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Design rules for out-of-plane stability of roller bent steel arches with FEM

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ABSTRACT

This paper describes a numerical investigation into the out-of-plane buckling behavior of freestanding roller bent steel arches. As roller bent arches have structural imperfections which differ considerably from those of hot-rolled or welded sections, specific attention is paid to their inclusion in the numerical model. Sensitivity analyses are performed to assess the influence of the imperfections due to roller bending on the out-of-plane buckling response. The accuracy of the finite element model is checked by comparing the results with earlier performed experiments as presented in a related paper. The finite element model is able to replicate the structural behavior displayed by the experiments with good accuracy. A database is created with elastic–plastic buckling loads for a large number of freestanding roller bent arches. The numerical data is analyzed and presented in a so-called imperfection parameter diagram from which imperfection parameter curves are derived. The imperfection parameter curves are substituted into the European column curve formulation, leaving the original column curve formulation unaffected but extending its applicability to the out-of-plane buckling response of roller bent arches. The column curve with proposed imperfection parameter expressions can be used to check the out-of-plane buckling response of a roller bent steel arch with known non-dimensional slenderness.

1. Introduction

The application of roller bent steel has seen a steady increase in the construction industry over the past decades. Ease of manufacturing make roller bending a suitable method for achieving curved structures. Roller bent steel is often applied in circular arch structures where its primary function lies in carrying the acting loads to the abutments. The loads are resisted by means of a combination of compression and bending, making the member susceptible to buckling. When local buckling is not considered, arch instability can be subdivided into three different categories: snap-through buckling (Fig. 1(a)), in-plane buckling (Fig. 1(b)) and out-of-plane buckling (Fig. 1(c)). The latter occurs when an arch has no lateral bracing and is considered ‘freestanding’. This paper presents a study of the structural performance of freestanding circular roller bent steel arches by means of the finite element method, for which out-of-plane buckling is the governing failure mode. The performance of the finite element model is verified through comparison with experimental results as reported in a related paper, La Poutré et al. [1].

1.1. Previous studies on out-of-plane arch buckling

The earliest theoretical studies on out-of-plane arch buckling only considered elastic buckling where material non-linearities and imperfections were ignored. Valuable contributions were published by Timoshenko and Gere [2] and Vlasov [3] who provided formulae to approximate the elastic out-of-plane buckling load of freestanding arches. Further refinements to calculation procedures for approximating the elastic buckling load were proposed by Vacharajittiphan and Trahair [4], Yoo [5] and Rajasekaran and Padmanabhan [6].

The necessity to include material non-linearities and imperfections to obtain an accurate representation of out-of-plane buckling behavior of arches was recognized in Japan by the end of the 1970s. Research studies included experiments conducted on arches with square hollow sections by Sakimoto et al. [7] and welded I-sections by Sakata and Sakimoto [8] supplemented with finite element analyses by Komatsu and Sakimoto [9], Sakimoto and Komatsu [10] and Sakimoto and Komatsu [11]. These Japanese research studies culminated in design rules. For the calculation of the slenderness, the arch was treated as a straight column under uniform compression with identical cross-section, where the arch length corresponded with the column length. Column curves were proposed by Sakimoto et al. [12] and Sakimoto and Sakata [13] to allow a check of the out-of-plane arch stability. Their applicability was limited to arches with square hollow sections and rise-to-span ratios between 0.1 and 0.2.

As the Japanese design provisions treated the out-of-plane arch buckling case identically to that of a column, the rise-to-span ratio

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