DL is represented in Fig. 5. It is found that the positive and negative maximum BM are increased by 10.93% and 11.4%, respectively in pinned pile head connection as compared with the fixed pile head connection. This shift in BM is because of the release in moment at the top of pile head where the maximum pile moment occurs by making pinned connection. The negative BM at the end of deck slab is reduced by 28.5% in pinned pile head connection as compared with the fixed pile head connection. Further it is seen that there is an increase of 5.9% in SF in pinned pile head connection as compared with the fixed pile head connection. Fig.6 presents the variation of SF in pinned pile head connection as compared with the fixed pile head connection.

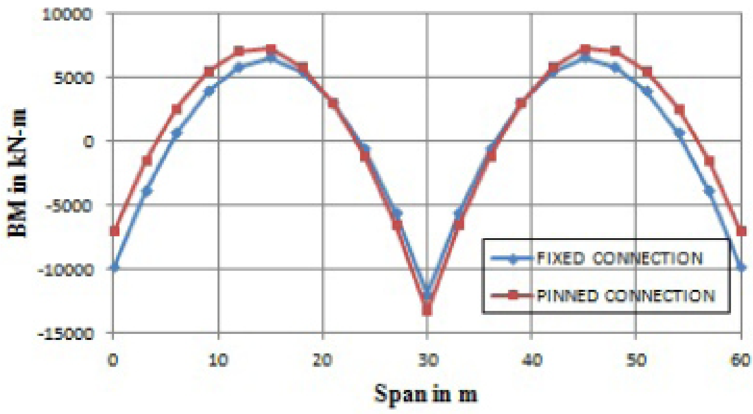


Fig.5. Comparison of BM variations in deck slab of two spans integral abutment bridge due to DL for pile head with fixed and pinned connection

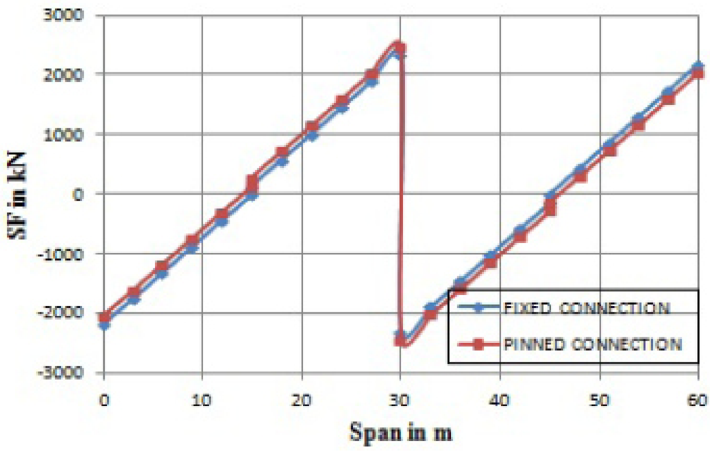


Fig.6. Comparison of SF variation in super structure of two spans integral abutment bridge due to DL for pile head fixed and pile head pinned connection

Figs. 7 (a) and (b) represent the variation of longitudinal stress under only DL at top and bottom fibre of deck slab with pile head having fixed and pinned connection. It is observed that positive longitudinal stress is increased by 11.9% at top and 11.3% at bottom, while negative longitudinal stresses is increased by 10.15% at top and 11.2% at bottom in case of pinned pile head connection as compared with the fixed pile head connection. This is due to the corresponding increase in positive and negative maximum BM by 10.93% and 11.4% respectively in pinned pile head connection as compared with the fixed pile head connection.

