



Buckling resistance of HSS box section columns part I: Stochastic numerical study



B. Kövesdi *, B. Somodi

Budapest University of Technology and Economics, Department of Structural Engineering, Műegyetem rkp. 3, 1111 Budapest, Hungary

ARTICLE INFO

Article history:

Received 12 June 2017

Received in revised form 16 August 2017

Accepted 15 October 2017

Available online xxxx

Keywords:

Welded box section

High strength steel

Flexural buckling

Monte Carlo simulation

ABSTRACT

The accurate consideration of the flexural buckling resistance of high strength steel (HSS) structures is highly important in the design. Higher yield strength indicates the applicability of smaller cross-sections, which might be more sensitive for stability problems. The purpose of the current study is (1) to investigate the flexural buckling behaviour of HSS welded box section columns and (2) to determine a reliable column buckling curve. The characteristic and design values of the buckling resistances for HSS welded box section column are determined by using Monte Carlo simulation technique for a wide range of relative slenderness and steel grades. Based on the simulation results buckling curves are proposed for all the analysed steel grades. Required value for the partial safety factor is also determined considering the design resistance level of the Eurocode. The proposed buckling curves are applicable for HSS welded box section columns made from steel grades between S420–S960.

© 2017 Elsevier Ltd. All rights reserved.

1. Introduction

The application field of high strength steel (HSS–S420 and higher steel grades up to S960) is growing nowadays in the civil engineering praxis due to the numerous advantages of the HSS structures compared to the normal strength steel (NSS–S235, S275, S355) structures. The stability behaviour of HSS structures is highly important because slender sections can be designed due to the high yield strength. Application range of the EN 1993-1-1 [1] is limited to steel materials up to S460 grade. The EN 1993-1-12 [2] gives design background for materials up to S700 grade. However, the proposed column buckling curve for the determination of the column buckling resistance of welded box sections is the same in both standards. Numerous research results [3]–[8] show that the flexural buckling behaviour of HSS structures is more favourable than that of NSS structures. The reason of the differences is based on the different (i) material properties, (ii) geometric imperfections and (iii) residual stresses. Previous residual stress measurements show that the residual stresses compared to the yield strength are smaller for HSS structures [9]–[11], which indicates higher flexural buckling resistances. The general aim of the current research is to give a revised flexural buckling curve which might be used to determine the flexural buckling resistance of welded box section columns for S420–S960 steel grades.

The current flexural buckling curves given in the EN 1993-1-1 [1] are based on the Ayrton-Perry type formulation. They take the

effect of the residual stresses and the geometric imperfections as generalized imperfections into account. Thus the residual stress magnitude is not implemented directly in the analytical method, it cannot be applied for HSS structures in the same form. To solve this theoretical problem there are two possible solutions. The first solution could be the modification of the imperfection parameter of the current Eurocode based buckling curves depending on the steel grade. The second possibility is the implementation of the residual stresses and the effect of the yield strength into the principle of the Ayrton-Perry type formulation, which could result in a more precise column buckling curve prediction. The authors studied both solution strategies and the results regarding the modified imperfection amplitude is presented in the current paper. The improvements regarding the theoretically based column buckling curve are presented in [12].

Stochastic numerical analysis is carried out for welded HSS box section columns in order to determine the improved imperfection factor and to classify the analysed cross section type, into column buckling curves. The numerical model and the distribution of the variables are validated and determined based on self-made column buckling tests and measurements. Large experimental research program is carried out at the Budapest University of Technology and Economics. The results of these measurements are used in the current stochastic analysis. Numerous Monte Carlo simulations are executed to determine the mean and the characteristic values of the buckling resistance and the lower 2.3% quantile values are obtained in function of the global slenderness. The determined characteristic buckling curves are compared to the buckling curves of the EN1993-1-1 [1] and proposals are formulated to the applicable

* Corresponding author.

E-mail address: kovesdi.balazs@epito.bme.hu (B. Kövesdi).

flexural buckling curve for the steel grades of S420–S960. The objectives of the research program are achieved by the following research strategy:

1. literature review on the buckling behaviour of HSS welded box section columns,
2. experimental research program to determine the column buckling resistance,
3. numerical model development and verification,
4. stochastic numerical parametric study using Monte Carlo simulations,
5. determination of the characteristic buckling curves,
6. comparison of the results to the buckling curves of EN 1993-1-1 [1],
7. proposals for applicable flexural buckling curves.

