Journal of Constructional Steel Research 96 (2014) 1–13

Contents lists available at ScienceDirect

Journal of Constructional Steel Research

Local buckling of cold-formed elements used in arched building with geometrical imperfections

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ARTICLE INFO

Article history:
Received 2 July 2013
Accepted 5 January 2014
Available online 31 January 2014

Keywords:
Buckling
Post-buckling
Cold-formed elements
Geometric imperfections
Double corrugated

ABSTRACT

This paper describes the influence of surface transverse geometric imperfections called corrugations on the local stability of cold-formed elements. Such elements are used to construct self-supported arch buildings and roofs. The authors of the paper compare the results obtained from analytical investigation based on Eurocode 3 formulas, from linear and nonlinear numerical stability analyses and experimental investigation. Two types of thin-walled elements are considered: a panel with smooth walls and panels with corrugations on their surfaces. Finally the conclusions are made which can be useful for design purposes.

1. Introduction

Due to today's difficult economy, cheap and short time consuming solutions for the building industry are very desirable. One of the solutions which fulfil the above requirements is the ABM (Automatic Building Machine) technology. It is a mobile factory used to fabricate and construct K-span arch steel buildings based on self-supporting panels made of MIC 120 and MIC 240 profiles. This technology comes from the USA and belongs to the M.I.C. Industries Inc. [1]. Such technology is commonly used by the U.S. Army to build temporary buildings and nowadays these structures become a popular solution in civilian life all over the world.

In Fig. 1 cross-sections of MIC 120 and 240 profiles are presented. Herein only the MIC 120 profile is considered for scientific investigation.

The ABM technology consists of a movable, steel building manufacturing plant, known as the MIC 120 System. This machine is placed on a trailer, forming factory on wheels which can be easily transported to any construction sites (see Fig. 2).

Once, the machine is delivered to the site, the construction process can be started by a small group of trained crew. Firstly, a coil of steel is formed to the straight panel of a channel cross-section. This panel is cut to achieve the needed span of the future arch building. Secondly, this panel is bent to form the arch and its shape changes due to surface corrugations—this element is called a corrugated or a curved panel. Both shapes are shown in Fig. 3 and it can be observed that these panels consist of the main corrugation—obtained during formation of cross-section at stage 1, and a secondary corrugation—folded surfaces achieved from a panel bend into an arch at stage 2. This is the reason for using the term “doubly corrugated” steel arch panel. Such terminology has been also used by Mang in [2].

After a few single panels are tightened together by the seam machine, they are fixed to the lifting sling and transported to the execution place by a crane (see Fig. 4). These groups of panels are seamed together to form an economical and waterproof steel structure. Ready K-Span, arch steel roof made in this technology is presented in Fig. 5.

The precise process of construction of ABM arch steel roofs and buildings is described in Refs. [3] and [4].

In Europe, especially in the Czech Republic, Poland and Slovakia, these self-supported arch buildings are designed and calculated according to Eurocodes 3 [5–7]. This is true for the straight panel which is assumed to be of Class 4 in which local buckling will occur before the attainment of yield stress. In such cross-sections effective widths may be used to make the necessary allowances for reductions in resistance due to the effects of local buckling. The calculation procedures for corrugated panels should be different. Authors of this paper have observed that in many projects, corrugation on the panel's surface is neglected by engineers during calculation procedures. This leads to the significant overestimation of the panel's ultimate load which in the worst scenario, can cause a failure of doubly corrugated structure like this one presented in Fig. 6. It must be stated that European design standards do not give a procedure for elements with transverse imperfection such as corrugations.

From the building failure presented in Fig. 6, it has been observed that the key factor for understanding such collapses lies in the local behaviour of neighbouring single corrugations. A few days before this failure, some photos of this structure had been taken, focussing on the

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0143-974X/$ – see front matter
http://dx.doi.org/10.1016/j.jcsr.2014.01.004

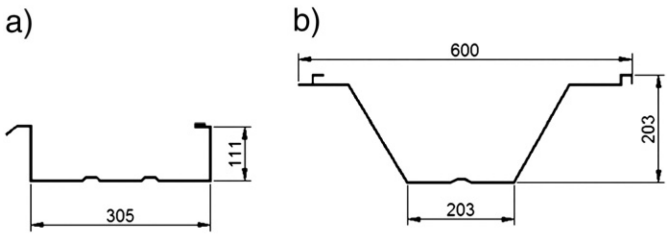

Fig. 1. Cross-sections of the ABM profiles a) MIC 120, b) MIC 240.

top part of the arch. In Fig. 7 it is clearly shown that instability which caused the warehouse's collapse had a local character—the only question that matters is why nobody had been trying to prevent this failure?