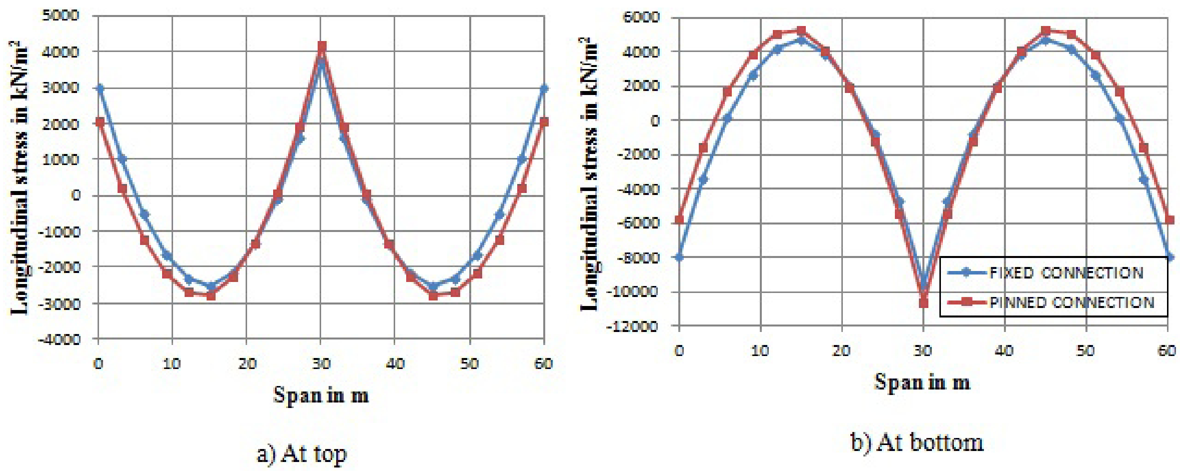


Fig.7.Variation of longitudinal stress maximum envelope (a) at top and (b) at bottom in deck slab of two spans integral abutment bridge due to DL for pile head with fixed and pinned connection

The comparison of variation of BM in the deck slab of three spans integral abutment bridge having pile head with fixed and pinned connection under only DL is shown in Fig. 8 It is interesting to observe that the variation in BM in the deck slab remains same for both end conditions. The BM in deck slab is not affected by the release in moment at the pile head.

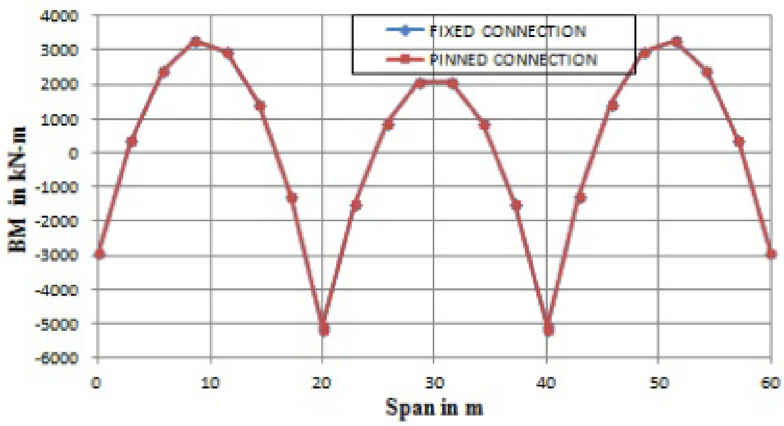


Fig.8. Comparison of BM variation in deck slab of three spans integral abutment bridge due to DL for pile head with fixed and pinned connection

The comparison of variation of SF in the deck slab of three spans integral abutment bridge having pile head with fixed and pinned connection under only DL is represented in Fig. 9. It is observed that there is no change in variation of SF with respect to end connections.