2. Literature review

Several previous investigations show that the flexural buckling behaviour of HSS column is more favourable than of similar columns made from NSS. Fukumoto and Itoh [3] collected a total of 1665 individual column buckling test results. Test results are statistically evaluated and compared to the ECCS column buckling curves separately for all cross section types. Among the test specimens there were 316 box and square tubes manufactured from annealed NSS and HSS materials. The test results showed that HSS columns have definitely larger resistances (normalized by the yield strength) than NSS columns, nine of the annealed welded box section columns with HSS material would be allocated over the ECCS buckling **curve a**. Rasmussen and Hancock [4] performed flexural buckling tests on 13 welded box and I-section specimens made of S690 steel grade investigating the local and global buckling behaviour. The specimens are manufactured from BISALLOY80 steel material. From the 6 box section specimens two short (700 mm), two medium (1950 mm) and two long (3451 mm) specimens are investigated; analysing dominantly different global slenderness ranges. One specimen was loaded centrically, and one eccentrically from each slenderness group. The residual stress pattern of the test specimens was also measured and evaluated. The authors concluded that the European buckling **curve b** is conservative for the investigated columns especially at intermediate and large slenderness region, and buckling **curve a** is proposed for application. Ban et al. [5,6] investigated the flexural buckling behaviour of welded box section columns made from S460 and S960 material with a b/t ratio smaller than 30. The experimental research program contained 5 welded box section specimens made from S460 and 3 specimens made from S960 steel grades. Numerical model has been developed and verified based on the test results, in addition to the experiments. Large number of parametric studies were carried out to study elastic and inelastic buckling behaviour, and all the results are compared to the design buckling curves of the EN1993-1-1 [1]. The authors concluded that all of the calculation results are above the column buckling **curve c** what is proposed in the EN1993-1-1 [1] for this section type. The authors proposed the application of the buckling **curve b** for S460 and the buckling **curve a** for S960 steel grades. Wang et al. [7] investigated the buckling behaviour of centrically loaded welded box section columns made from S460 steel material. The experimental program included 6 centrically loaded welded box sections with pinned supports. Prior to the tests the initial out-of-straightness of the specimen and the end-eccentricities during the loading were measured and recorded. The residual stresses of all the test specimens are also measured using sectioning technique. The applied geometric imperfections used in the tests varied between 0.19 and 1.5 $L/1000$. The authors proposed the column buckling **curve b** instead of **curve c** for the flexural buckling resistance calculation of welded box section columns made from S460 steel material.

Based on the literature survey the following conclusion can be drawn. Box section columns made from HSS provides higher resistances than the columns having the same geometry made from NSS. These observations can lead to the application of higher buckling curves, however a

systematic comparison of different steel grades between S235 up to S960 is still missing from the literature. The previous investigations explained the obtained differences by the following three reasons:

- residual stresses of HSS members are smaller than of NSS members,
- geometric imperfection magnitude does not depend on the steel grade,
- different material properties (increased yield and ultimate strength, different stress–strain relationship).

Due to these differences improved column buckling curves are needed for HSS columns. There are two different ways for the evaluation of the column buckling curves. The first option is based on an experimental way performing real tests, or stochastic numerical simulations using residual stresses and geometric imperfections. Using this evaluation process the buckling curve representing the characteristic values can be determined by statistical evaluation of the obtained results. The second option is to carry out numerical simulations applying residual stresses and global initial geometric imperfection with amplitude of $L/1000$. This approach gives an excellent approximation of the characteristic value of the buckling reduction factor [13].

All the previous investigations used deterministic numerical analyses to explain the differences of HSS and NSS structures and to obtain design proposals for HSS columns. In the current investigation a stochastic numerical research program is carried out by using Monte Carlo simulation technique. Based on the current results buckling curves are proposed in order to provide more reliable flexural buckling resistance for welded box section columns.

3. Experimental research program

A total of 49 global column buckling tests are carried out at the Budapest University of Technology and Economics, Department of Structural Engineering between 2015 and 2016. A total of 18 different cross section geometries made from welded square box sections are investigated using 7 different steel grades (S235, S355, S420, S460, S500, S700 and S960). The experimental research program is unique in the field of the buckling behaviour of HSS columns, because the NSS and HSS columns are tested using the same loading and supporting conditions, the same testing rigs and manufacturing process. Same boundary conditions ensured the comparability of the buckling resistances and to evaluate their differences. During the test program the followings are measured on each specimens:

- residual stresses for each cross-section geometries,
- out-of-plane straightness (geometrical imperfections),
- material properties,
- loading eccentricities,
- load-displacement diagrams (load carrying capacities),
- stress distribution within the cross-section.

The specimens are tested using hinged support conditions. The test set-up is shown in Fig. 1. The failure mode of all the test specimens was flexural buckling failure eliminating the local plate buckling (class 1–3 sections).

Imperfection measurements are executed prior to the buckling tests. The results showed that the out-of-straightness imperfections varied between $L/10000$ – $L/1000$, and all the measured values were smaller than the manufacturing tolerance given by the Eurocode ($L/750$). Results proved, that the imperfection magnitude does not depend on the steel grade and the global slenderness. The measured flexural buckling resistances are plotted in Fig. 2, where χ_{test} is calculated by the measured geometries and material properties for each test specimen. The previous test results obtained on HSS members are also presented on the diagram. Based on the results of the extensive experimental program and on the connected numerical study the

Download English Version:

<https://daneshyari.com/en/article/6751193>

Download Persian Version:

<https://daneshyari.com/article/6751193>

[Daneshyari.com](https://daneshyari.com)