Proceedings of 12th IOE Graduate Conference
Peer Reviewed
ISSN: 2350-8914 (Online), 2350-8906 (Print)
Year: 2022 Month: October Volume: 12

Effect of Orientation of Arches and Hangers in Tied Arch Bridge System

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Abstract

This paper presents an attempt to compare between parallel, cross (spider) and infinite orientation of arches with vertical, network and fan-type arrangement of hangers. The comparison criteria set up were arch moment, arch thrust, tie moment, axial force in hangers and fatigue stress in hangers. Bridges were modeled for different span range, altogether 81 models were studied in this research. For 51.45 m span , we used standard data of Bijuli-Bazar tied arch bridge, Dhobi khola, kathmandu. For other span length, empirical design values were used. This study gave some interesting finding which can be useful for design of tied arch bridge. It was found that, for vertical arrangement of hangers, cross (spider) orientation will give lower value of arch moment, arch thrust, tie moment and axial force in hangers than parallel (conventional) orientation of arch. But, for network type of arrangement of hangers, it was found that conventional orientation will result lower member forces than cross orientation. However, in fan type orientation of hangers, it was found that for small span range, cross orientation will show better performance than parallel orientation. For all the arrangement of hangers, infinite orientation resulted higher value of arch moment, tie moment, axial force in hangers (except arch thrust) than cross and parallel orientation of arches. In addition, when fatigue was the design criteria it was found that conventional system will show better performance than cross and infinite orientation for all arrangement of hangers.

Keywords

parallel (conventional) orientation, Cross (spider)orientation, infinite orientation, vertical hangers, network hangers, fan-type hangers

1. Introduction

In tied arch bridge system, load from the deck goes to arch through the help of hangers and from the arches it's distributed to the support.

Member forces in tied arch system can vary according to different orientation of hangers. It's found that network type of arrangement of hangers will result lower value of axial force in hangers and moment in tie and arches than vertical and fan type arrangement of hangers. But, when fatigue stress in hangers was the design criteria, it was found that fatigue performance of hangers in network type arrangement was poor when compared to vertical and fan type arrangement of hangers[1]. Similarly, it was found that when compared to conventional type of arch design, network tied arch bridge saves over 2/3 of steel making it more economic than traditional design [2] .

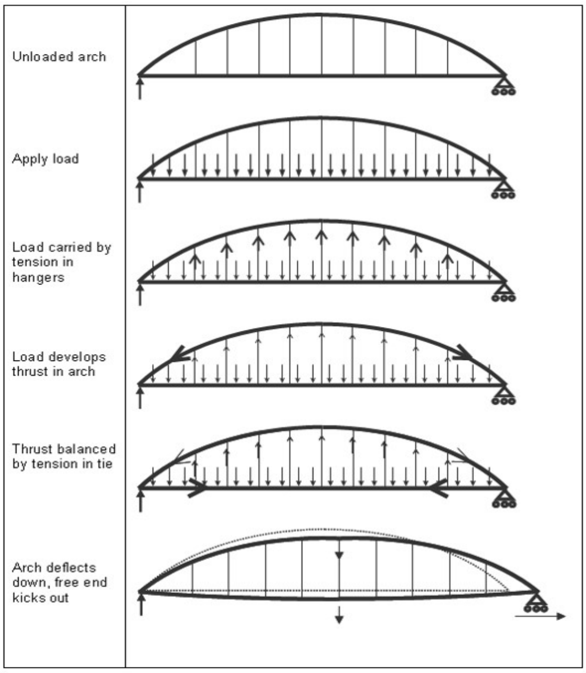

Figure 1: Load transfer mechanism in tied arch bridge.

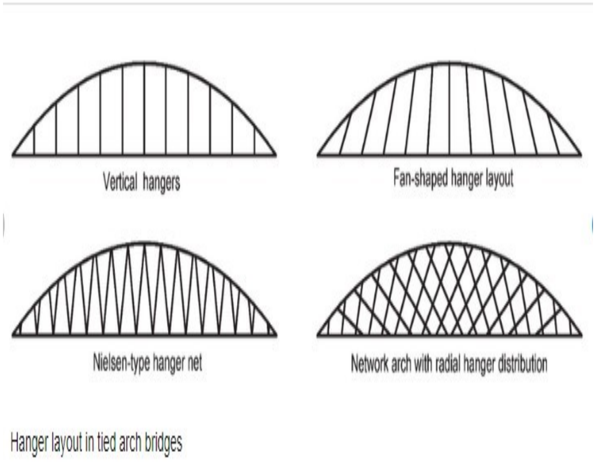

Figure 2: Different arrangement of hangers in tied arch bridge.