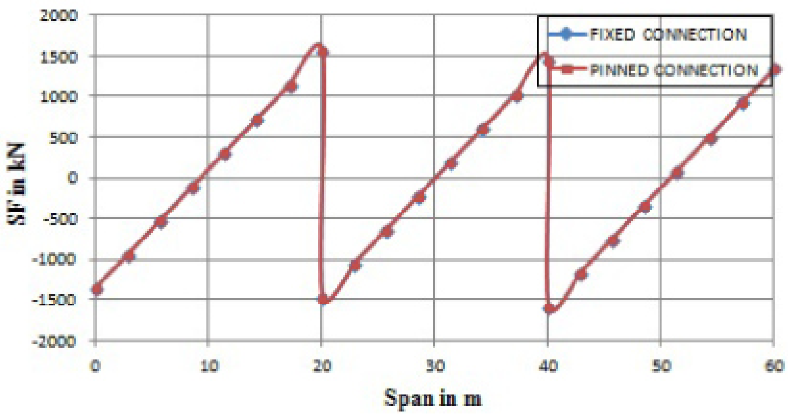
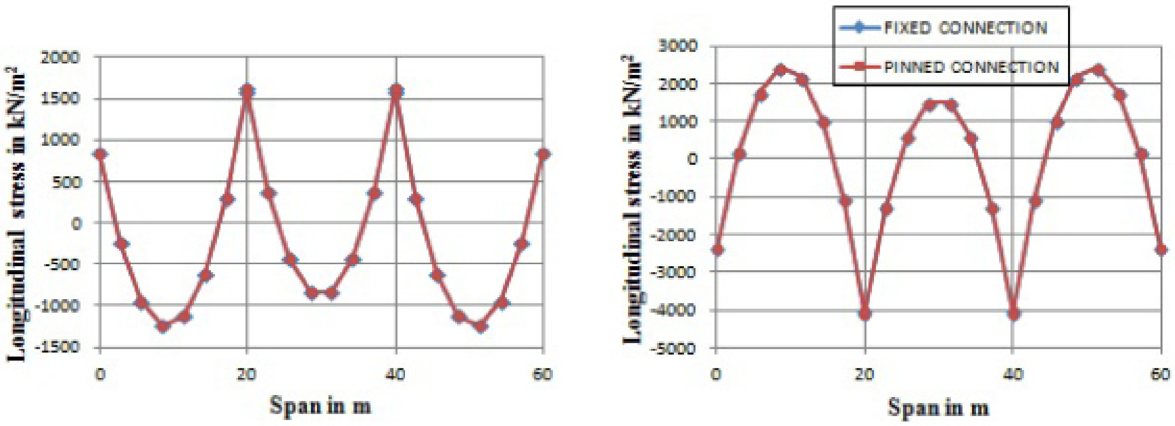


Fig.9. Comparison of SF variation in deck slab of three spans integral abutment bridge due to DL for pile head with fixed and pinned connection

On the other hand, Fig. 10 illustrates the comparison of longitudinal stress variation in the deck slab (a) at top and (b) at bottom of three spans integral abutment bridge having pile head with fixed and pinned connection. It is found that there is no effect of pile head connection on deck slab longitudinal stresses at top and bottom fibre for three spans integral abutment bridge.



a) At top b) At bottom

Fig.10. Variation of Longitudinal maximum envelope (a) at top and (b) at bottom in deck slab of three spans integral abutment bridge due to DL for pile head with fixed and pinned connection

Fig.11 shows the comparison of BM variation in the deck slab of single span, two spans and three spans integral abutment bridge having fixed pile head connection due to only DL. It is observed that the BM is maximum for single span (60 m). However, for two spans (30 m each) integral abutment bridge, the BM is reduced upto75% and for three spans (20 m each), it is reduced to 88% as compared with single span. This reduction in BM is because of increase in span number and decrease in span length.

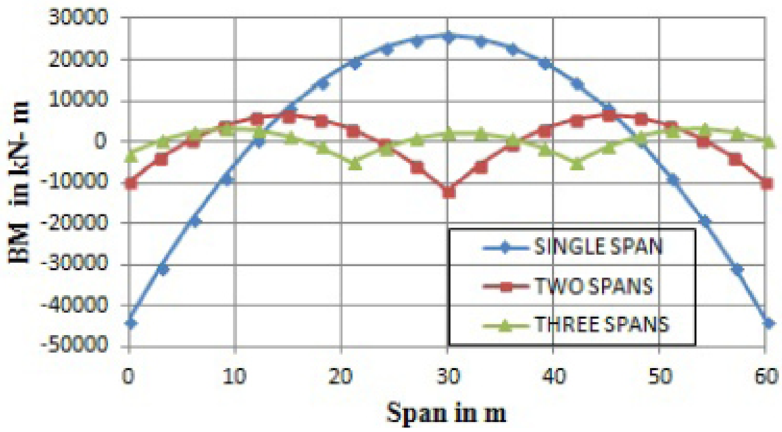


Fig.11. Comparison of BM variation in deck slab of single span, two spans and three spans integral abutment bridge due to DL having fixed pile head connection

The comparison of variation of SF in the deck slab of single span, two spans and three spans integral abutment bridge having pile head with fixed connection under only DL is represented in Fig.12. It is observed that SF is maximum for single span (60 m) integral abutment bridge. For two spans bridge, the SF reduces to 50% and for three spans (20 m each) SF further reduce to 66% as compared with single span.

