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In-plane strength of concrete-filled steel tubular circular arches

Yong-Lin Pi [a], Changyong Liu [a,b,*], Mark Andrew Bradford [a], Sumei Zhang [b]

[a] Centre for Infrastructure Engineering and Safety, The University of New South Wales, UNSW Sydney, NSW 2052, Australia
[b] School of Civil Engineering, Harbin Institute of Technology, Harbin 150090, China

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ABSTRACT

More than 400 concrete-filled steel tubular (CFST) arch bridges have been constructed worldwide so far. However, design codes or guidance for the in-plane strength design of CFST arches are yet to be developed. In current design practice, the philosophy for the in-plane strength design of reinforced and prestressed concrete arches is widely adopted for CFST arches. For this, the CFST arches are considered under central or eccentric axial compression and are treated similarly to CFST columns, and the classical buckling load of CFST columns is used as the reference elastic buckling load of CFST arches. However, under transverse loading, the in-plane elastic buckling behaviour of CFST arches, particularly shallow CFST arches, is very different from that of CFST columns under axial compression. In addition, different from CFST columns under central or eccentric axial compression, CFST arches are subjected to significant nonlinear bending actions and transverse deformations prior to buckling and these will influence the strength of CFST arches greatly. Therefore, it is doubtful if the current method for in-plane strength design of CFST arches can provide correct strength predictions. In this paper, a method for the in-plane strength design of CFST circular arches, which is consistent with the current major design codes for steel structures, is developed by considering both geometric and material nonlinearities. A design equation for the in-plane strength capacity of CFST arches under uniform compression, and a lower-bound design equation for the in-plane strength check of CFST arches under combined actions of bending and compression are proposed.

1. Introduction

This paper is concerned with the strength design of circular concrete-filled steel tubular (CFST) arches. Arches with a CFST section, which consists of a thin-walled steel tube and a concrete core, are widely used in bridge construction because arches resist in-plane external loading predominantly by axial compressive action and CFST sections have good structural behaviour under compression. The steel tube provides confinement to the concrete core, which significantly improves its load carrying capacity and ductility, while the concrete core provides restraint to prevent local buckling of the steel tube. The well bonded steel tube and concrete core composite cross-section can provide the required structural stiffness and strength, and the usage of steel can be minimized by taking advantage of the high compressive strength of the concrete. Advancement of concrete pumping technology has heralded a rapid increase of CFST arch bridge construction and more than 400 CFST arch bridges have hitherto been constructed worldwide, among which 300 CFST arch bridges have been constructed in China in the last 20 years [1]. Typical examples of CFST arch bridges are the 56 m half-through Damen Avenue Bridge in the U.S, the 126 m Arco del Escudo Bridge in Spain, and the 240 m Shinsaikai Bridge as shown in Figs. 1(a)-(c), and the 430 m deck CFST arch bridge over the Zhijing River in China, the 460 m half-through CFST arch bridge over the Yangtze River at Wuxia in China, and the 338 m through CFST arch bridge over the Yong River in China as shown in Figs. 2 (a)-(c).

Despite so many arch bridges having been constructed worldwide, there is no prescriptive code or guidance available for the in-plane strength design of CFST arches. In current design practice, the same philosophy for the in-plane strength design of reinforced and prestressed concrete arch bridges such as given in JTG-D62 [2] is commonly adopted for the in-plane strength design of CFST arches. For this, CFST arches are considered as CFST columns under uniform axial compression or uniform eccentric compression (i.e. uniform axial compressive and bending actions), which uses the classical buckling load of CFST columns as the reference elastic buckling load in the strength design of CFST arches. However, CFST arches are different from reinforced or prestressed concrete arches. Firstly, the span of a number of CFST arch bridges is quite large (for example, Wuxia Yangtze River Bridge in China has a span of 460 m) and this makes most CFST arches quite slender, with buckling being one of the major concerns in the strength design of CFST arches. Secondly, using the classical elastic flexural buckling load of columns as the reference elastic buckling load for the strength design of CFST arches is questionable because the in-plane elastic buckling of arches has been shown to be very different from that of columns [3–6]. Thirdly, most completed CFST arch bridges have a rise-to-span ratio from 1/8

* Corresponding author at: School of Civil Engineering, Harbin Institute of Technology, Harbin 150090, China. Tel.: +86 151 45093600.
E-mail address: siamy@163.com (C. Liu).

