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Comparative Study of Arch Bridges with Varying Rise to Span Ratio

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Abstract— *This paper presents a comparative study of Arch bridges based on their varying rise to span ratio. The comparison is done between different steel Arch bridges which have variable span length and rise to span ratio keeping the same support condition. The aim of our present study is to select the optimum value of rise to span ratio of Arch bridge as the cost of the Arch bridge increases with the increasing of the rise. In order to fulfill the objective, several rise to span ratio have been considered for same span of Arch bridge and various structural parameters such as Bending moment, shear force etc have been calculated for different model. A comparative study has been done for several Arch bridges finally to select the optimum rise to span ratio of the Arch bridges. In the present study, Finite Element model for medium to long span, with different rise to span ratio have been modeled and are analyzed with the help of a Computational Software named MIDAS Civil to evaluate the results such as Bending moments, Shear force, displacements, Stresses, influence line diagrams, critical loads. In the present study, 60 models of Arch bridges for 80 to 120 m span with different rise to span ratio has been thoroughly investigated.*

Keywords: *Arch bridge, Analysis, Comparative study, rise to span ratio.*

1. INTRODUCTION

T has been years that bridge designers and engineers are not only concerned about stability of bridge structures but being concerned about their efficiency, economy and aesthetic as well. Arch bridges are often selected as solution over girder bridges to cross over deep George in mountain area when greater span ranging from 40 to 550m is required. As of today most bridges in this range of span are used in countries like United States, Japan, China and Australia are tied-arch and truss bridges. The reason for this is that arch bridges are aesthetically pleasing as well as economically feasible and are very popular and widely used since ancient times. Many researchers have worked on Arch Bridge based on design, load carrying capacity, creeping effect, seismic response, in plane and out of pane behavior, the stability of the structure, arrangement of its structural components, vibration control, out of plane problems, lateral load effects etc. and there have been an continuous improvements in the development of Arch bridges. From the literature review it is seen that most of them have focused on the buckling of the arches as buckling is a common criteria of a curved beam or arch when it is loaded in its plane and the beam buckle by deflecting laterally out of its plane and twisting. However the important aspect in designing any structure is to ensure its safety, structural stability and economy of the structure etc. which can be achieved by designing the structure for the optimum dimensional parameter of the structure. In case of an arch bridge the rise to span ratio is an important geometrical parameter and it has relatively large impact on the structural behavior of the bridge. Moreover the increase in the dimensional parameters also increases the self weight of the structure leading to increase in the cost of construction. Thus the aim of our present study is to investigate the structural behavior of different arch bridges considering different rise to span ratio, when they are subjected to static, wind and traffic loading and to study their economical potential, their efficiency and finally obtaining an optimum value of rise to span ratio for different spans.

In studying the stability analysis of a special shaped arch bridge, where the arch rib is skewing across the girder and hangers hanging unevenly along the arch rib with different aslant Wen-Liang, Chin-Sheng, Chang-Huan, Jeng-Lin Tsai and Guang (2010) found that for long span the slant hangers at both sides of the girder reduced the tendency of arch instability and the increase in the height of the main girder improves the structural stability, but the effect is limited. Moreover, the restrained condition of spring provides more stability than a two hinged arch bridge. Their result also shows that the rise-span ratio has a relatively large impact on the stability coefficient. Austin and Ross (1976) studied the impact of rise to span ratio of two dimensional parabolic arches and circular arches on in-plane buckling and found that parabolic arches had larger buckling load than centenary arches and circular arches. A.S Vlahinos, J.Ch. Ermopoulos and Yang-Cheng Wang (1993) have studied the buckling analysis of steel arch bridge where the influence of arch rib height on the critical loads is studied and an effort has been made to determine the shape as well as the rise to span ratio of the arch in order to maximize the buckling strength. A non linear finite element program and Jacobi Eigen value solver technique is used to determine the critical load and buckling mode shapes. R. Shankar Nair (1986) has presented a simple method for computing the planner buckling load, natural frequencies and corresponding mode shapes for all kind of arch and for the arches that have rise to span ratio within the range customarily encountered for medium to long spans but the method is limited for very steep arches. John P. Papangelis and Nicholas S. Trahair (1986) developed a flexural torsional buckling theory for doubly symmetric arch where non linear expression for axial and shear strain are derived for a circular member of doubly symmetric crossection that deforms in three-dimensional space. These equations are substituted into the second variation of the total potential to obtain the buckling equation. Shigeru Kuranishi and Tetsuya Yabuki (1984) has presented a limit state design criteria concept for lateral load effect on two-hinged parabolic steel arch bridge. E. Tufekci and O.Y Dogruer (2006) has dealed with some exact solution of differential equation for the out of plane behavior of arch with varying crossection and radius of curvature by using the initial value method. Using these analytical expression displacements, twist angle, slope and stress resultants can be calculated analytically along the arch axis. Dongzhou Huang, P.E (2005) has presented results of an investigation of dynamic and impact characteristics of half through arch bridges with rough decks caused by vehicles moving across them, considering some bridge model with overall span ranging from 20m to 200m. The result shows of analysis shows that the impact factor of bending moment and axial force will not exceed 0.4 and 0.25 respectively. The effect of impact factor of span length, rise to span ratio and vehicle speed is also discussed. Shen-Haw Ju and Hung-Ta Lin (2002) studied the vibration characteristics of arch bridge and resonance effect when high-speed trains pass over arch bridge. Aria Aghajani Namin(2012) has done a comparative study between Tied-arch bridge and truss bridge when the bridges are subjected to wind load and traffic load for medium to long span. The steel weight needed for the long and medium span bridges is assessed from the final design to compare and evaluate tied-arch Bridge and truss bridge efficiency. These results are compared together in order to identify the most optimal bridge.