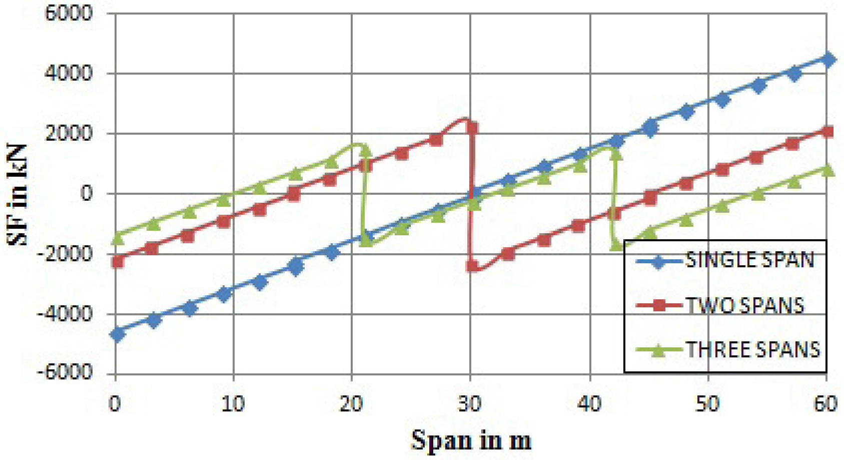
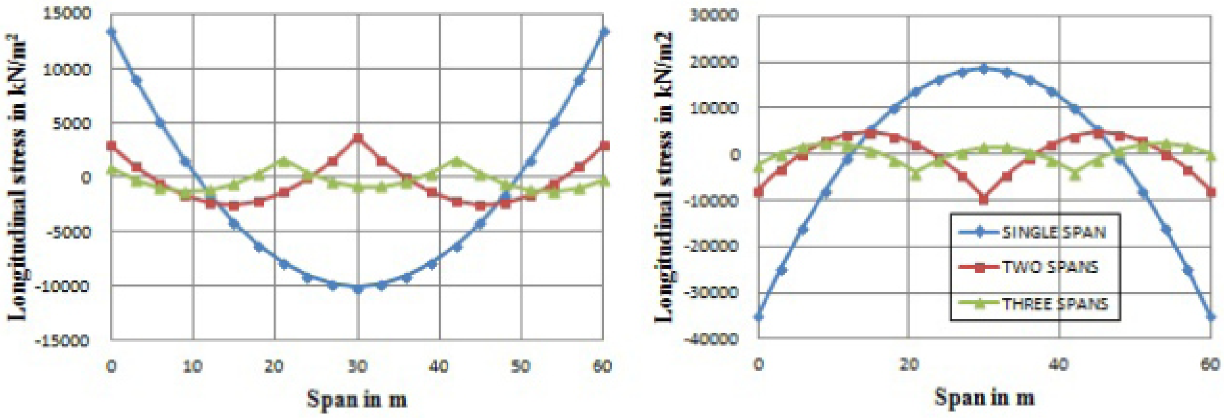


Fig.12. Comparison of SF variation in deck slab of single span, two spans and three spans integral abutment bridge due to DL having fixed pile head connection

Figs. 13 (a) and (b) represent the variation of longitudinal stress under only DL at top and bottom fibre of deck slab with pile head having fixed connection for single span, two spans and three spans. It is observed that longitudinal extreme top and bottom fibre stresses are maximum for single span (60 m), and they reduce to 75% for two spans (30 m each) integral abutment bridge and 89% for three spans (20 m each) integral abutment bridge as compared to single span. This reduction is due to the corresponding reduction in BM.



a) At top b) At bottom

Fig.13. Variation of Longitudinal stress maximum envelope (a) at top and (b) at bottom in deck slab due to DL for single, two and three spans integral abutment bridge with fixed pile head connection

The percentage changes in BM, SF and longitudinal stress in deck slab with pile head having fixed connection for two spans and three spans with respect to single span is shown in Fig.14. And from Fig.15 it is observed that the nearly same percentage variation in considered parameters of deck slab with pile head having fixed connection for two spans and three spans with respect to single span as that in fixed connection.

