Thin-Walled Structures 130 (2018) 613–621

Contents lists available at ScienceDirect

Thin-Walled Structures

journal homepage: www.elsevier.com/locate/tws

Full length article

In-plane buckling and design of steel tubular truss arches

Chao Dou[a,b], Yu-Fei Guo[c], Zi-Qin Jiang[d,*], Wei Gao[e], Yong-Lin Pi[e]

[a] School of Civil Engineering, Beijing Jiaotong University, Beijing 100044, PR China
[b] Beijing's Key Laboratory of Structural Wind Engineering and Urban Wind Environment, Beijing 100044, PR China
[c] Department of Civil Engineering, Tsinghua University, Beijing 100084, PR China
[d] College of Architecture & Civil Engineering, Beijing University of Technology, Beijing 100124, PR China
[e] School of Civil and Environmental Engineering, University of New South Wales, Sydney, NSW 2052, Australia

ARTICLE INFO

Keywords:
Arch
Truss
Buckling
Normalized slenderness
Interactive

ABSTRACT

Studies on buckling of steel tubular truss arches are lacking in contrast to steel arches with solid web sections, although they have been widely applied in long-span structures. This paper deals with the in-plane elasto-plastic buckling and strength design of circular steel tubular truss arches with triangular sections by using finite element analyses (FEA). Firstly, the in-plane buckling failure modes are explored to reveal the buckling mechanics of truss arches. By introducing the normalized slenderness of the entire arch and the chord tube, as well as the interactive coefficient that accounts for the effect of chord tube buckling, the unified buckling curve for truss arches in uniform compression are obtained. Lastly, an interactive equation is proposed for in-plane buckling resistance of steel tubular truss arches under combined compressive and bending actions. It is found that, the buckling of diagonal web tubes greatly reduces the load-carrying capacity and deformation ability of truss arches hence should be prevented in design. The chord tube deformation always exists during the buckling failure of the truss arch and its effect on the buckling resistance is inevitable. The buckling curve *b* in the codes can used for truss arches in uniform compression, and the interactive equation can provide satisfactory lower bound predictions for truss arches under general loading.

1. Introduction

The curved profile and the end thrust provide an arch with high-efficient in-plane load-carrying capacity. For a steel arch with adequate lateral bracing, in-plane buckling is a key concern in design. Circular arches under general loading are subjected to combined axial compression and bending moment, whereas the axial compressive force especially the in-plane bending moment varies significantly along the arch axis. Thus compared to a beam-column, the buckling and design of an arch are more complicated.

Extensive studies have been conducted on in-plane buckling of steel arches, pertaining to elastic buckling [1–13] or elasto-plastic buckling resistance [14–22]. In inelastic buckling range, for an arch in uniform compression, it is analogous to an axially loaded column by adopting the effective length concept. The effective length factor can be obtained from the linear elastic buckling load with end restraints, arch axis shape and rise-to-span ratio taken into account. For an arch under combined compression and bending moment in general loading, the common approach is to establish a lower bound interaction equation for the in-plane buckling resistance. However, most of the investigations were focused on steel arches with solid web sections and only the global buckling resistance was considered, by assuming web and flange plates with adequate thickness avoiding local buckling. Compared with the solid web arches, due to the latticed configuration, steel tubular truss arches have two distinct features involving buckling: (1) Effect of sectional shear deformation is substantial for buckling. (2) Multiple buckling modes namely global buckling, chord tube buckling and web tube buckling may occur and the interactive effect of local and global buckling on the load-carrying capacity of arches is inevitable thus has to be evaluated.

For steel tubular truss arches, Dou et al. [23] derived equations for sectional rigidities of latticed configuration and the out-of-plane buckling loads of circular steel tubular truss arches in uniform compression and in uniform bending. Guo et al. [24] investigated the out-of-plane buckling resistance of truss arches, showing the load-carrying capacity of the arch is reduced by the local member buckling, and interaction equations for general loading against out-of-plane buckling failure were proposed. More recently, Huang et.al [25] experimentally investigated the flexural behavior of CFST trusses with interfacial imperfections. Halpern and Adriaenssens [26] explored the in-plane non-

* Corresponding author.
E-mail address: jzqbj2010@163.com (Z.-Q. Jiang).

https://doi.org/10.1016/j.tws.2018.06.024
Received 26 March 2018; Received in revised form 16 May 2018; Accepted 18 June 2018
Available online 04 July 2018
0263-8231/

