The effect of rise-span ratio on the rigid-framed arch bridges

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Abstract. The rigid-framed arch structure is a popular bridge structure on medium and small span bridge such as flyover. Rise-span ratio affects the rigid-framed arch structure performance, in order to analyse the influence on the rigid-framed arch structure of different rise-span ratio, a calculation model of the rigid-framed arch structure on the basis of the project established using the large general finite element software, by adjusting the rise value to change the rise-span ratio, analysing and comparing the structural internal force and deformation condition of the rigid-framed arch in different rise-span ratio under the action of constant live load, temperature change, and foundation settlement. The influence of different rise-span ratio on the rigid-framed arch stress summarized.

1. Introduction
Rigid-framed arch structure has the mechanical characteristics of both rigid-framed bridge and arch bridge. The mechanical performance of the structure is not only affected by boundary conditions, load conditions and other external factors, but also affected by internal factors such as rise-span ratio, the stiffness ratio of arch and beam, and whether the arch beam is consolidated or not. The rise-span ratio is a very important parameter in the design of rigid-framed arch, which also has a great influence on the structure internal force distribution and deformation. In addition, the rise-span ratio has a great impact on the coordination with the structural landscape of the rigid-framed arch and the surrounding environment. Therefore, it is great significant to choose an appropriate rise-span ratio for the reasonable internal force distribution and economical material consumption of the rigid-framed arch structure.

2. Project profile and finite element model
The arch continuous box girder structure located on wuhan city adopts the span layout of 30 m+40 m+30 m, the bridge deck width is 35 m, the main beam height is 1.6 ~ 3.673 m, among which the main beam height at the top of arch foot is 1.4m. The upper and downstream separated foundations are adopted for the piers and the two abutments.

Midas Civil was adopted to simulate the whole bridge. Figure 1 shows the finite element model diagram when the rise height f=5 m, the rise-span ratio f/L=1:8, and the arch axis is an arc line. The whole bridge is divided into 122 units and 125 nodes.

![Finite element model of the full bridge.](image)
In the analysis and calculation, in order to exclude the influence of other factors, the assumptions are made as following: (1) the bridge deck layout and section size of main girder, the main arch ring and the main beam at the top of arch foot are unchanged; (2) arch axis maintains arc line; (3) the relative position of prestressed steel to the beam structure edge remains unchanged; (4) the boundary conditions remain unchanged; (5) The load condition remains unchanged.

3. Influence of internal forces of the structure with different rise-span ratio

The rise-span ratio of the structure is changed through adjusting the rise value of the arch ring. The rise value $f$ evaluates 4.0, 5.0 and 6.0m respectively, and the corresponding rise-span ratio $f/L$ is 1/10, 1/8 and 1/6.7 respectively. The internal force and deformation of rigid-framed arch structures with different rise-span ratio are analyzed and compared under the action of constant load, live load, temperature change and foundation settlement, so as to analyze the influence of different rise-span ratio on the internal force distribution of rigid-framed arch structures.

3.1. The influence of internal forces on foundation settlement by the rise-span ratio

The bending moment of the main beam section of the rigid-framed arch structure is calculated respectively when the rise value $f$ evaluates 4.0, 5.0 and 6.0m respectively and the middle foundation settlement is 5 mm, as shown in figure 2.

![Figure 2. Bending moment of main beam under 5 mm middle foundation settlement.](image)

It is calculated that when the rise value $f$ evaluates 4.0, 5.0 and 6.0m respectively, the axial force of the side span arch ring structure under 5 mm middle foundation settlement is 1.000:0.967:0.922, and that of the middle span is 1.000:0.976:0.938.

It can be seen that the middle foundation settlement causes a large internal force on the main beam of the side and middle span, while the main beam at the top of the arch foot hardly generates any structural internal force, so the internal force caused is small. With the increase of the rise-span ratio, the influence of foundation settlement on the internal force of the main beam is also more obvious. The rise value $f$= 4.0m increases to $f$= 6.0m, the bending moment of the main beam increases by 31.0% and the axial force of the arch ring decreases by 6.2%.

3.2. The influence of internal forces under constant load by the rise-span ratio

The bending moment of main beam section when the rigid-framed arch structure is subjected to constant load is calculated respectively in the case that the rise-span ratio $f$ evaluates 4.0, 5.0 and 6.0m respectively, as shown in figure 3.