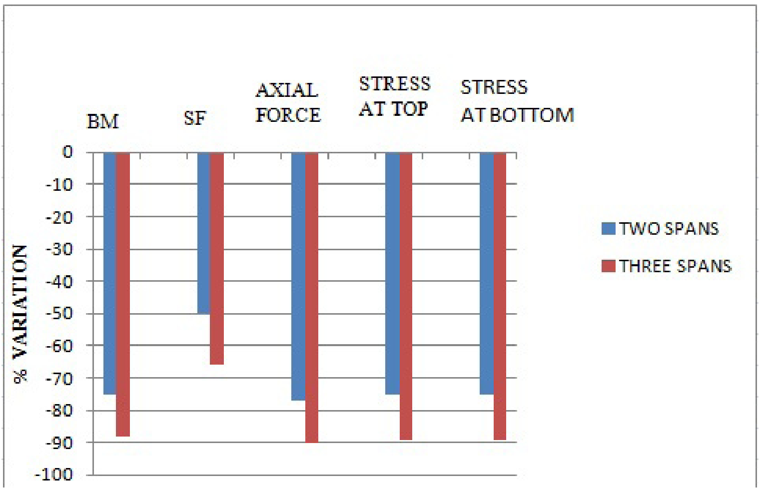


Fig.14. Comparison of percentage changes in all the parameters considered in deck slab of integral abutment bridge having pile head with fixed connection for two and three spans with respect to single span due to dead load

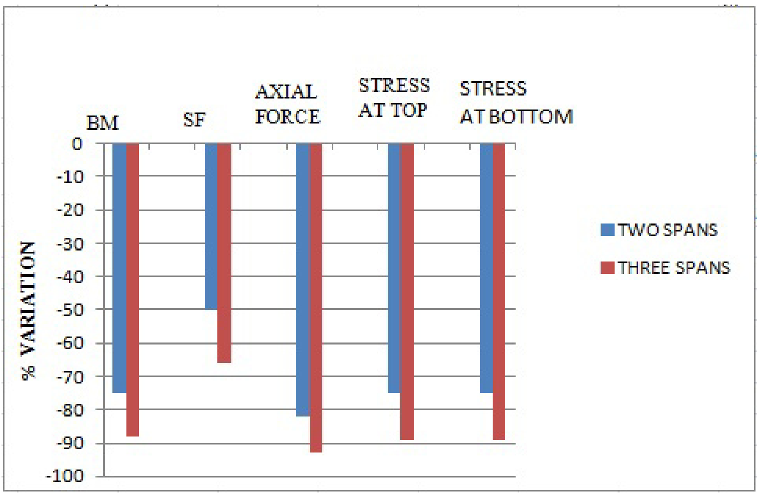


Fig.15. Comparison of percentage changes in all the parameters considered in deck slab of integral abutment bridge having pile head with pinned connection for two and three spans with respect to single span due to dead load.

The variation of BM, SF and extreme fiber stresses in the deck slab due to DL + temperature (10°C positive increase in temperature) case only and DL+ temperature (10°C positive increase in temperature) + live load (IRC 70 R wheeled vehicle) are compared for single span, two spans and three spans integral abutment bridge having pile head with fixed and pinned connection. It is seen that percentage change in variation of all the parameters of single span, two spans and three spans integral abutment bridge having pile head with fixed and pinned connection in DL + temperature case and DL + LL + temperature case are same as that of single span, two spans and three spans integral abutment bridge respectively with only dead load.