2. METHDOLOGY

For studying the structural behavior of the models, professional software named MIDAS civil is used for doing the analysis of the bridge models. The bridge model is a three dimensional finite element model where each element has two nodes and six degree of freedom. In our present study, we have considered a tied arch bridge model which is most commonly encountered in practice, the dimensions and other sectional properties are referred from an example which are then modified time to time during modeling in order to achieve the best result. In our present study models for 80m span are only considered where the models for 120m span will also be considered further in the dissertation. Thus the models considering 80m span are modeled in Midas civil software with varying rise to span ratio. For more accurate comparison similar deck plan and structural arrangement for each and every bridge of the span length are considered only varying in their sectional property and the material property where ever needed to obtain the suitable results. After modeling the bridge structure are subjected to dead load, moving load and wind load in the transverse direction, which are assigned in the structure following Indian codes. The static load cases includes the self weight of the structural elements which are acting in the global Z direction, loads for deck slab which are acting as line load on the main girder and cross beam in the global Z direction. The wind load is assumed to be acting transversely in the global Y direction. The deck of the bridge is modeled as four lane of width 15m however for simplicity only two lanes are created in the model with an eccentricity of 3.75m and 11.25m from the global X axis. For the moving load analysis IRC Class A and IRC Class B are chosen randomly as vehicle load. The models are then analyzed both for static and moving load and later will be analyzed for buckling to get the critical load factor and buckling mode shapes. The results were extracted for each model which is presented in tabular and graphical form.

TABLE I
UNITS FOR MAGNETIC PROPERTIES

Symbol	Quantity	Unit
Dz	Displacement in the global X direction	mm
My	Moment about the global Y direction	KNm
Y	Length of hanger	m
X	Distance along the global X axis from ordinate	m
L	Length of Span	m
f	Crown of the arch	m
Ixx	Moment of Inertia about X axis	mm^4
Iyy	Moment of Inertia about Y axis	mm^4
Izz	Moment of Inertia about z axis	mm^4
R/L	Rise to Span ratio	-
Fz	Tension forces in the global Z direction	KN

3. FINITE ELEMENT MODEL

The super structure of the bridge consists primarily of the main girder, arch rib, Cross beam, Stringers, bracing and hangers. Each arch rib, Struts and the main girders are simulated as a beam element of hollow steel box section. The cross beam is simulated as a beam element of steel I section. However the stringers and bracing are carrying axial loads so they are assembled in the structure as truss member, which is a two-force member only, where the members are organized so that when assemblage as a whole behaves as a single object. Therefore the hangers are simulated as tension member which are solid round section and are vertically attached with the arch rib and the floor system on each side. The stringer are bracing are simulated at truss members of I section. The floor system consists of a deck slab of 250 mm thick concrete slab supported directly by the cross girder at a spacing of 5.33m (in case of 80m span). In addition to this all nodes of the structure are defined properly such as both ends of the hangers, the stringers, bracing are connected as pin joint, both end of the cross beam are also connected as pin jointed with the main girder and no constraint is applied for the strut element. The bridge is kept as simply supported that is one end fixed and one end hinged.

