

## **Behavior of Concrete-filled Fiber Reinforced Polymer(FRP) Tubular Arches**

Lingqiang Yang <sup>1, a</sup>, Rui Gao <sup>1, b</sup>, Yan Wang <sup>1, c</sup>

<sup>1</sup> School of Civil engineer and architecture, University of Jinan, Jinan, Shandong province, China

<sup>a</sup>cea\_ yanglq @ujn.edu.cn, <sup>b</sup>cea\_ Gaor @ujn.edu.cn, <sup>c</sup>eo\_wangy @ujn.edu.cn

**Keywords:** arch tubes; FRP; Load-Strain.

**Abstract.** The arch tubes are filled with concrete using a small concrete pump. The tubes may be filled quickly with no external vibration using a self consolidating concrete mix. After a short curing period, the arches gain the majority of their final strength, providing the entire superstructure for a bridge in a short amount of time. To develop a numerical model to predict the behavior of the concrete-filled, testing and modeling at the material level for the FRP laminate properties are given.

### **Introduction**

The arch tubes may be formed to nearly any desired geometry either in a manufacturing facility or on-site. They are then infused with resin, and allowed to cure prior to placement. Due to the light weight of the hollow arch members, they can easily be placed by hand labor or light construction equipment, providing potential for cost and time savings over conventional construction methods. In order to carry out effective design using the arch members for structural applications it is necessary to have a predictive model that accurately describes the member behavior under various combinations of loads. In this research a model has been developed using the finite element method and a moment-curvature based analysis. Full scale structural testing has been completed on concrete-filled FRP arch members for model validation and member performance evaluation. This chapter will discuss the aspects of model development specific to the arch members, the structural testing procedures, and test results. Results of the experimental work will be compared with model predictions for validation of the model, conclusions will be drawn, and recommendations future work will be given.

### **Structural Testing**

In order to provide member level validation for the finite element model, full scale structural testing was carried out on four concrete-filled FRP arch specimens. The arches were subjected to quasi-static loading via a single point load acting vertically downward at the crown. The specimens were subjected to two stages of loading. In the initial stage, load was applied to the specimen until fiber tensile failure, and corresponding peak loading, was achieved. In the second stage, arches were loaded continuously until complete collapse of the specimen occurred. The initial stage of loading is primarily of interest for this research as this condition is representative of the in service response of the members, and as such will be the focus of this chapter. Second stage tests show significant reserve strength and deflection capacity due to the inherent redundancy of the arch members.

In total, four specimens were subjected to quasi-static testing. Prior to testing, the first specimen sustained significant damage due to accidental preloading. As a result, the majority of concrete cracking had occurred prior to testing. The results of this test will be presented and discussed separately from the remaining three specimens. Additionally, two specimens were subjected to 2,000,000 cycles of fatigue loading using an identical setup and loading scenario. These specimens are not reported on in this thesis.

### **Specimen Preparation**

Six concrete-filled FRP arches were manufactured and prepared for test specimens in this research. The arch specimens had a nominal diameter of 12 in, a constant radius of curvature of 13 ft, and a

span of 22 ft. In order to provide a positive 108 locating and mounting system, the ends of the arches were cast into 2 ft × 2 ft × 3 ft reinforced concrete footings.

### Test Setup

Arch specimens were tested under a single patch load applied vertically downward at the crown. Load was applied to the specimens using a 300 kip Instron servo-hydraulic actuator. The specimens were arranged on simple supports to provide a two-pinned arch configuration. Lateral support for the specimens was provided at two points along the span, approximately 3 ft on either side of the crown. The test setup is shown in Fig. 1.

The two-pinned arch is a first-degree statically indeterminate structure. Due to the indeterminacy, internal forces (shears, moments) cannot be calculated analytically using simple statics. In order to provide an experimental procedure for measurement of internal forces, the support setup was designed such that horizontal thrust force could be monitored, eliminating one unknown static degree of freedom and resulting in a determinate structure. Thrust force measurements were taken using a horizontal strut incorporated into the south arch support which was instrumented with strain gages. Using this data and an assumption of symmetry about the crown, all internal forces may be solved for directly.



