The theory and application of plane-hinged arch in the stone arch bridges

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ABSTRACT: The stone arch bridge is a basic kind of bridges used in urban and suburban roads in China. Some stone arch bridges are decaying because of increasing road traffic volume and loading, lack of maintenance and especially dehiscence of arch springer. On the basis of investigation and survey on the achievement in loading experiment, the calculation model that can consider the theory of plane-hinged arch and teamwork is proposed. The software SAB (Stone Arch Bridge) and design diagram of 30-80 meters light stone arch bridge are also accomplished. The results of theoretical analysis and loading experiment are compared. The calculation model are tested and verified. It indicates that bearing capacity is increased because of teamwork and internal force redistribution. The estimation of structural ultimate bearing capability could not be scientific and economical if the plane-hinged arch and team-work were ignored.

1 INTRODUCTION

The amount of transportation of existing highway traffic continuously increases along with the country expanding economy in China. The status quo of bearing capacity of the existing stone arch bridges become one of the topic that engineering and academic circles pay attention to. Many stone arch bridges are built within the highways and byways before 2000 (Ding 2000) . Compared with the old specification for design of highway masonry bridges, the calculation models of stone arch bridges have changed. In the first instance, the loads level and frequency are substantially increasing. Secondly, the stone arch bridges have some breakage because of long-term use. Its main materials have been subjected weathering and aging. And finally, the investigation and survey states that the arch springing have breaking joint. The arch springing sections have already got in elastic-plastic phase. The arch springing boundary conditions have been changed It is not a fixed-end arch. It has characteristic of two-hinged and fixed-end arch. The arch springing plays an elastic-plastic support role. The current specification rules that the stone arch bridge analysis methods are the theory of elasticity of the fixed-end arch. So, the calculation models need to be research.

The stone arch bridges can still normally work although exterior action and material resisting force have changed. To evaluate its bearing capacity should consider that the superstructure work with the arch ribs. Idealizing structure calculation models also need to study. It is a vital step to put forward an opinion to the safety valuation.

2 CALCULATION MODEL

It is more accurate for the valuation of bearing capacity of the existing stone arch bridges if the elastic-plastic phase of the arch springing are considered. The science experiments and long-term practice had proved that the huge bearing potential of arch stone bridge comes from internal force redistribution. It also comes from co-operation of the main arch ring and superstructure (ShangGuan 1983). The two plane-hinged arch theory allows the springing cracking and rotating about a axis of diameter ∞. The plane-hinged can decrease the excessive peak value of moment presented at spingings under the dead load condition. The deflection and internal force would be reduced because of fortified flexural rigidity of the whole bridge if the co-operation of the main arch ring and superstructures are considered. Then the live loads level of the stone arch bridge would be heightened.

2.1 Calculation assumption (Yna Yun 2004)

(1) The stone arch bridges have the characteristics of "the board skewback and the narrow vertical-wall". Let it is supposed that the vertical-wall's top and bottom terminal are the hinges, don't account shearing rigidity of vertical-wall. The buttresses of the open spandrels are supposed as compression member in the calculation model.

(2) The displacement of arch vault is mainly horizontal displacement under the unsymmetrical loads. The other side of loading is compressed. Let it is supposed that the spring substitutes the arch superstructure as restriction. The spring compressional stiffness also equals the arch superstructure compressional stiffness.

(3) Let it is supposed that the arch superstructure can absorb all its horizontal constraint reaction force. Namely, its horizontal constraint reaction force can not transfer the arch rib.

2.2 Restriction moment W_K of plane hinge (Yan Yun 2004)

The arch ring displacement boundary conditions are between hinged and fixed according to loading and deflection. Let it is supposed that the arch springing angular displacement equals the arch rib's angular displacement. The restriction moment could be computed from the arch springing angular displacement and section bending rigidity. The restriction moment that is indicated in Fig.1 is an applied force of the model.

Where: $W_k = -N \cdot e$

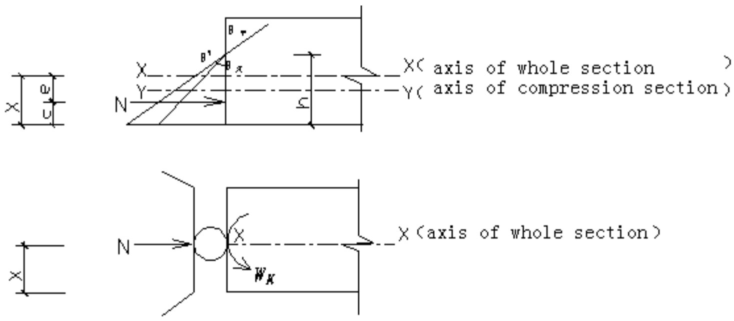

Figure 1 : Restriction moment of arch springing

2.3 Spring and plane-hinged model

According to the calculation assumption and restriction moment, the model is seen as Fig. 2.

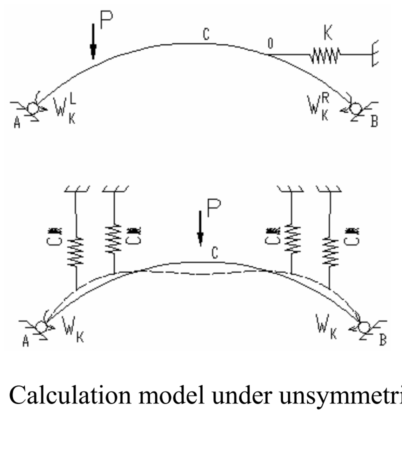

Figure 2 : Calculation model under unsymmetrical load.

