Mechanical States Studies on Half-span Swinging Arch Bridge of Open Thin-walled Section in the Construction Stage

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Keywords: swinging arch bridges, open thin-walled, static analysis, finite element method, stability safe factor

Abstract. Basing on an actual swinging arch bridge, some mechanical properties in the construction stage that the half-span swinging structure breaking away the brackets are analyzed by the finite element software ANSYS, such as the structural curve mode, bracing cable force, key section stress and the global stability. According to the static and buckling analysis, some useful information can be provided for the same type bridges' structure designs, construction and inspection.

Introduction

In recent years, for several advantages, namely, not requiring complex technical equipments, less working at heights and low cost, swinging construction technique used for arch bridge [1-3] has shown great vitality in mountainous regions of western China. During the open thin-wall box construction process, in order to form a relatively light half span arch ring, relatively thin arch ring constituent elements including bottom slabs, walls and part of transverse walls are cast on brackets which are located at both sides of bank at first. Then after the two halves of the arch ring join together in the swivel erection, the second phase concrete is cast to increase the thickness of the whole arch ring. Finally, other part of structures above arch ring and bridge decks are built. According to dividing the concrete casting into two phases, the total weight of arch ring before swinging is reduced greatly. In order to ensure the construction safety, in this paper, by way of a certain swinging arch bridge, at the stage that after the arch ring breaking away the brackets and before the arch ring join together, the mechanical states including the structural curve mode, bracing cable force, key section stress and the global stability are analyzed by the finite element software ANSYS.

Finite element model

As shown in Fig.1, a top-bear reinforced concrete box ribs arch bridge with 132 m span distance and 17.6 m net height is mainly composed of arch ring and superstructure. The curve mode design of main arch ring adopts catenary with 2.0 arch axis coefficient. Three-room in single box constitutes the section configuration of arch rib. Each half of arch ring equips a backwall as matching weights. In order to reduce the total weight during the swivel erection process, the swivel members adopt open thin-wall box structure with 8 cm thickness of bottom slabs and walls.

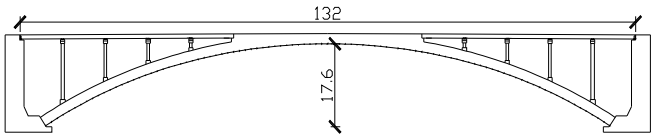

Fig.1 Elevation of a swinging arch bridge (unit: m)

Due to the symmetry of structure, the spatial finite element model conceived in ANSYS is shown in Fig.2 and the element details of the main bridge structure members are given in Table 1.

Table. 1 Elements used for simulating structure members

Member	Element	Type	Amount
backwall	SOLID185	solid	7948
arch ring	SHELL63	shell	6698
bracing cable	LINK10	truss	24
steel reinforcement cage	LINK8	bar	39

The whole half-span arch structure is mainly composed of backwall, open thin-walled section and bracing cable. The security of swinging construction is decided by the following factors at the state that the arch rib breaking away the brackets, such as the structural curve mode, bracing cable force, key section stress distribution and the stability of arch rib. In order to ensure the safety of swinging construction under the half-span arch ring dead load and meet the closured curve mode requirement, the stepped tensioning to reach the design cable force for the bracing cable should be considered before the half-span arch breaking away the brackets. In the finite element simulation, adjusting the initial strain of LINK10 elements which are used to simulate the bracing cable is adopted. The detail algorithm process is given in Fig.3.

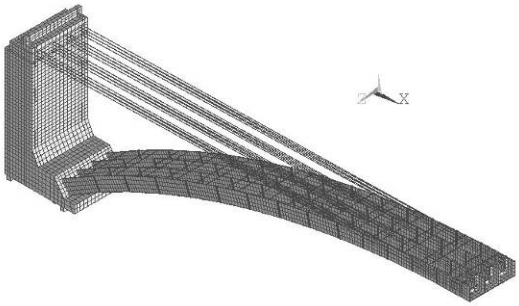

Fig.2 Half-span arch bridge finite element model

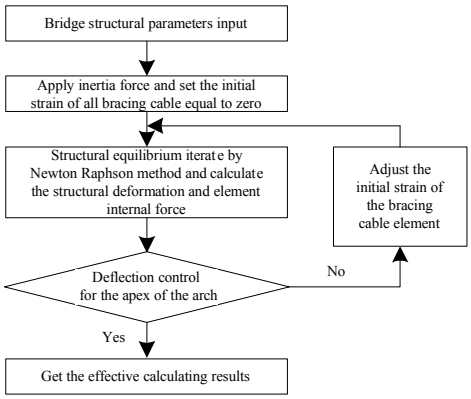

Fig.3 Calculation analysis flow chart

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Arch rib curve mode. The underside nodes vertical displacements of the arch rib are shown in Fig.4. When the displacement of the apex of arch is between 0~10 mm, the arch ring is completely pull up and there is a counter deflection of 39.3 mm in 1/4 span of arch ring.