Nomenclature

A	cross-sectional area of the arch
A_c	cross-sectional area of the chord tube
A_d	cross-sectional area of the diagonal web tube
b	width of cross-section
D_c	outer diameter of the chord tube
D_d	outer diameter of the diagonal web tube
E	modulus of elasticity
EI_x	flexural rigidity of cross–section
f	rise of an arch
f_y	yield stress of steel material
G	shear modulus of elasticity
h	height of cross-section
I_x	in-plane second moment of area of the cross-section
i_x	$=\sqrt{I_x/A}$, in-plane gyration radius of the cross-section
K_a	buckling coefficient for arches
K_v	sectional in-plane shear rigidity of a truss arch
L	span of an arch
l_c	length of the chord tube within a truss panel
l_d	length of a diagonal web tube
N_{acr0}	elastic bucking load of arches in uniform compression without considering shear deformation
N_{acr}	elastic bucking load of arches in uniform compression considering shear deformation
N_u	axial compressive force of cross–section corresponding to buckling resistance
N_{u0}	buckling compression force of truss arches without accounting for chord tube deformation
N_y	$=f_yA$, squash load of the cross-section
q	distributed load on the arch
q_{cr}	distributed load corresponding to elastic buckling of an arch
q_u	distributed load on the arch corresponding to buckling resistance
R	radius of an arch
S	half of the developed length of cross-sectional centroid axis
S_a	$= 2\ S$, full developed length of cross-sectional centroid axis
t_c	wall thickness of the chord tube
t_d	wall thickness of the diagonal web tube
W_x	in-plane section modulus of truss arches
Θ	subtended angle of an arch
β	included angle between two adjacent diagonal web tubes
η	interactive coefficient accounting for chord tube deformation
ϕ	included angle between the plane of diagonal web tubes and the vertical symmetric plane of the cross-section.
φ	reduction factor of truss arches accounting for chord tube deformation
φ_0	reduction factor of truss arches without accounting for chord tube deformation
λ_{cn}	normalized slenderness of the chord tube within a truss panel
λ_{gn}	normalized global slenderness of the truss arch
λ_x	$=S/(i_x)$, in-plane global slenderness of an arch
θ	included angle between the chord tube and the diagonal web tube

linear elastic buckling of shallow truss arches, by generating an equivalent arch model to predict the buckling behavior of shallow truss arches. Han et al. [27] conducted a shaking table test for steel truss arches and studied the failure mechanism of truss arches under earthquakes. It can be seen that, studies on in-plane buckling design of steel truss arches are lacking, although they are commonly adopted in practice.

This paper, therefore, is to deal with the in-plane buckling and design of two-hinged circular steel tubular truss arches with triangular latticed sections, by using finite element numerical approaches. Firstly, the interaction of member buckling and the global buckling of truss arches are explored and the in-plane buckling curve on global buckling is presented for arches in uniform compression, by considering the effects of shear deformation and the cord tube buckling. Then, truss arches in combined compression and bending moment under general loading are treated and an interactive equation predicting the buckling resistance is proposed.

As shown in Fig. 1, R is the radius of the arch and S is half of the developed length of cross-sectional centroid axis (full length $S_a = 2S$). The height and width of the triangular section dimensions are h and b respectively. f/L denotes the rise-to-span ratio where f and L are the rise and the span respectively. l_c is the length of the chord tube within a truss panel, θ is the included angle between the chord tube and the diagonal web tube and β is the included angle between two adjacent diagonal web tubes. The above geometric dimensions are all determined based on the sectional centroid axis.

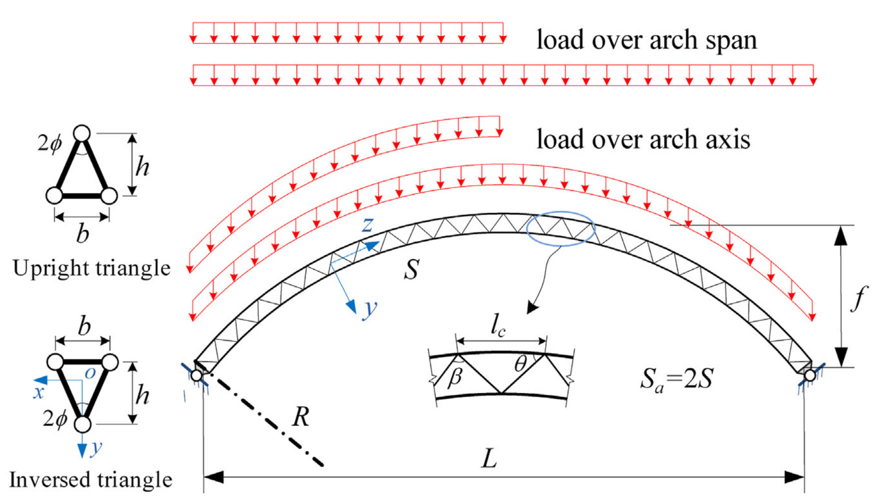

Fig. 1. Circular hinged steel truss arches with triangular sections.