Fig.1 Arch Test Setup

### Test Specimen Modeling

The nonlinear arch finite element model was used to predict the response of the arch test specimens. The following sections describe the development of the arch geometry in the arch model and input parameters for the Burgueño moment-curvature model.

### Model Geometry for Arch Specimens

The model was developed for the arch specimens by discretizing the specimen with a varied number of 2D plane frame elements. Symmetry was assumed about the vertical axis at the crown in order to provide a numerically efficient analysis, and allow for rapid modification of boundary conditions at the crown. The concrete support blocks were modeled using rigid links extending from the point at which the center line of the arch enters the concrete block to the center of rotation. A pinned boundary condition was enforced at the supports (horizontal and vertical translation fixed, rotation free).

Two conditions were modeled at the crown representative of the two damage states of the arch specimen. Prior to peak loading (Fig2), the crown behaves as a “fixed roller”, that is, rotation is fixed, translation in the horizontal is fixed, and translation in the vertical is allowed. This condition satisfies the symmetry condition assumed during the discretization. After rupture of FRP has occurred the arch forms a plastic hinge at the crown. This condition may conservatively be modeled as a “pinned roller”, that is, rotation and translation in the vertical direction allowed, while horizontal rotation is fixed. This is a conservative lower bound as the hinge retains some amount of rotational stiffness after sustaining damage. The state of damage is however highly variable and cannot easily be modeled using this simple finite element model.

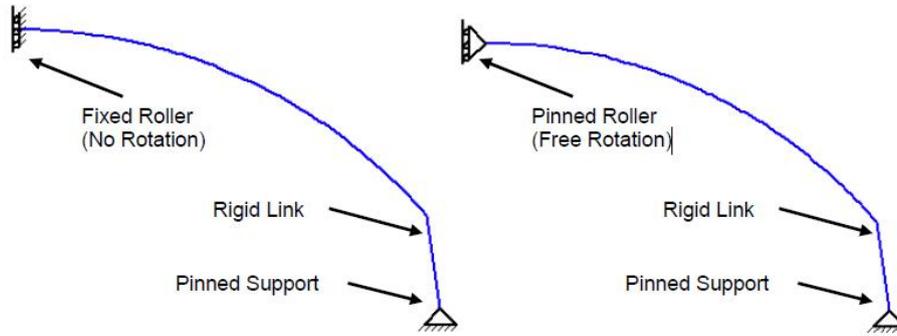


Fig.2. Arch Specimen Finite Element Models

### Test Results and Model Predictions

Predictions of the specimen behavior were made using the nonlinear arch finite element model. The following sections will present the results of structural testing, and correlation of test results with model predictions for model validation. Any discrepancies will be discussed and recommendations for model improvement will be made.

### Load-Strain

Strain in the longitudinal direction was measured at two sections along the span of the arch using resistance foil strain gages. The sections were located 18 in to either side of the crown of the arch. Three gages were installed at each section to measure strain of the extreme tension and compression fibers and the mid height of the section. The layout for strain gages on the section is given in Fig3. Gages were labeled based on their respective section (‘N’ or ‘S’) and location on the section (‘1’, ‘2’, or ‘3’), thus each gage is given a unique identifying description (eg. ‘N1’, ‘S2’).