Backwall curve mode. As shown in Fig.5, after the arch ring breaking away the brackets, the horizonal rebound displacements towards the arch rib direction increase gradually along the vertical direction and the maximal value at the top of the backwall reaches about 7 mm, which indicates that the displacement of the backwall as a matching weights is so small and can be neglected to monitor.

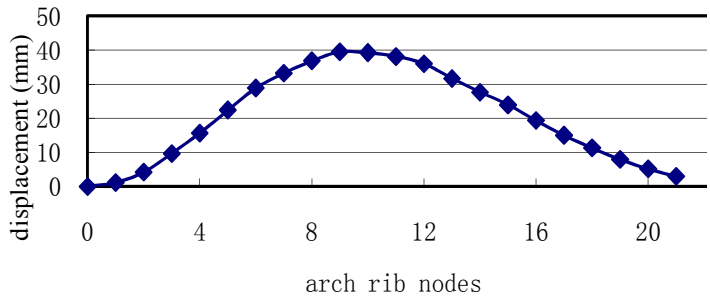

Fig.4 Displacement of the arch rib

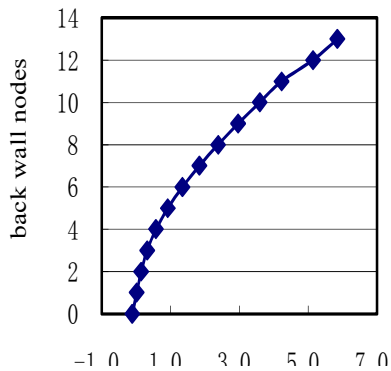

Fig.5 Displacement of the backwall

Bracing cable force. In order to improve the computational efficiency and save nodes, 64 bracing cable in 8 groups are simplified to 24 LINK10 elements. Due to the fact that the defection in mid section is larger than it in side section, the average force of bracing cable in mid section of 88.20 kN is larger than the value in side section of 88.16kN. Table 2 gives the general information of bracing

cable, in which the cable force is converted into the actual average force for 64 bracing cable and the safety factor is defined by the ratio of the ultimate tensile strength and the maximum cable stress. The maximum cable stress of 484MPa accounts for 26.0% of the ultimate tensile strength, which shows the safety degree for bracing cable is high.

Table. 2 General information of bracing cable

Total cabel force(kN)	Number of cable	Cable force(kN)	Diameter(mm)	Maximum cable stress(MPa)	Safety factor
5643.34	64	88.18	15.24	484	3.843

Arch rib stress. The lateral and bottom plates stress distribution contours after the arch rib breaking away the brackets are showed in Fig. 6 and Fig.7. It can be seen that tensile stress appears in the top edge of the lateral plate at the 1/4 span axial tensile stress with maximum value of 3.07 MPa, which indicates that there some concrete cracks occur in the area and the stress is undertaken by reinforced. And the monitoring results in-site also verifys the simulation [4]. The bottom plates stress mainly appears compressive stress with maximum value of 10.0 MPa, which is lower than the code [5] requirment for the compressive yield strength of concrete. However, in some bottom plate areas, such as the foot and apex of arch, tensile stress appears with maximum value of 1.84 MPa, which indicates that the mechanic state in this two areas is complex and should be pay attention to.