4. BRIDGE GEOMETRY AND PROPERTIES

The rise to span ratio is an important parameters for the structural behavior of the bridge. Thus in order to compare the result for the bridge models different rise to span ratio ranging from .15 to .3 is considered for our study. As per code, solid-ribbed arches fabricated with segmental chords, the panel length should not exceed 1/15 of the span [11]. This is recommended for esthetic reasons, to avoid large angular breaks at panel points. Moreover, for continuously curved axes, bending stresses in solid-ribbed arches become fairly severe if long panels are used Therefore the arch rib is divided in to 15 segments with different panel length for both type of bridge. To make the model simple the hanger spacing are kept same as the cross beam and their height can be obtained from the arc equation in x-y plane $y = f\ [1- (\frac{2x}{L}-1)^{2}]$ where f is the crown of the arch and L is the span of the bridge. Spacing of the main girder should be greater than L/20. So three girders are provided at a spacing of 7.5m in the transverse direction. Since our aim is to compare the results for many models and not designing , the material that have been incorporated for the study are IS Fe 540 for the arch rib, main girder and hangers where IS Fe 370 has been used for the cross beam stringer and bracing. The Sectional properties of the Structural members are given in table 2 below.

Table 2: Properties of the Structural Members

Member	Area(mm2)	Ixx (mm4)	Iyy(mm4)	Izz(mm4)
Arch rib	67648	14.954 x 109	13.753 x 109	7.795 x 109
Main girder	229000	87.487 x 109	257.08 x 109	30.16 x 109
Strut	40832	5.371 x 109	4.349 x 109	3.096 x 109
Stringer / bracing	18911.09	0.003 x 109	0.615 x 109	0.078 x 109
Cross beam	80500	0.014 x 109	60.916 x 109	1.759 x 109
Hanger	25446.90	0.103 x 109	0.052 x 109	0.052 x 109

The 3D model view, the elevation and the plan along with the nodes and element number are shown in fig.1 (a) (b) and(c)

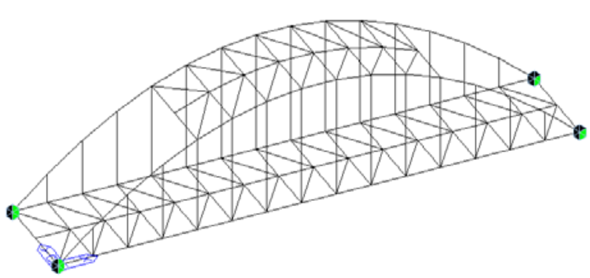

Fig. 1: (a) 3D View

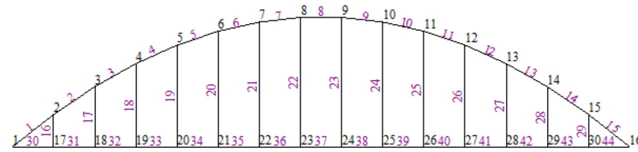

Fig. 1: (b) Elevation

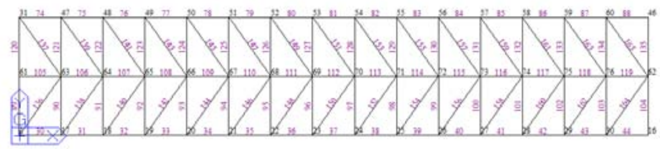

Fig.1: (c) Plan

5. NUMERICAL RESULTS OBTAINED

In modeling the Arch Bridge the dimensions and sectional property are extracted from an example [11]. The referred model of bridge was of 225m span 33m width which is modified time to time for 80m span and the results are checked if it is lying under permissible limit following Indian codes like permissible deflection etc. Then the rest of the Arch bridges are modeled considering the same properties only varying in rise to span ratio. After properly modeling all the models are analyzed for static and moving load. The static loads and Wind load are considered following Indian codes and IRC ClassA and ClassB vehicle is considered for moving load analysis. In order to extract the results the various load cases that have been considered were finally combined all together forming two load combination named as LCB1 which consist of dead load , self weight and the wind load and LCB2 which consist of moving load only. In order to study the structural behavior of the models and to compare the different structural parameters, the results are then extracted and presented here in graphical form.