However, the effect of different orientation of arches on member forces is rarely studied. Here, we intend to compare between parallel type (conventional) orientation, cross-type(spider) orientation and infinite-type orientation of arches which are shown in figure (3), figure (4) and figure (5) respectively. Similarly, the different arrangement of hangers used are vertical, network and fan-type arrangement of hangers which is shown in figure (2). The comparison criteria set up are arch thrust, arch moment, tie moment, axial forces in hangers and fatigue stress in hangers which is briefly discussed in result section.

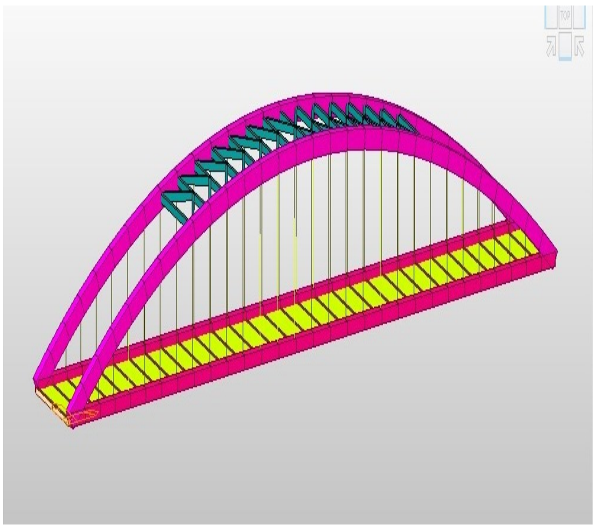

Figure 3: Parallel orientation of arches in tied arch bridge system.

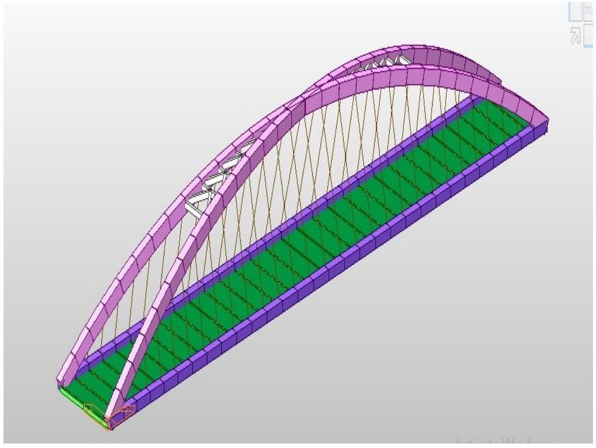

Figure 4: Cross (spider) orientation of arches in tied arch bridge system.

Figure 5: Infinite orientation of arches in tied arch bridge system.

In conventional type of orientation one arch is tied to one tie through the help of hangers, so it forms one-to-one system. But, in cross or infinite type orientation of arches two arches are connected to one tie, so it forms two-to-one system. Thus, two arches get simultaneously activated at a time in cross or infinite type orientation than conventional type orientation which might ensure better forces distribution than conventional system.

2. Theory and Methodology

2.1 Empirical design of tied arch bridge

The general span length of tied arch bridge is from 50m to 550m [3]. For network tied bridge best suited length is from 80m-170m but will perform well in wider ranger of span[2].

The optimized height to length ratio in tied arch bridge is 0.15-0.16 [4]. For construction of fan type of arrangement, it's required to maintain the ratio of rise of arch to radius of converging hangers more than 0.5[5].

The optimized location of bracing in tied arch bridge system is 0.15 from springing of arch based on transverse moment criteria. But, if buckling criteria is considered it's location should be either at 0.4 or 0.21 from the springing based on primary and secondary buckling criteria [6].