Also the variation of BM, SF, axial forces and extreme fiber stresses in the super structure due to DL, DL + temperature and DL + LL + temperature load are compared for different span with fixed pile head connection. It is found in single span integral abutment bridge having pile head fixed connection that the positive BM is decreased by 3% in case of DL + temperature and increased by 22% in DL + LL+ temperature combination as compared with only DL. Similarly, negative BM is increased by 2% in DL + temperature and 18% in DL + LL + temperature combination. SF is increased by 20% in case of DL + LL+ temperature combination and there is no change in DL + temperature combination respectively as compared with only DL. Longitudinal extreme top fibre positive stresses are increased by 2% in DL +temperature and 36.3% in DL + LL+ temperature combinations respectively, as compared with only DL. On the other hand, negative top fibre stresses are reduced by 2% in DL + temperature and DL + LL+ temperature combination than in DL case. Similarly, positive stresses at bottom fibre are reduced by 4% in DL + temperature combination and increased by 48% in DL + LL+ temperature combination and there is no change in negative stresses as compared with only

DL.

In two spans integral abutment bridge having pile head with fixed connection BM is decreased by 11.2% in case of DL + temperature combination increased by 28% in DL + LL+ temperature load combination as compared with only DL. Similarly negative BM is increased by 30% in case of DL + temperature and 57% in DL + LL+ temperature combination. And the SF is increased by 7% for DL + temperature case and is increased by 43% in DL + LL+ temperature combination as compared with only DL. Similarly the longitudinal extreme top fibre positive stresses are increased by 4% in DL +temperature case and 55% in DL + LL+ temperature combination as compared with DL. On the other hand negative top fibre stresses are reduced by 5% in DL + temperature and by 31% in DL + LL+ temperature combination than in case of DL. Similarly, positive stresses at bottom fibre reduced by 15% in DL + temp combination and increased by 94% in DL + LL+ temperature combination and negative stresses increased by 8% in DL +temperature and by 7% in DL + LL+ temperature case as compared with DL.

BM is decreased by 22% and negative BM is increased by 25% in case of DL + temperature combination as compared with DL. Similarly, positive BM is increased by 21% and negative BM is also increased by 38% in DL + live + temperature combination as compared with only DL in the two spans integral abutment bridge having pile head with fixed connection. SF is increased by 133% in case of DL +temperature combination and 188% in case of DL+ live + temperature combination as compared with only DL. And longitudinal extreme top fibre positive stresses are increased by 17% in case of DL +temperature and 67% in DL + LL+ temperature combinations as compared with DL. The negative top fibre stresses are reduced by 6% in DL + temperature and by 130% in DL + LL+ temperature combination than in case of DL. Similarly, positive stresses at bottom fibre are reduced by 30.3% in DL + temp combination and increased by 100% in DL + LL+ temperature combinations and negative stresses are increased by 28% in DL +temperature and by 17% in DL + LL+ temperature as compared with only DL.

The percentage changes in variation of BM and SF of integral abutment bridges having pile head with fixed connection for single, two and three spans bridges due to DL+ temperature and DL + LL + temperature cases in reference to only dead load for deck slab is shown in Fig. 16 and Fig. 17.

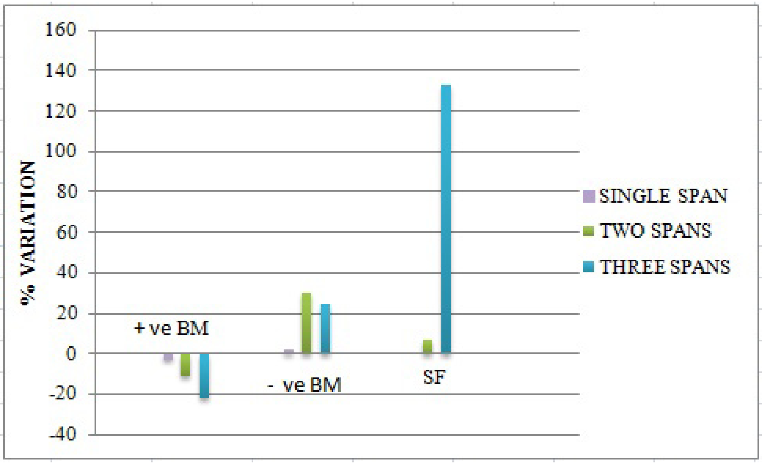


Fig.16. Comparison of percentage changes in all the parameters considered in deck slab of single, two and three spans integral abutment bridge due to DL+ temperature with respect to DL