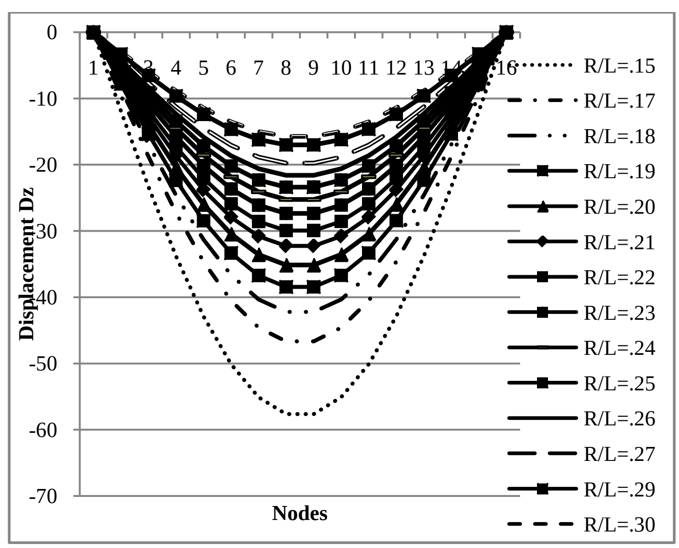

Fig. 2: Displacements in the Girder Due to Lcb1

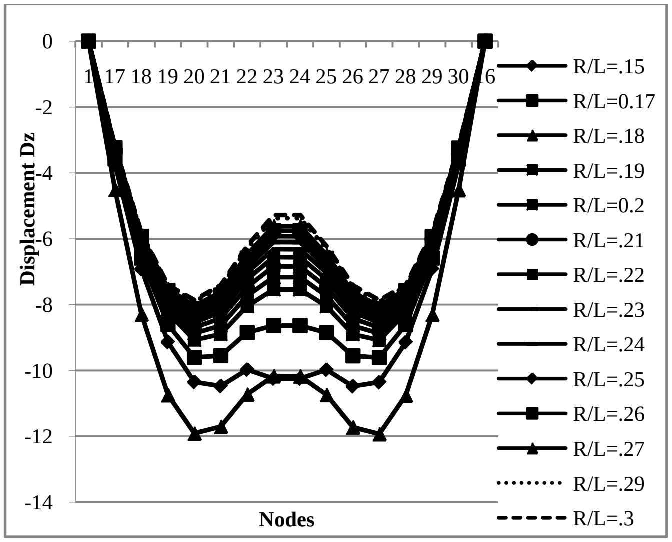

Fig. 3: Displacement in the girder due to Moving load (LCB 2)

Discussion: The results obtained for the two load combination are plotted in graph as shown in fig.2 and fig.3. From the figure it is seen that under the same loading condition, the displacement in the main girder for the dead loads (LCB1) as well as Moving load (LCB2) goes on increasing as we increase the rise to span ratio of the bridge. It is seen that the displacements in the girders lie within the permissible limit of displacement, L/600 [13] i.e. 133mm. Here the highest displacement that we have got is -67.123 mm. The graph also shows that the displacement due to rise to span ratio .15 is much high compared to the displacements for rise to span ratio of .30. However the decrease in the displacement gradually decreases and become minimal for rise to span ratio nearer to .3.

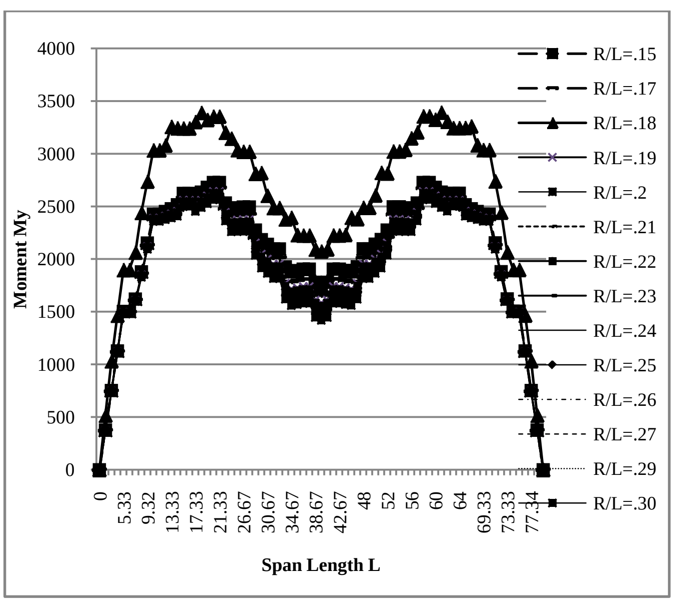

Fig. 4: Bending moment in the Main girder due to Moving load (LCB2)

