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Elliptical hollow section steel cantilever beams under extremely low cycle fatigue flexural load – A finite element study

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ABSTRACT

A comprehensive non-linear finite element (FE) study carried out on elliptical hollow section (EHS) steel cantilever beams of 1740 mm^2 cross-sectional area and 1500 mm long under extremely low cycle fatigue (ELCF) uni-directional flexural load along major and minor axes separately is presented using the general FE package, Abaqus. The aspect ratio (major to minor axis diameter ratio), a/b and shell thickness, t of EHS beam models are varied between 1–2.33 and 4–6 mm respectively. The effect of a/b ratio and section slenderness on cyclic rotation capacity and flexural over-strength of the EHS FE beam models is investigated in this study. It is observed that the effect of a/b on rotation capacity under major axis bending is significant. Also, the cyclic flexural over-strength is not significantly affected by a/b ratio. New slenderness limits for circular hollow sections under bending are proposed. Modified slenderness parameters for EHSs under bending based on equivalent circular hollow section approach are derived. Empirical expressions for predicting cyclic rotation capacity and flexural over-strength of EHS beams are derived based on the FE study.

1. Introduction

Tubular shell construction is synonymous with modern architecture and widely used in the construction of airports, stadia, shopping malls, bridges, railway platforms, pylons, nuclear reactor components etc. Multifarious steel tubular members have evolved in the construction sector with a wide range of cross sectional shapes. In addition to the familiar range of hollow structural section (HSS) tubular family, namely circular, square, rectangular, oval hollow sections (see Fig. 1), the evolution of the construction sector in its endeavour to meet the demands of architects and design engineers has led to the latest inclusion of elliptical hollow sections (EHSs) due to their aesthetic appeal [2,3]. Tubular members are often used in designing seismic resistant steel moment frames because of their lighter weight and ability to resist lateral forces [4]. Unlike Square, rectangular and other polygonal hollow sections with sharp edges and flat faces, curved shell sections like circular, elliptical, oval sections etc. are known to offer higher torsional rigidity, corrosion resistance, lesser drag coefficients when exposed to wind or water forces and excellent strike load endurance in addition to the desirable tension and compression strengths (see e.g. [5,6]).

1.1. Elliptical steel hollow tubular sections

More than a century after their initial use by Brunel [7] in the Royal Albert bridge, UK, EHSs have emerged again in the market of the structural steel tubular member family and are now available as hot-rolled (HR) and cold-formed (CF) structural members with an aspect ratio (major to minor axis diameter ratios, a/b) of 2.0 [2,3]. Since its resurgence in 1994 in France, EHS offered an intriguing choice for engineers and architects to meet their design visions from an architectural perspective due to its aesthetic appeal [2,3]. EHSs are preferred over circular (CHSs) and rectangular hollow sections (RHSs) as they have the combined benefits of both CHSs and RHSs of same cross-sectional area, A or weight and wall thickness, t [8]. Usage of EHSs can result in an enhanced structural performance as they offer higher flexural resistance under eccentric loading due to their differing flexural rigidities about the two principal axes (allowing the sections to be oriented in a direction to efficiently resist the applied load) [8,9]. EHSs are also favoured over CHSs owing to their lesser curvature nearby the minor axis diameter, which makes their structural end connections much simpler at that location for the designer. Further benefits of EHSs over CHSs and RHSs include reduced visual intrusion and wind loading effect due to the smooth convex shape of their cross-section, when oriented in one predominant direction. Consequently, as structural members EHSs can be more economical than circular and rectangular

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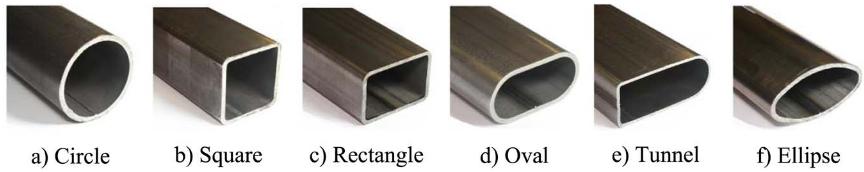

Fig. 1. Tubular hollow steel sections [1].

HSSs with more efficient use of the material in a number of primary structural configurations [8]. Some applications of EHSs include beams and columns (Fig. 2a), bracing members (Fig. 2b), arches in pedestrian bridges (Fig. 2c), handrails, wind turbine masts, electricity transmission line pylons etc. Extensive range of these applications in the construction industry reflects the vibrancy of EHSs and the link between their distinct geometrical features and contemporary design.

EHSs have a cross-sectional geometry of an ellipse with one larger outer diameter ($H = 2a$) and one smaller outer diameter ($B = 2b$) along major and minor axes of symmetry respectively as shown in Fig. 3. The sectional properties of EHS have been published in the European code, EN 10210-2 [13]. Few of these Eqs. have been investigated for their over-conservatism [3]. One of these over-conservative Eqs. is the cross-sectional area of steel formula, which is given in Eq. (1).

$$A = \frac{\pi}{4}[(2a \times 2b) - ((2a - 2t)(2b - 2t))] \tag{1}$$

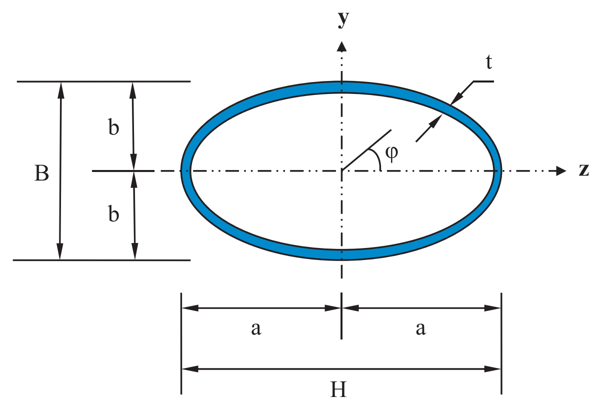

Fig. 3. Basic cross-sectional geometry of an EHS.

Fig. 2. Applications of EHS steel tubes as structural members [10,11].