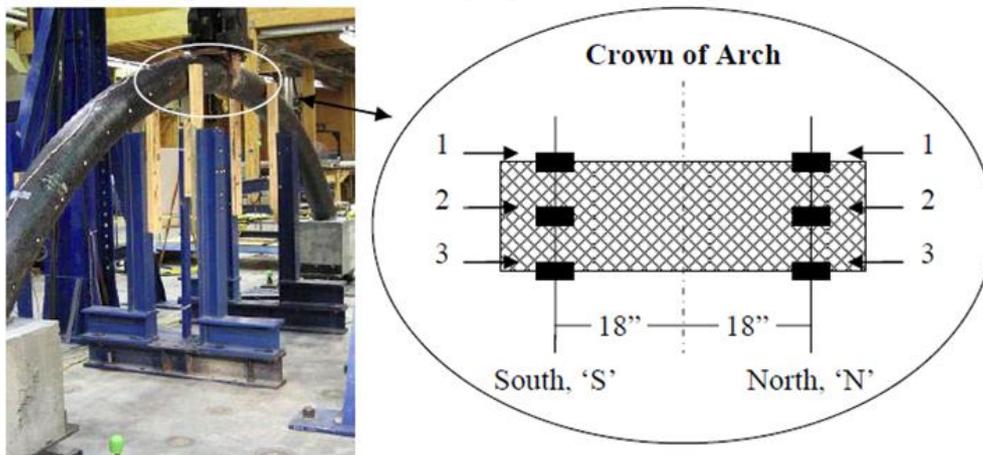


Fig.3 Strain Gage Layout on Arch Test Specimens

The sections labeled ‘N’ and ‘S’ are subjected to positive bending moment simultaneously with axial compression. As a result, the ‘1’ gages always measure the maximum compressive strain in the

section, '3' gages measure the maximum tensile strain, while the '2' gages may measure either tensile or compressive strain depending on the relative magnitudes of bending moment and axial force. Particularly at low levels of applied load where tensile cracking of concrete has not yet occurred, the '2' gages may record a net compressive strain. Plots of cross section strain vs. applied load are given for the four arch specimens in Fig 4– Fig5.

In Arch 01 (Fig4) a symmetric response is seen between the north and south sections. The absence of an initial linear region and subsequent plateau due to concrete cracking is apparent; this is a result of the significant damage sustained by the arch during preloading. Arch 02 (Fig 5) shows a much less symmetric response. In this specimen, a large void was present at the crown of the arch, extending south into the instrumented section. The non-composite action due to this void resulted in a measurement of essentially zero compressive strain in the S1 gage, and a much higher tension strain in the S3 gage than in N3. The voided section has a smaller moment of inertia, and must therefore undergo a larger curvature to carry the applied moment.

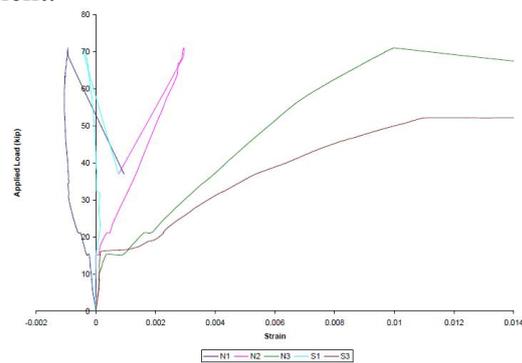
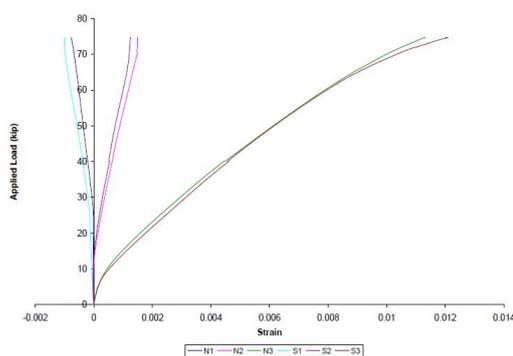


Fig 4 Applied Load vs. Cross-Section Strain, Arch 01      Fig 5 Applied Load vs. Cross-Section Strain, Arch 02

## Conclusions

The behavior of the concrete-filled FRP arches was studied through four specimens were subjected to quasi-static testing. All specimens exhibit an initial linear region up to tensile cracking of concrete, followed by a plateau in the tension response and an increasingly nonlinear strain response up to failure.

## Acknowledgements

This work was financially supported by the Shandong Natural Science Foundation (ZR2014EL038).

## References

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