In order to understand the corrugated panel's local stability behaviour, the research project "Stability of doubly corrugated thin-walled structures" has been established which is financed by the Polish National Science Centre. Based on this research, it is possible to propose the calculation procedure of an effective cross-section area for corrugated panels under axial compression load. This paper compares different methods (analytical, numerical, and experimental) for axial compression ultimate load calculations and can be seen as a warning for engineers from often thoughtless use of any design standards. So far it can be stated that no research has been conducted about doubly corrugated cold-formed elements in order to compare the analytical, numerical and experimental results. In Ref. [8] the author focusses only on compression tests of samples without any comparison, author Wu in [9] compares experimental and numerical ultimate loads for compressed samples but the accuracy of results is very low. In Ref. [10] written by Sweeney, advanced laboratory tests on doubly corrugated panels were conducted but no result comparison was discussed.

In order to conduct an expensive experimental investigation of ABM panels (laboratory tests under axial compression) full understanding of local buckling behaviour is needed. This can be ensured by the very precise numerical buckling and post-buckling analyses conducted in Abaqus FEM system. Three different types of analyses are used: linear buckling analysis [11] based on eigenvalue problem, Riks Method [12] analysis based on arc length iteration method, and Automatic Stabilization [13] analysis based both on the Newton–Raphson iteration method and on the artificial mass proportional damping.

2. Analytical solutions

The analytical solution for the ultimate load of straight and corrugated panels is based on Eurocode 3 Part 1-5 [7]. Due to future experimental investigation of both types of panels, where local stability will be examined, distortional buckling is neglected. So the use of Eurocode 3 Part 1-3 [6] for cold-formed elements is omitted and only cross-sections of effective widths will be used to make the necessary allowances for reductions in resistance due to the effects of local buckling.

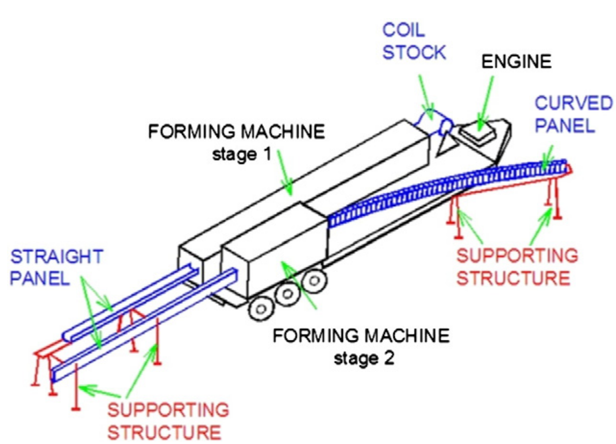

Fig. 2. Prefabrication machine.

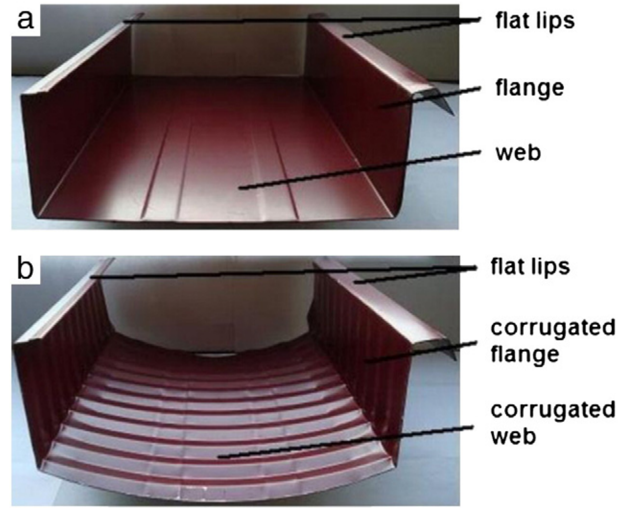

Fig. 3. ABM panels a) straight, b) corrugated.

Material properties of both types of steel panels are as follows: Young Modulus $E = 203.3$ GPa, Poisson ratio $\nu = 0.3$, yield strength $f_y = 355.9$ MPa. E and f_y are obtained from tension material test which will be shortly discussed in further sections.

2.1. Straight panel

So in the first step let us consider the cross-section of a straight panel shown in Fig. 8. Based on Eurocode 3 Part 1-1 [5] all the cross-section's elements are of Class 4. So the cross-section of a straight ABM panel is of Class 4. According to the definition given in Ref. [5] "Class 4 cross-section are those in which local buckling will occur before the attainment of yield stress in one or more parts of the cross-section." The effective area of the cross-section can be used in order to reduce resistance due to the effects of local buckling and a post-buckling investigation is needed.

The lengths of the straight panel samples are limited due to the hydraulic press clearance which will be used in future compression tests. So the effective length of each sample which is measured between the clamps is equal to 540 mm.

Fig. 4. Group of panels.