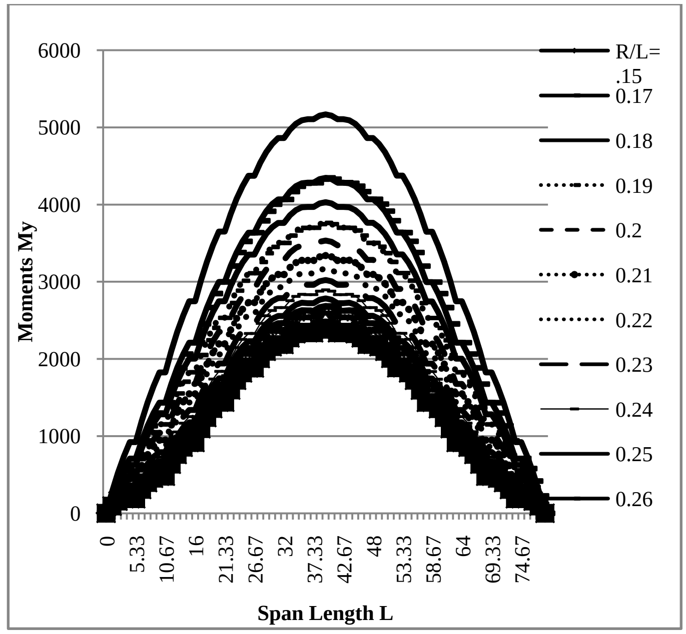

Fig. 5: Bending moments in the main girder due to LCB1

Discussion: The result of the bending moment for the main girder that has been plotted in the graph is shown in fig.4 and fig.5. The result shows that when we increase the rise to span ratio from .15 to .30 the corresponding bending moment in the girder goes on decreasing. However it is observed that the decrease in the bending moment becomes minimal nearer to rise to span ratio of .30.