Zotti et.al. Modeled more than 400 configurations in 3D-FEM Midas Civil for parametric study of hanger arrangements and concluded that an angle between 28° and 37° (with vertical) gives good results in terms of internal forces. In addition, there is a good bending moment distribution in network tied arch bridge when angle closes to 30° with vertical [7].

Shah et. al. in their research related to vertical acceleration in network tied arch used spacing of @2.5m,@5m, @7.5m for hangers [8]. Hall and LaWln, in their paper mentioned that, cross beam need to be arranged in the same spacing as of hangers in order to minimize the bending moment in the tie beam [9].

2.2 Bridge description

The bridge sample selected was Dhobi-khola network tied arch bridge which has span of 51.45 m. However, for other span range, empirical design criteria were used. Dhobi-khola tied arch bridge is single span simply supported bridge having 10.5 m width of carriage way. For vertical arrangement of hangers, the span range used were 51.45 m , 100 m , 150 m and 200 m. Similarly, for network arrangement of hangers, span range used were 51.45 m , 100 m and 150 m. Finally, for fan type arrangement of hangers, span used were 51.45 m , 55 m , 60 m , 65 m, 70 m ,100 m , 150 m and 175 m. For validation this work were performed on both steel and concrete tied arch bridges.

2.3 Finite Element Modeling

The bridge was modeled in 3-D FEM Midas Civil Software and were analyzed for static, moving vehicle and dynamic vehicular case. For moving vehicle analysis 70R and class A vehicle were used as defined by IRC-6 and for dynamic analysis, a train load of Class - A vehicle moving at 60 kmph was used. Altogether 81 models were analyzed and their result were compared between parallel, cross and infinite orientation of arches which is briefly discussed in result section. For validation of work, the results were compared with research done by Pellegrino et.al. [1]

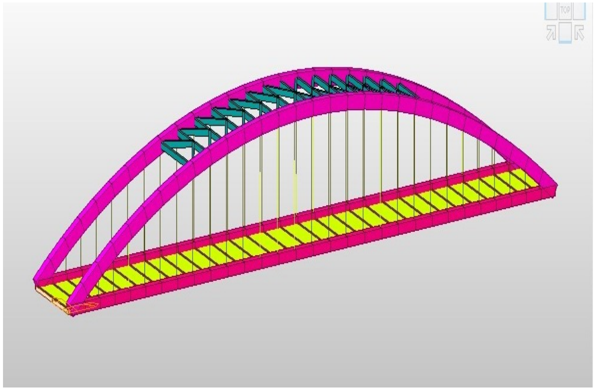

Figure 6: Typical Parallel orientation of arches with vertical arrangement of hangers modeled in Midas Civil

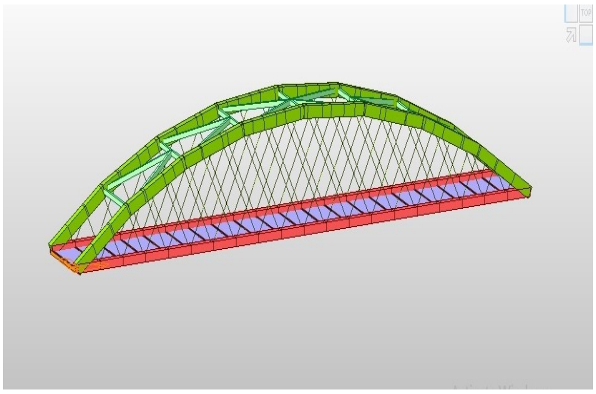

Figure 7: Typical Parallel orientation of arches with network arrangement of hangers modeled in Midas Civil

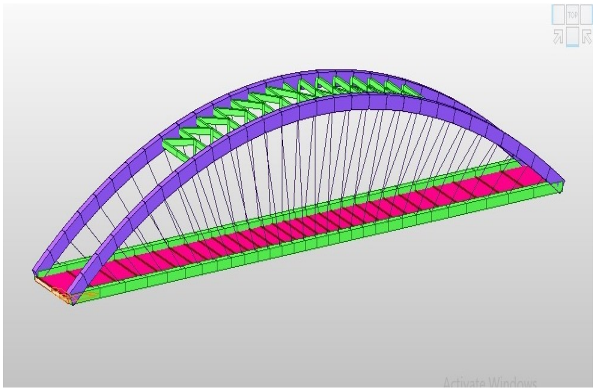

Figure 8: Typical Parallel orientation of arches with fan type arrangement of hangers modeled in Midas Civil

2.4 Rainflow counting alogrithm

After performing analysis we obtain time history graph for different hanger elements, the time-history graph shows a zig-zag pattern of stress cycles. In order to convert, those zig-zag patterns of ups and down into an equivalent cycle of stress, we use rain flow cycle counting method.