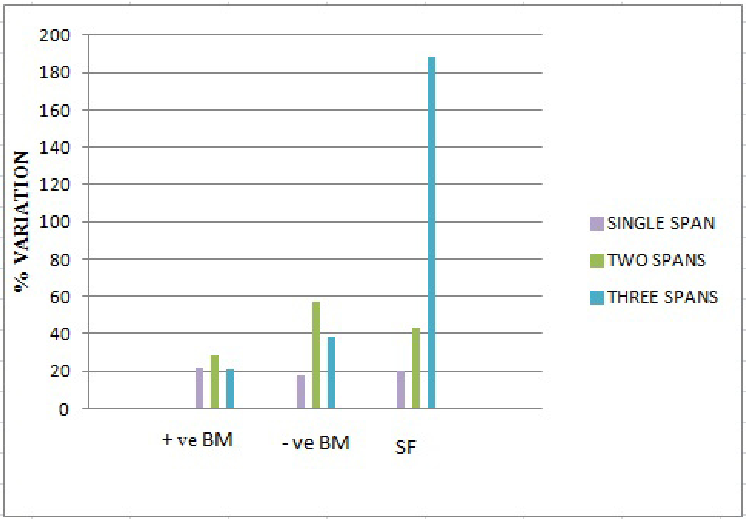


Fig.17. Comparison of percentage changes in all the parameters considered in deck slab of single, two and three spans integral abutment bridge due to DL+ LL + temperature with respect to DL

CONCLUSION

Based on the study of concrete integral abutment bridge under dead load, live load and temperature effects, the following conclusions are drawn in this paper.

1) In integral abutment bridge the design parameters are affected by the pile head to abutment connection.
2) Negative BM at the end of deck slab and girders are reduced by 10.5% in single span and 28.5% in two spans, while there is no change in three spans integral abutment bridge. Correspondingly, stresses at the end of deck slab also reduced for the bridge having pinned pile head connection as compared with fixed pile head connection.
3) SF in deck slab is increased by 5.9% in two spans integral abutment bridge having pile head with pinned connection but there is no change in SF in single and three spans.
4) Abutment and deck connection can be designed for less BM in integral abutment bridge having pile head pinned connection as compared with fixed connection.
5) As the number of span increases all the design parameters such as BM, SF decreases drastically. The percentage in reduction is same for integral abutment bridges having pile head with fixed and pinned connection.
6) Top and bottom fibre stresses in deck slab are decreased with increase in number of spans in integral abutment bridge.
7) In general, the increase in temperature increases negative moment as compared only with DL because of its hogging effect decreases in the positive BM. This trend is opposite to that of only DL which shows increase in positive BM and decrease in negative BM.
8) With DL + temperature combination, the positive BM is increased nearly 17.69% and negative BM is reduced by 10.5% in deck slab with single span. In two span integral abutment bridge, the both positive and negative BM are increased by nearly 10.93% and 11.4% respectively. However, there is no change in three spans bridge with pinned pile head as compared with fixed condition. Similar trend is also observed with DL + LL + temperature case.
9) There is no change in shear force is observed in deck slab of one and three spans bridge, but in case of two spans, there is 5.9% increase for the bridge with pinned pile head connection as compared with fixed connection.
10) The positive maximum BM in deck slab of integral abutment for different spans are reduced in case of DL and temperature combination as compared only with DL. On the other hand negative maximum BM show increasing trend in case of both DL and temperature and DL, LL, and temperature cases.
11) The SF in deck slab of integral abutment bridge for different spans are increased both in case of DL + temperature combination and DL + LL + temperature combination as compared with DL, but it is zero for single span bridge with DL + temperature combination.

FUTURE SCOPE OF THE STUDY

Following are the scope for further work-

1) Parametric studies incorporating soil - structure interaction as well as appropriate backfill behavior, simulating prevailing conditions at the site, would provide greater insight into the behavior of

integral abutment bridges.
2) Nonlinear aspects of the structural system and the foundation media would enhance appreciation of the integral bridge as a design alternative.
3) The study can be extended to different temperature changes considering increase and decrease in temperature.
4) The influence of seismic loading on integral abutment bridge having pile head with fixed and pinned connection can be studied.

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