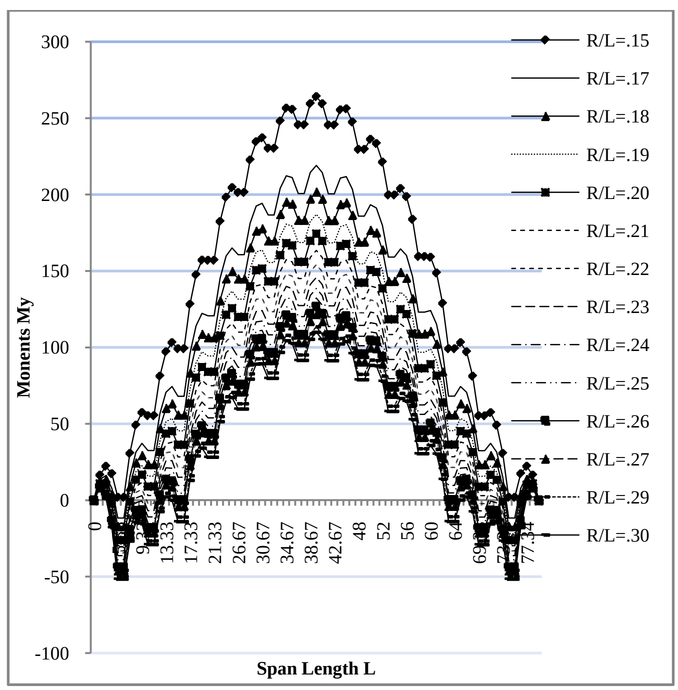

Fig. 6: Bending moment in the Arch rib due to LCB1

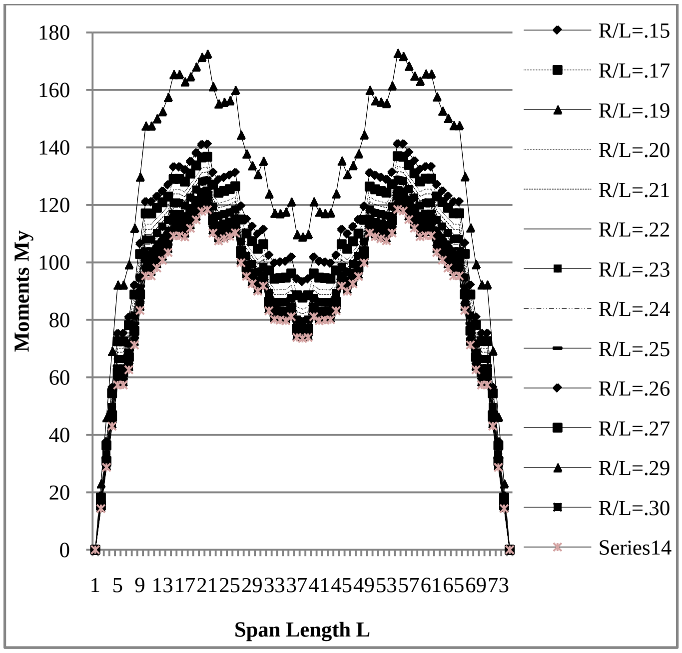

Fig. 7: Bending moment in the Arch rib due to moving load (LCB2)

Discussion: The result of the bending moment for the arch rib that has been plotted in the graph is shown in fig.6 and fig.7. From the graph it has been observed that for the dead load i.e. LCB1, there occurs no point of contra-flexure for rise to span ratio of .15. However we have got point of contra-flexure as we have increases the rise to span ratio from .17 to .30 and also there occurs a continuous decrease in the positive bending moment in the mid span for higher value of rise of arch. In case of moving the moment in the arch rib decreases as we have increases the rise to span ratio. And the decrease in the bending moment becomes minimal for rise to span ratio of .30.

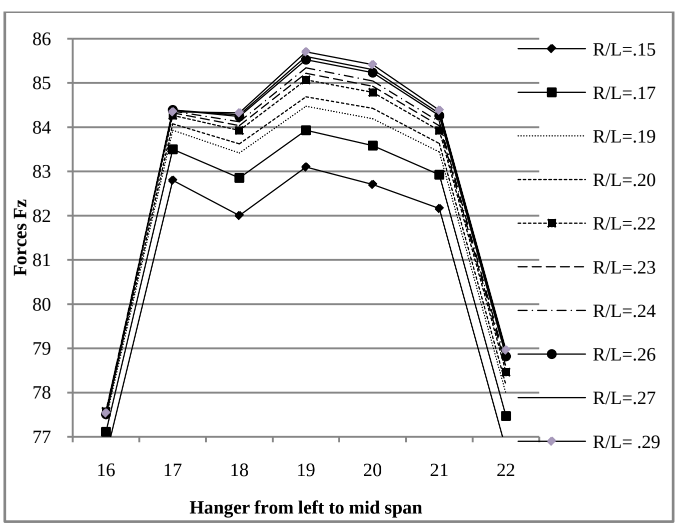

Fig. 8: Tension forces in the Hangers due to LCB1

Fig. 9: Tension forces in the hanger due to moving load (LCB2)

Discussion: In our study the hangers are simulated in the model as Tension element. Therefore the tensile forces for hanger no. 16 to 22 are plotted in the graph shown in fig.9. The result shows that with the increase in rise to span ratio the tensile forces in the hangers' increases.

6. CONCLUSION

The current study is done to see the behavior of the Arch Bridge when we vary the arch rise to span ratio. For our study steel bridge is considered as it is widely used in case of arch bridge. The most important conclusions of our study are drawn from the figs. 2,3,4,5,6,7,8 and 9. By observing the results and from the above discussion, it is seen that the displacements of the girders decreases with the increase of rise to span ratio. However decrease in displacement leads to less vibration in the deck of the bridge. Again lower rise to span ratio provides higher bending moment in the girders and arch rib. Higher bending moment means higher plastic section modulus which in turn leads to selection of higher section of members and as a result the cost of construction also increases. In our study it has been observed that in both cases either from displacement criteria or bending moment, there occurs decrease in the displacements and bending moments as the rise to span ratio is increased and the decrease becomes minimal nearer to rise to span ratio equal to .30. Thus from our present study of the arch bridge model the reasonable rise to span ratio in this paper is .30.

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