In rain-flow counting technique at first the rising peak are compared with each other, each rising peak are numbered in a series. If the next approaching rising peak (second rising peak) is at higher limit than previous peak, then the limb of the previous peak (first peak) is transferred to the limb of approaching peak (second peak) otherwise previous peak is treated as higher peak and so on. Similar steps are also followed for falling limbs [10].

Finally, each corresponding numbered rising limbs and falling limbs were added to obtain equivalent stress value.

2.5 SN-curve

SN- curve relates the equivalent stress in specimen to corresponding number of cycles it can withstand before failure. Through the help of SN- curve one can get a tentative idea that higher the equivalent stress in specimen lower will be the number of cycles it will be withstanding before failure, so lower will be it's fatigue performance and vice-versa.

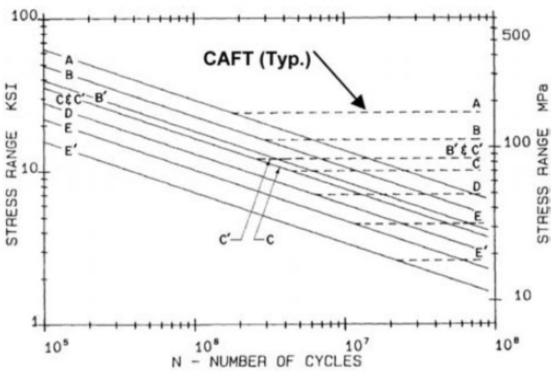

Figure 9: SN- curve by AASHTO for steel

3. Result and Discussion

Parallel, cross (spider) and infinite orientation of arches were modeled with vertical, fan and network type arrangement of hangers. Arch moment, arch thrust, tie moment, axial force in hangers (which were obtained through combined effect of static and moving load case) and fatigue stress in hangers (obtained through class-A train load) were the comparison criteria set up for this research. The result of different orientation of arches for different hanger arrangement are shown below.

3.1 Arch moment comparison

In vertical arrangement of hangers, arch moment will be lower in cross (spider) type orientation of arches than parallel and infinite orientation. However, in network arrangement of hangers, parallel system will result lower value while in fan arrangement of hangers, for small span range, cross (spider) orientation will result lower arch moment than parallel and infinite orientations.

3.1.1 Vertical arrangement of hangers

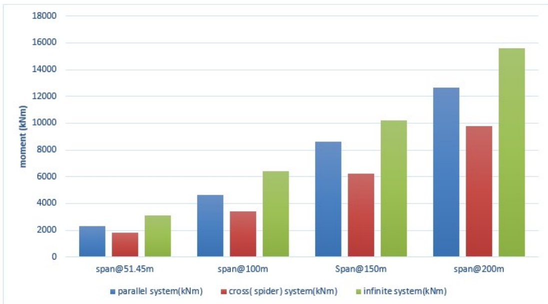

Figure 10: Arch moment variation for different orientation of arches having vertical arrangement of hangers

3.1.2 Network arrangement of hangers

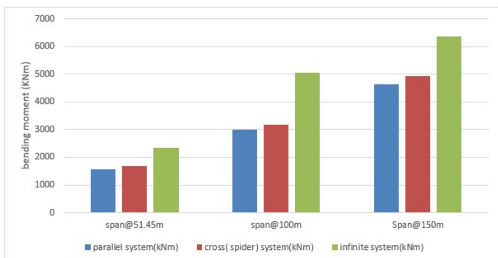

Figure 11: Arch moment variation for different orientation of arches having network arrangement of hangers