2.4 Analysis with SAB (stone arch bridge)

The software SAB was developed by Xu Hai-yan, Liu Ying-chun and Shang Guan-xing, who are professors from school of civil engineering and architecture in East China Jiaotong University. The SAB can consider dead loads, live loads, experiment loads, temperature and support settlement. The models of two-hinged, fixed-end, plane-hinged and teamwork could be computed. The analysis flow diagram of stone arch bridge is indicated in Fig.3. Firstly, the fixed- end arch and two-hinged arch are solved, then to access database obtain the results of load step 1 and 2. Secondly, the restriction moment of plane-hinged could be resolved. Finally, the parameters from above are use to set up the model and solve.

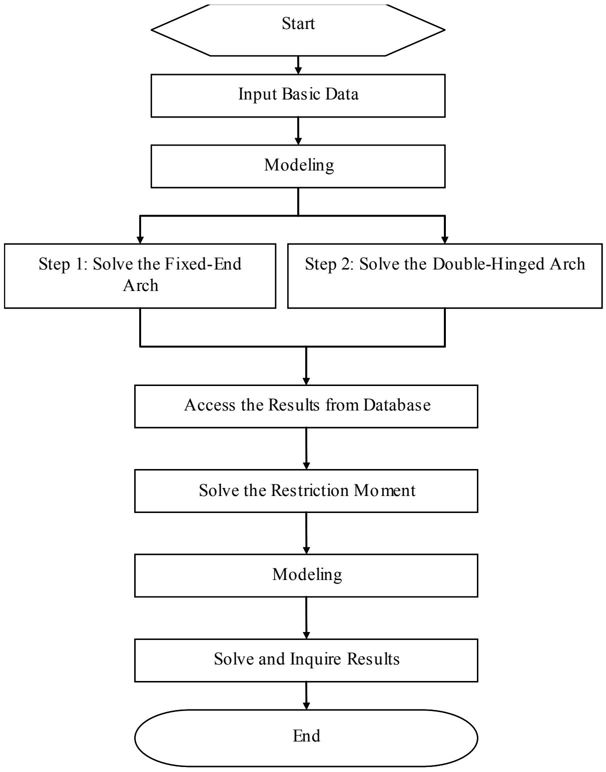

Figure 3 : SAB flow chart and function

3 EXAMPLE ANALYSIS

The examples are Shixi Bridge and Guanyin Bridge in Hunan Province, China. The fixed-end arch ring model without teamwork, plane-hinged arch model with co-operation and the whole bridge fixed-end arch model are built. By contrast with experiment and survey analysis results, it has some conclusion. The arch rib deflection is approaching to experiment results when the spring and plane-hinged arch model is L/4 loading. Compared with the fixed-end arch ring model without teamwork, the deflection reduced 35%. It proves that the arch superstructure action of teamwork is obvious. The compared results are seen as Fig.4. In the Fig.5, in addition to the fixed-end arch model without teamwork, the vertical-wall section bending moment diagram indicates non-velvet. It accords with the rule of structure mechanics. From the Fig.4 and Fig. 5, it explains that the deflection and internal force could be reduced if consider the teamwork. From the Fig.6, it explains that the arch springing and L/4 moment could be reduced about 30% if the theory of plane-hinged was considered. Compared with the fixed-end arch ring model, the internal force and deflection redistribution are more practice and uniformity.

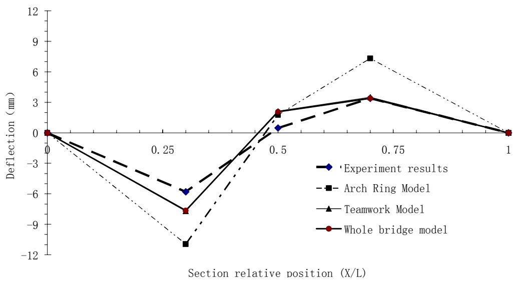

Figure 4 : Comparison of arch rib deflection under L/4 loading of Shixi Bridge

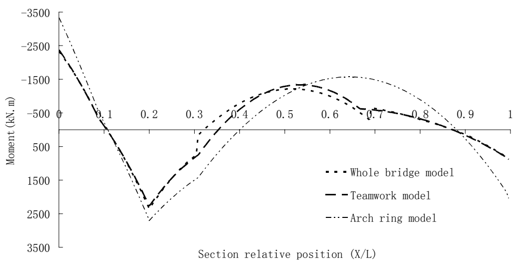

Figure 5 : Comparison of arch rib moment under L/4 loading of Shixi Bridge

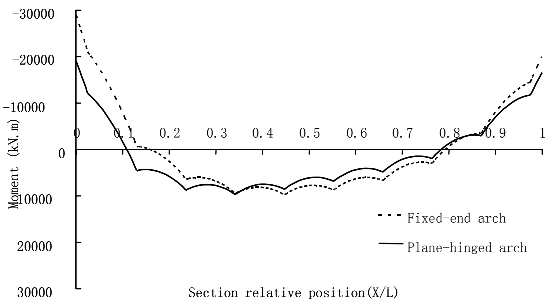

Figure 6 : Comparison of arch rib moment under L/4 loading of Guanyin Bridge

4 CONCLUSION

According to comparison, the spring and plane-hinged arch models approach experiment results. The model and method is feasibile and reliable. It can more accurately evaluate bearing capacity. The estimation of structural ultimate bearing capacity could not be scientific and economical if the co-operation of the main arch ring and superstructure was ignored. It is vital for both existing stone arch bridges and new stone arch bridges.

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