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Effect of Load Eccentticity on Buckling of Short Composite Profiles

Paweł Wysmulski

Department of Machine Design and Mechatronics Faculty of Mechanical Engineering Lublin University of Technology Nadbystrzycka 36, 20-618 Lublin, Poland p.wysmulski@pollub.pl

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The object of the study was a short profile with a C-shaped section, made of a carbonepoxy composite. The column is a structure consisting of thin-walled flat plates joined on longer edges. The analysed C-section was subjected to eccentric pressure shifted from the cross-section centre of mass. The boundary conditions assumed for the study ensured the appropriate support of the end sections of the profile. The conducted analysis allowed for the evaluation of the effects of eccentricity on the value of the critical force of the structure. The scope of the study included both experimental research conducted on a physical model of the structure and numerical analysis by the finite element method using Abaqus software. The conducted numerical analysis included the solution of the eigenvalue problem of structure's stability. On the basis of the example analysed below, it was possible to determine the effect of the eccentricity of load on the behaviour of the thin-walled composite column.

Keywords: FEM, buckling, eccentricity load, thin-walled structures, composite.

1. Introduction

Thin-walled constructions belong to a group of falsework/load carrying structures that are characterized by high rigidity and strength compared to their specific weight. Owing to these properties these structures are widely used in many technologically advanced aerospace and automotive designs. Thin-walled profiles with complex cross section shapes are predominantly applicable in such projects as they are effectively used as the stiffening elements for the structures' sheathing. One important disadvantage of such load carrying structures is the possibility of stability loss even under operational load [1–3]. In case of a local and elastic buckling of the element, the structure does not become damaged, and the element construction element may be safely utilized even in the post-critical state. [2, 4]. Given the above, the knowledge of the specific data pertaining the critical load at stability loss of a thin-walled structure is an essential for the structure's operation. Yet another difficulty arises from the fact that experimental methods used for determining the critical load of thin-walled structures are not unequivocal which is a factor that additionally complicates the process of well-balanced designing of such structures. An alternative tool allowing for the determination of critical load value is the numerical analysis by finite element method [2, 5–7]. The critical load value is determined using linear eigenproblem analysis based on the minimum potential energy of the system. In such cases, the numerically established value of the critical force ought to be a preliminary assessment of the obtained value due to the fact that the abovementioned calculations are performed for an ideal structure without taking into account various kinds of defects which may occur in real structures. The nature of the occurring imperfections may be as following: geometrical, pertaining to boundary conditions, irregular compression, all of which have significant effect on the behaviour of the real structures. It means that numerical models created for these kinds of constructions, often with complex cross section shapes should be validated in experimental tests. Such a procedure facilitates the development of adequate discrete models which in turn allows for the analysis of complex problems of thin-walled structures' stability [3, 8-10].

The development of engineering techniques as well as the increasing industrial requirements have created the need for designing thin-walled load carrying elements with improved physical properties. Currently, it has become desirable to decrease the total weight of the structure while maintaining its high mechanical properties. The research conducted on advanced orthotropic materials reveal that laminate based load carrying structures are particularly efficient. An important characteristic of multilayer composites is their high durability/ strength to weight ratio. Yet another advantage of these materials is the possibility of shaping their mechanical properties by arranging the laminate layers in a desired configuration in the design stage. As a result, materials of this kind became the object of may extensive studies [2–3, 8–9, 11–12]. There is a considerable number of studies that analyse the behaviour of laminates subjected to axial compression [1, 3, 9]. These papers present the results of analyses conducted for ideal load conditions which usually do not occur in real structures.

The purpose of this study was to assess the effect of load eccentricity on the critical behaviour of composite profile under compression. The object of the study was a thin-walled channel cross section profile made of multilayer carbon-epoxy composite. The study involved both experimental and numerical investigation.

2. Object of study

The object of the study was a thin-walled channel-section profile subjected to eccentric compression. The analysed element is a typical thin-walled structure, consisting of perpendicular walls in the form of flat plates which are joined on longer edges. The channel section was manufactured by the autoclave technique and it was made of multilayer carbon-epoxy composite denoted as M12/35%/UD134/AS7/143. The composite lay-up consists of 8 layers in a symmetric arrangement relative to the central plane described by the configuration $[45/-45/90/0/0/90/-45/45]_T$.



Figure 1 The model of the channel-section profile with its geometric dimensions and the eccentricity direction

The dimensions of the channel-section profile and the direction of measurement of the eccentric load marked by e symbol are shown in Fig. 1.

The Figure 1 shows a model of the compressed channel-section and the value of eccentric compressive load e presenting the eccentricity direction. This parameter was determined by changing the displacement of the compression force relative to the axis of the column in the direction of greater stiffness of the cross-section. The mechanical properties of the channel-section's material were determined in experimental tests according to the relevant ISO standard are as follows: Young's modulus according to the fibres' arrangement $E_1 = 130710$ MPa, elasticity modulus perpendicularly to the fibres' direction $E_2 = 6360$ MPa, Poisson's ratio in the plane of the layer $\nu_{12} = 0, 32$ and the Kirchoff's modulus $G_{12} = G_{23} = G_{13} = 4180$ MPa.