3.1.3 Fan-type arrangement of hangers

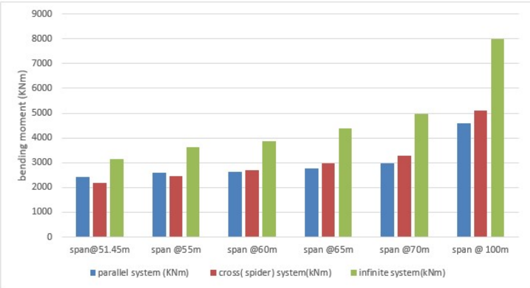

Figure 12: Arch moment variation for different orientation of arches having fan-type arrangement of hangers

3.2 Arch thrust comparison

For all arrangement of hangers, infinite orientation of arch will result lower value of arch thrust than cross and parallel orientation of arches. Similarly, cross(spider) orientation will result lower value of arch thrust than parallel orientation of arches.

3.2.1 Vertical arrangement of hangers

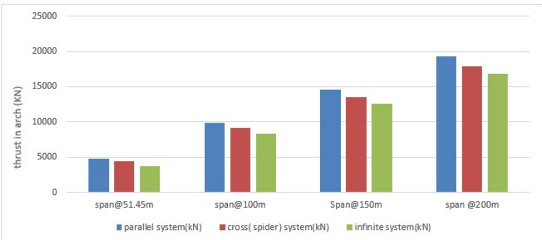

Figure 13: thrust variation for different orientation of arches having vertical arrangement of hangers.

3.2.2 Network arrangement of hangers

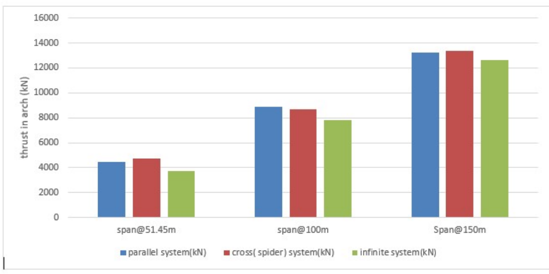

Figure 14: thrust variation for different orientation of arches having network arrangement of hangers.

3.2.3 Fan-type arrangement of hangers

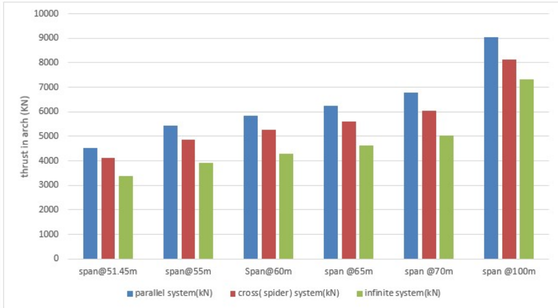

Figure 15: thrust variation for different orientation of arches having fan-type arrangement of hangers.

3.3 Tie moment comparison

In vertical arrangement of hangers, when the span of the bridge increases tie moment will be lower in cross (spider) type orientation of arches than parallel and infinite orientation. However, for both network and fan type arrangement of hangers, parallel system will result lower tie moment value than cross and infinite orientation.

3.3.1 Vertical arrangement of hangers

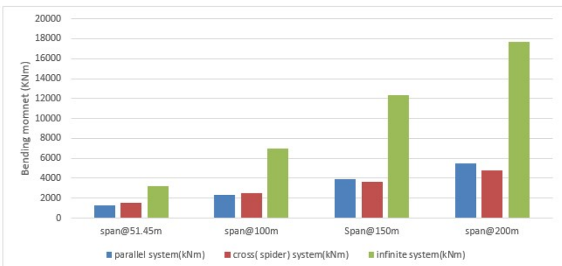

Figure 16: tie moment variation for different orientation of arches having vertical arrangement of hangers.

3.3.2 Network arrangement of hangers

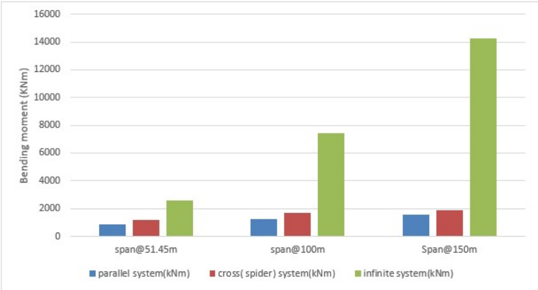

Figure 17: tie moment variation for different orientation of arches having network arrangement of hangers.