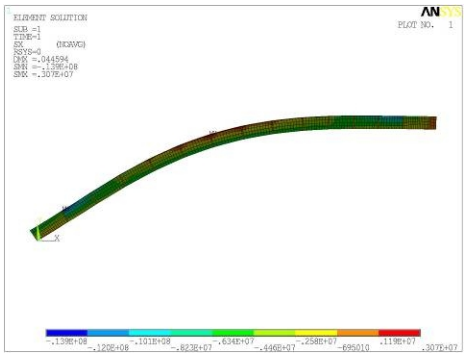

Fig.6 Lateral plates stress of arch rib

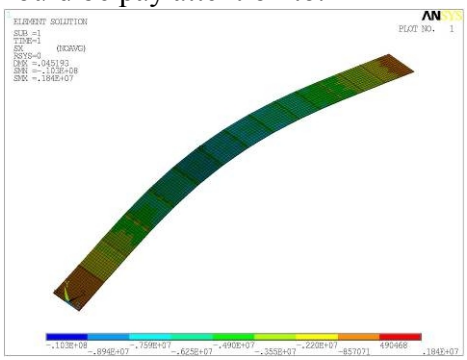

Fig.7 Bottom plates stress of arch rib

Backwall stress. The backwall stress distribution contour in vertical direction after the arch rib breaking away the brackets is shown in Fig.8. The maximum compressive and tensile stress appears at the variable cross-section areas of 3.70 MPa and 1.68 MPa. And the tensile stress is beyond the the code [6] requirment for the bending tensile strength of concrete, where the stress redistribution occurs and the backwall stress is undertaken by reinforced fabric piece at the rear of back wall.

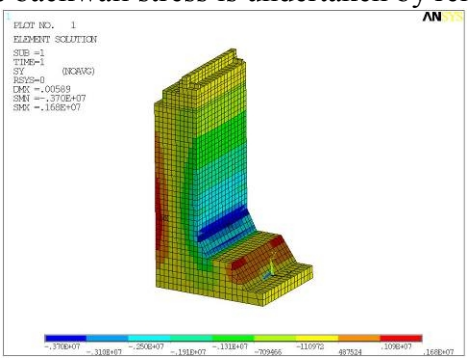

Fig.8 Backwall stress in vertical direction

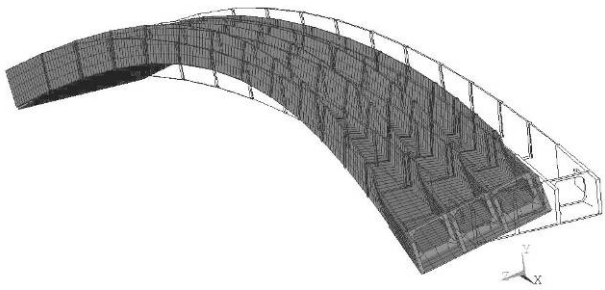

Fig.9 1st order torsion-bending instability

Structural stability safety factors. With the increasing of bridge span length, the stability of the arch rib become important for the construction safety. Before the bridge swinging, there is no load acting on the arch rib when it breaks away from the brackets. Structure gravity multiple loading means is used to carry out the stability analysis of arch rib, namely, $n = \lambda_{cr} W / W = \lambda_{cr}$, where λ_{cr} represents the first order eigenvalue and n delegates the stability safety factor.

Table 3 gives the specific descriptions about the arch rib buckling safety factors and buckling modes under different bracing cable initial tension. The results show that the buckling safety factors reduce gradually with the increasing of bracing cable initial strain and the buckling modes change from the

whole out-of-plane torsion-bending to the local arch rib buckling. Fig. 9 shows a typical out-plane bulking mode at the first order modal and no in-plane buckling happen for varied initial tension cases at the first order instability modal.

Table. 3 Stability safe factor under different initial strain

Initial strain	Eigenvalue	Bulkling modal
0.0000	7.6443	Out-of-plane torsion-bending
0.0026	5.5141	Out-of-plane torsion-bending
0.0028	5.3912	Out-of-plane torsion-bending
0.0030	4.9712	Local bulkling at some lateral plates of arch rib

Conclusions

From the simulation analysis, some conclusion can be draw as follow:
(i) In order to ensure the design displacement of the apex of arch, bracing cable gradation tension before the half-span structure breaking away the brackets is necessary. The counter deflection in 1/4 span of arch ring after the stage that breaking away the brackets should be pay attention to. Due to the trivial rebound, the backwall displacement monitoring in horizontal direction can be omitted.
(ii) The maximal tension stress may occur in the variable cross-section areas of the backwall and the 1/4 span of arch rib, where the potential structure cracks due to tensile stress should be monitored.
(iii) Due to the bracing cable constrain, the local instability is the main buckling mode and the elastic buckling factor is not less than 4.0, which meets the Ref [7] requirement for the stability safety factor.

Acknowledgements

The research work reported in this paper was supported by the National Engineering Laboratory for Fiber Optic Sensing Technology, Wuhan University of Technology, China. Thanks to the Fundamental Research Funds for the Central Universities (WUT: 2014-IV-009, WUT: 2014-II-012), and National Natural Science Foundation of China (Major Program: 61290310).

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