3. Methodology of the research

3.1. Experimental research

The experimental tests performed on a real thin-walled composite profile were conducted under axial compression e = 0 mm and in two variants of eccentricity of load: e = 10 mm and e = 20 mm. The experiments were performed using Zwick-100 testing machine in room temperature at a constant speed of the upper cross beam set to 2 mm/min. Special rubber pads were provided in order to guarantee appropriate support for the end sections of the profile. Moreover, the assessment of the eccentric load during experimental tests was conducted with the use of pads allowing for the appropriate alignment of the end sections of the profile in the testing machine relative to their axis. Special soft polymer pads were used to ensure even load of the end sections of the specimen during compression tests.

Resistance strain gauges were attached to the real channel-section structure on both sides of the web in areas where the most significant buckling was expected to occur. Fig. 2 shows the real profile specimen during experimental tests.

The conducted experimental tests do not allow to directly determine the critical load value. Results obtained in the experiment included the characteristics of the

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strain value (strain gauges) in the function of compressive force variations. In this case it is necessary to use the approximation method, allowing for the assessment of the critical force value basing on the results obtained in the experimental tests. In order to assess the value of the critical force, Koiter's approximation method was used in this study [3, 9].



Figure 2 The physical sample of the channel-section profile mounted in the testing machine with eccentricity value e = 10 mm

3.2. Numerical analysis

The numerical model of the structure was created using SHELL elements having 3 translational and 3 rotational degrees of freedom in each node of the element. 8-node S8R elements were used described by a second-order shape function and reduced integration. Boundary conditions were assumed in order to reflect the articulated support of the end sections of the profile. A discrete model with the applied boundary conditions and the load is shown in Fig. 3.

In order to numerically determine the critical load value it was necessary to solve a linear eigenproblem based on the minimum potential energy of the system. Determining the mode of stability loss of the structure corresponding to the lowest critical load was also one of the study results.



Figure 3 The discrete model of the channel-section with load eccentricity value e = 20 mm

4. Results

The experiments conducted on the eccentrically compressed short thin-walled channelsection profile provided essential information enabling the assessment of the effects of shifting of the compressive force on the value of the critical load and on the modes of deformation of the real specimen. Obtained experimental results allowed for the validation of the developed numerical models of the structure, allowing for performing a qualitative and quantitative analyses of the critical states of studied composite profiles. The experimental and numerical modes of deformation corresponding to the buckling of the channel-section for three variants of compression.

The loss of stability in all of the studied specimens manifested itself as a local buckling on the walls and on the web of the channel-section profile. When axial compression was applied, two identical half-waves were created lengthwise the column, on the walls and on the web of the channel-section profile (Fig. 4a, b). Applying eccentric compression in the direction of the greater rigidity of the profile e = 10 mm (Fig. 4c, d) and e = 20 mm (Fig. 4e, f) significantly changed the modes of deformation of the structure. In these cases an asymmetric mode of profile walls deformation was observed, manifesting itself as local buckling, in the shape of two half-waves, exclusively on the wall towards which the load eccentricity value was applied. The opposite wall of the channel-section did not buckle, whereas the buckling of the web of the channel-section profile manifested itself as one half-wave in the lower part of the profile.

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Figure 4 Loss of stability of the channel-section profile: a, b) axial compression, c, d) eccentricity value e = 10 mm, e, f) eccentricity value e = 20 mm

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Obtained results confirm the qualitative effect of the eccentric load compression in the direction of the greater rigidity of the profile on the mode of stability loss of the structure. Both experimentally and numerically determined values of the critical load corresponding to the shown in Fig. 4 lowest modes of stability loss of the structure were juxtaposed in Fig. 5. Obtained results confirm the significant effect of the value of the eccentric compressive load e on the value of the lowest critical force. A considerable decrease of the critical load value was observed when increasing the load eccentricity value. In the study, the difference between axial compression and eccentricity value e = 10 mm was 23%, whereas in the case of eccentricity load value e = 20 mm the difference was approx. 39%.



Figure 5 The effect of the eccentricity load on the critical load value

5. Conclusions

This study investigated the behaviour of a short, thin-walled channel-section profile subjected to axial and eccentric compressive load. Conducted research confirmed high sensitivity of the studied thin-walled structures on the eccentricity load value e. Obtained results confirm both qualitative and quantitative effect of the eccentricity of compression on the buckling mode and critical load value. It was demonstrated that as the eccentricity load value e increases in the direction of the greater rigidity of the profile, the strength of the structure decreases significantly, and the structure buckles in substantially lower critical load values. What is more, the structure's mode of operation changes significantly, as with the increase of the eccentricity load value its buckling asymmetry also increases.

The results yielded in experimental tests and numerical computations by the finite element method show high agreement. In all of the studied specimens (real structures and numerical) identical buckling modes appeared. Qualitative verification of the experimentally and numerically determined critical load values show high agreement of the received results – maximum differences in critical force values obtained for the e = 20 mm eccentricity load variant was lower than 6%. High qualitative and quantitative agreement of the experimental tests and numerical computations confirms the adequacy of the developed FEM models for the analysed thin-walled composite structure.

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