3.3.3 Fan-type arrangement of hangers

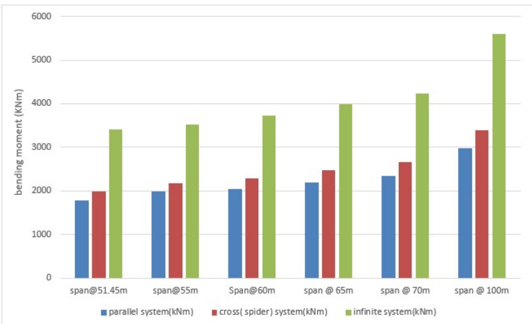

Figure 18: tie moment variation for different orientation of arches having fan-type arrangement of hangers.

3.4 Hanger axial force comparison

In vertical arrangement of hangers, there was small variation in axial forces between parallel and cross type orientation for small span length and when the span length increases, cross orientation will result lower value than parallel system. However, in network type arrangement of hangers, parallel system will result lower value of axial forces than both cross and infinite orientation. For fan type arrangement of hangers, when the span increases, cross orientation will result lower value than parallel and infinite orientation.

3.4.1 Vertical arrangement of hangers

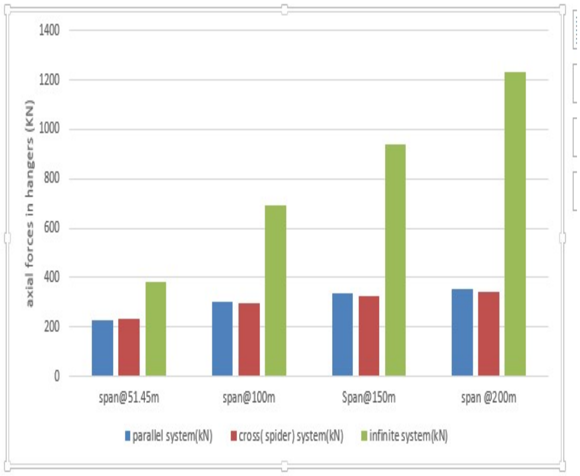

Figure 19: hanger axial force variation for different orientation of arches having vertical arrangement of hangers.

3.4.2 Network arrangement of hangers

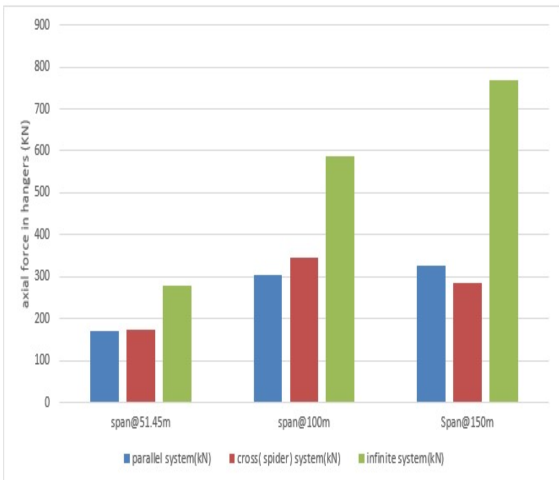

Figure 20: hanger axial force variation for different orientation of arches having network arrangement of hangers.

3.4.3 Fan-type arrangement of hangers

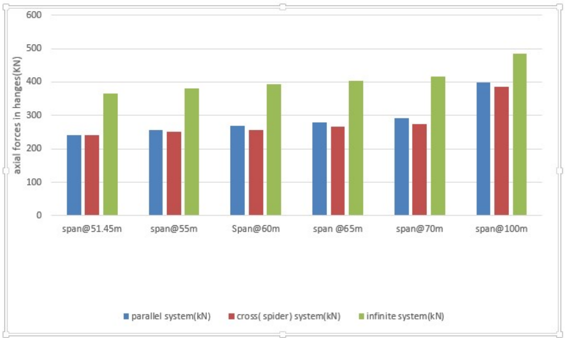

Figure 21: hanger axial force variation for different orientation of arches having fan-type arrangement of hangers

3.5 Hanger fatigue stress comparison

For all orientation of hangers, infinite orientation will result higher fatigue stress than parallel and cross orientation. In addition , parallel orientation will result lower fatigue stress than cross orientation for all arrangement of hangers.