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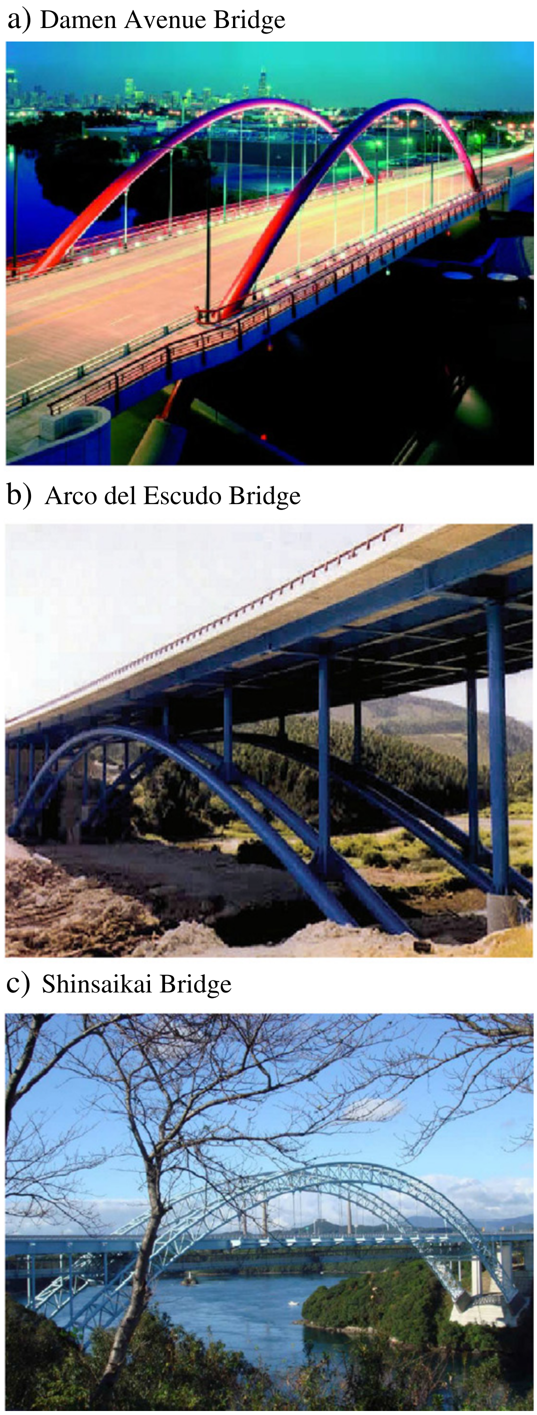

Fig. 1. Typical CFST arch bridges worldwide.

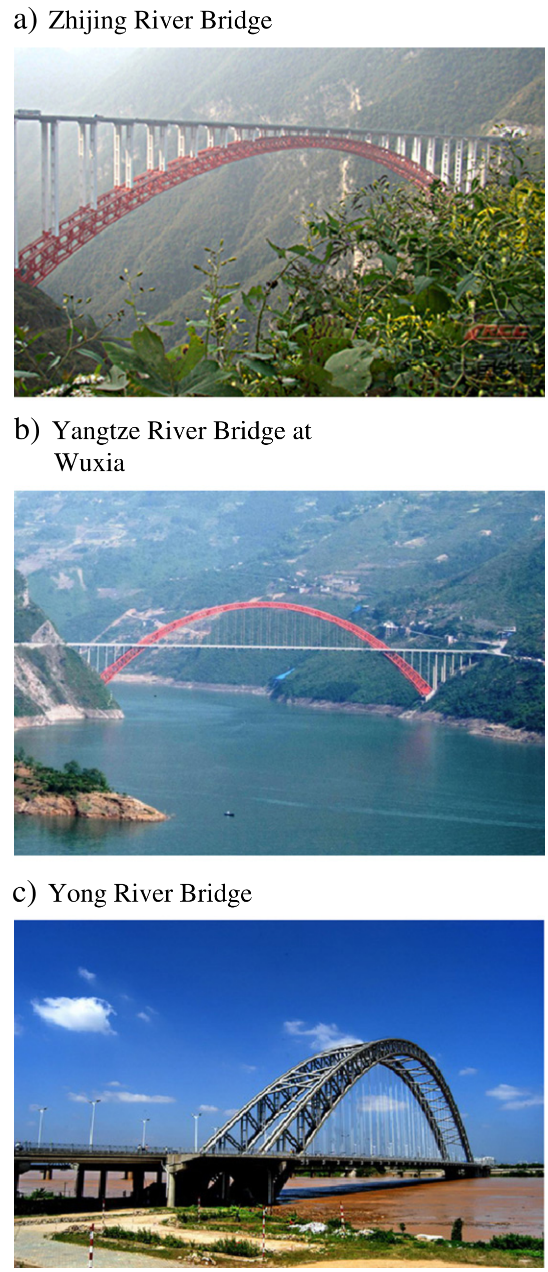

Fig. 2. Typical CFST arch bridges in China.

to 1/4 with more than half having a rise-to-span ratio less than 1/5. For circular arches, the rise-to-span ratio of 1/5 corresponds to an included angle $\Theta = 87.21° < 90°$. It has been shown by Pi et al. [3–5] that arches with an included angle $\Theta \leq 90°$ are considered to be shallow arches. Shallow arches under transverse loading are subjected to significant transverse deformation and bending action prior to buckling. The classical in-plane elastic buckling load of arches, which does not consider significant transverse deformation and bending action prior to buckling, overestimates the buckling resistance of shallow arches although it can provide reasonably good prediction of the buckling resistance of deep arches [3–5]. Pi et al. [3] obtained the nonlinear in-plane buckling loads for shallow circular arches under a uniform radial load considering geometric nonlinearity, which can provide accurate predictions of the buckling resistance of shallow arches. It is known that the in-plane elastic buckling load is an important reference load in the formulation of in-plane strength design equations [7], and so an incorrect in-plane elastic buckling load may lead to incorrect in-plane strength predictions for CFST arches. Fourthly, because a number of CFST arches are slender and shallow, they resist general loading by combined non-uniform bending and axial compressive actions. The non-uniform distributions of the bending actions have to be considered in the formulation of the in-plane strength design equations. Current design methods based on the philosophy for the in-plane strength design of reinforced and prestressed concrete arch bridges do not appear to consider these important factors.