![Figure 3. Bending moment of main beam under constant load.](image)
As can be seen from figure 3, with the increasing of the rise value, the positive bending moment of the main beam on the middle and side span decreases while the negative bending moment increases under the constant load, and the negative bending moment of the main beam on the top of the arch foot decreases while the positive bending moment increases. When the rise \( f = 4.0 \text{m} \) changes to \( f = 6.0 \text{m} \), the bending moment of the mid-span at the vault reduces by 93.9% under constant load. In addition, the axial force of the main beam under constant load is 1.000:0.892:0.806 when the rise \( f \) evaluates 4.0, 5.0 and 6.0m respectively.

It can be seen from the above that the change of the rise-span ratio has a significant impact on the internal force of the main beam under constant load. The increase of the rise value greatly reduces the mid-span bending moment of the main beam, but increases the negative bending moment at the beam-arch junction.

3.3. The influence of internal forces on temperature change by the rise-span ratio

The bending moment of main beam section is calculated when rigid-framed arch structure is under temperature rise under the three conditions of 4.0, 5.0 and 6.0m rise value respectively, as shown in figure 4.

It is calculated that when the rise value \( f \) evaluates 4.0, 5.0 and 6.0m respectively, the axial force of the side-span arch ring under the temperature rise action is 1.000:1.098:1.174, and that of the middle span arch ring is 1.000:1.084:1.142.

From the above, it can be seen that the influence on beam bending moment caused by the overall temperature change is very obvious. When the rise value \( f = 4.0 \text{m} \) changes to \( f = 6.0 \text{m} \), the beam bending moment increases by 70.8% under the overall temperature change. When the rise value \( f = 4.0 \text{m} \) changes to \( f = 6.0 \text{m} \), the axial force of the arch ring increases by 14.2% under the overall
temperature change. The influence range of the rise-span ratio on the internal force and that of the temperature change are basically the same.

3.4. The influence of internal forces under live load by the rise-span ratio

The maximum bending moment of the main beam section is calculated respectively when the rigid-framed arch structure is under the action of automobile load, in the case that the rise-span ratio $f$ evaluates 4.0, 5.0 and 6.0m respectively, as shown in figure 5.

![Figure 5. Maximum bending moment of main beam under automobile load.](image)

It can be seen from FIG. 5 that the change of the beam bending moment caused by the change of the rise value is less than 10%, indicating that the change of the rise-span ratio has a limited impact on the stress of the beam. With the increase of the rise-span ratio, the maximum positive bending moment of main beam under the automobile load decreases slightly, while the negative bending moment increases somewhat. In addition, it can be seen from the figure that the influence of the rise value changes on the main beam of the middle span is more obvious than that of the side span.

It was calculated that when the rise $f$ was set at 4.0, 5.0 and 6.0 m respectively, the axial pressure of the side-span arch ring under automobile load was 1.000:0.890:0.803, and the axial pressure ratio of the mid-span arch ring was 1.000:0.896:0.815. It can be seen that the change of the rise has a great impact on the axial force of the arch ring under live load. The rise $f= 4.0m$ changes to $f= 6.0m$, and the internal force of the arch ring decreases by 15% ~ 20%.

It can be seen that the change of the rise-span ratio has limited influence on the internal force of the rigid-framed arch main beam under live load, but it has obvious influence on the axial force of the arch ring. With the increase of the rise, the mid-span bending moment of the main beam is slightly reduced, but the negative bending moment at the junction of beam and arch is slightly increased.

4. Conclusion

Though analyzing the influence in internal forces under constant load live load, temperature change and foundation settlement caused by different rise-span ratio, the following conclusions can be drawn:

(1) On the basis of the analysis comparison of rigid-framed arch structure internal force and deformation condition under constant load live load, temperature change and foundation settlement with different rise-span ratio, the influence of constant load is larger, rise-span ratio increase while the main beam bending moment decreases obviously, the negative bending moment in beam arch junction increases, the whole structure stiffness increases. The change of rise-span ratio has limited influence on the internal force of rigid-framed arch under live load, the axial force of arch ring and deformation of the main beam have obvious influence. The arch ring pressure and deformation of arch beam reduce while the rise-span ratio increase.

(2) In order to improve the allowable bearing capacity and driving comfort of the bridge, the rise-span ratio of rigid-framed arch structure with similar span should be more than 1/9, and more than 1/8 recommended.
(3) In addition to the structure rise-span ratio, changes in factors such as the span of the bridge will also affect the static characteristics of rigid-framed arch, the stress characteristics of rigid-framed arch in span layout other factors change can also be analysis in future, so that the stress characteristics of rigid-framed arch analysis for further more comprehensive research.

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