3.5.1 Vertical arrangement of hangers

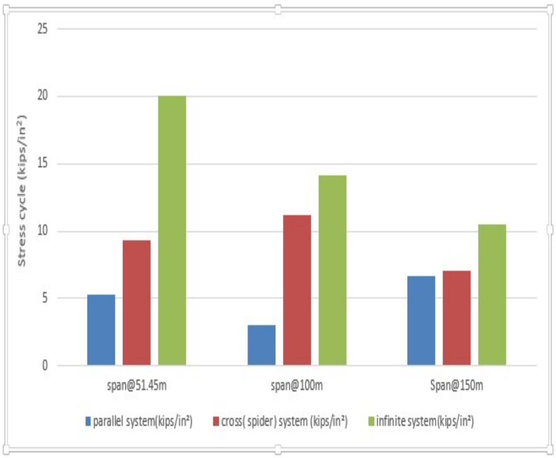

Figure 22: hanger fatigue stress variation for different orientation of arches having vertical arrangement of hangers.

3.5.2 Network arrangement of hangers

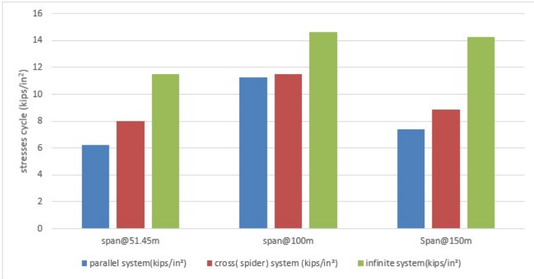

Figure 23: hanger fatigue stress variation for different orientation of arches having network arrangement of hangers.

3.5.3 Fan-type arrangement of hangers

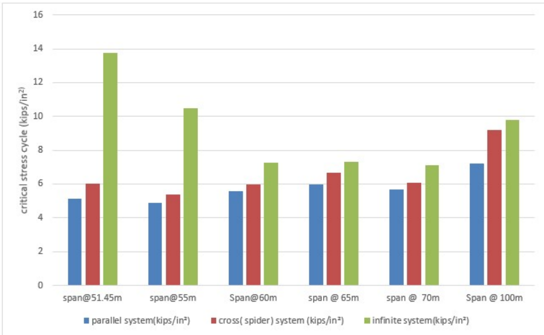

Figure 24: hanger fatigue stress variation for different orientation of arches having fan-type arrangement of hangers.

4. Conclusion

In this paper, a comparison between parallel, cross (spider) and infinite orientation of arches with vertical, network and fan-type orientation of hangers were carried out. After analyzing the results, following conclusion can be withdrawn.

1. For vertical arrangement of hangers, when span of tied arch bridge increases, cross-type orientation can be better replacement to parallel orientation as there will be lower value of arch thrust, arch moment, tie moment and axial force in hangers.
2. For network type arrangement of hangers, parallel (conventional) orientation will perform better than cross and infinite orientation of arches.
3. For fan type orientation, it's found that cross (spider) orientation will result lower member forces than parallel orientation for small span range. For higher span length, parallel orientation is

recommended over cross orientation.
4. For all arrangement of hangers, infinite orientation will result higher value of arch moment, tie moment, axial force in hangers than cross and parallel orientation. However, arch thrust in infinite orientation will be lower than parallel and cross orientation.
5. When fatigue is design criteria, parallel orientation will result lower fatigue stress than cross and infinite orientation of arches.

Acknowledgments

The first author is thanful to Er. Parbin Wagle, Er. Utkarsha Bhetwal, Er. Dipendra Thakur, Er. Prashanta Dhimal, Er. Dilendra Panta, Er. Ajay Thapa, Er. Naresh Bastakoti, Er. Madan Acharya, Er. Diwakar Khanal, Suman Aryal, Bishal Thapa, Sudhir Tharu, Santosh Ghimire, Mohan Guragain and author's family members for their invaluable support and motivation during this research work.

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