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STABILITY AND LOAD BEARING CAPACITY OF A BARS WITH BUILT UP CROSS SECTION AND ELASTIC SUPPORTS

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Abstract

The present paper is devoted to the numerical analysis and experimental tests of compressed bars with built–up cross section which are commonly used as a top chord of the roof trusses. The significant impact on carrying capacity for that kind of elements in case of out-of-plane buckling is appropriate choice of battens which are used to provide interaction between separate members. Linear buckling analysis results and nonlinear static analysis results, with material and geometrical nonlinearity, are presented for the bar with built-up cross section which was used as the top chord of the truss made in reality. Diagonals and verticals which are supports for the top chord between marginal joints were replaced by the elastic supports. The threshold stiffness (minimum stiffness) for the intermediate elastic supports which ensures maximum buckling load was appointed for the beam and shell model of the structure. The magnitude of limit load depended on length of the battens was calculated for models with initial geometric imperfections. The experimental tests results for the axially compressed bars with built-up cross section and elastic support are presented.

Keywords: built-up cross section, batten, buckling load, limit load, support stiffness

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1. INTRODUCTION

Structural elements such as chords of the roof trusses are often made as bars with built-up cross section. Compressed top chords of the trusses buckles in the truss plane between diagonals or out-of-plane between braced joints (if the braces are rigid). Appropriate choice of battens which are used to provide interaction between separate components of the bars with built-up cross section has significant influence on load bearing capacity of the structure.

The main purpose of the present paper are stability and load bearing capacity analysis for the part of top chord of the truss made in reality and described in [4]. It was assumed that distance between the side braces of the truss was equal to 4,8 m and it was a base for the length of the analyzed bar. Verticals and diagonals which are supports for the top chord between marginal joints were replaced by the elastic supports. The influence of battens length on load bearing capacity of the bar was considered.

Stability analysis of the truss with battened top chord cross section were presented in paper [7]. Similar numerical analysis and experimental tests of the compressed bars with built-up cross section were the subject of papers [3], [5]. [6] and the instructions for design are present at code [8].

2. DESCRIPTION OF THE ANALYZED STRUCTURES

Numerical analyses were performed for the bar consisted of two profiles L90×90×9 (S235). Battens made of C65 profile were situated between the angles walls (with distance equal to 0,4 m). Total length of the bar was equal to 4,8 m (Fig. 1a). It was assumed that the structure was pinned on the marginal supports and the intermediate elastic supports with nominal stiffness „*k*” [kN/m] were modeled (with distance equal to 1,2 m). The torsion was blocked on every of the supports. In each part of the bar between the supports two battens were situated and the length of the battens was changeable from 5 cm to 25 cm.

The beam model of the structure was made using standard 1D elements with 6 degrees of freedom at node. Analyses for single beam model (both angle bars modeled by one element) were performed in program [1]. In program [2] each angle bar was modeled separately (double beam model) and rigid elements were used as battens. The bar was divided in 40 parts along length. Shell model (Fig. 1b) was made in program [2]. About 4000 elements type QUAD4 were used and the size of the element was about 20×20 mm^2.

Experimental test were carried out for the bar consisted of two angles L20×20×3 (S235) and the length was equal to 1,3 m. One elastic support placed in the middle of the span was used. Battens were welded between the walls of angles. Length of the battens was 2,0 cm or 4,0 cm and the cross section was C-profile: 1,5 cm (web) × 1,0 cm (ledges), thickness 0,15 cm. The distance between battens was equal to 21,5 cm.

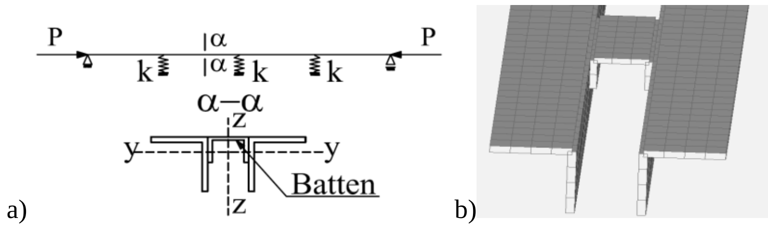


Fig. 1. Bar with the built-up cross section: a) static schema, b) shell model

3. NUMERICAL ANALYSIS RESULTS

For the axially compressed bars linear buckling analysis (LBA) and nonlinear static analysis with geometric and material nonlinearity (GMNA) were carried out (for beam and shell models).

The LBA analysis results showed that there is threshold stiffness for elastic supports necessary to obtain maximum buckling load (Fig. 2). The threshold stiffness was equal *k* = 650 kN/m for the single beam model or *k* = 550 kN/m for the double beam model (1D elements) and the differences between magnitudes of buckling load were about 1%. For the shell model of the structure the threshold stiffness was depended on battens length and was equal to *k* = 320 kN/m (for battens length 5 cm) or *k* = 430 kN/m (for battens length 25 cm). In this case the differences between the magnitudes of buckling load were up to 20%. For that stiffness of elastic supports the compressed bar buckled out-of-plane (in plane perpendicular to the *z-z* axis).

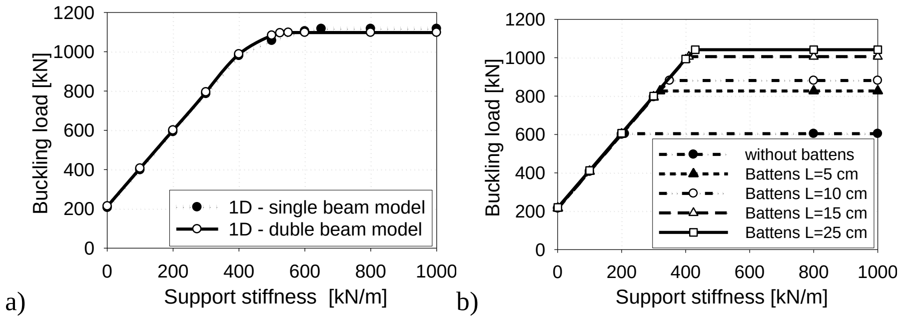
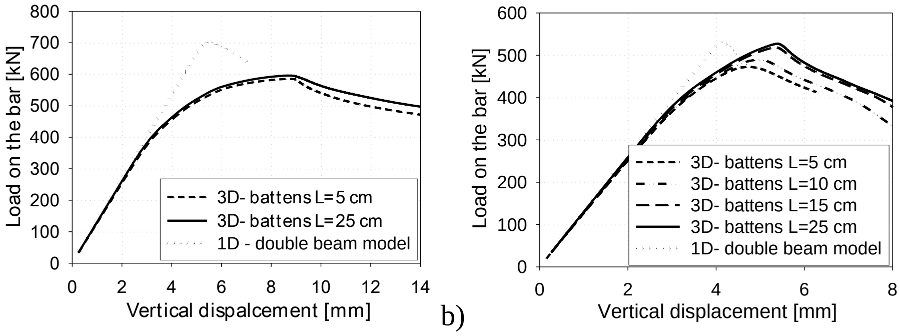


Fig. 2. The relation between the first buckling load for the bar with respect to the supports stiffness: a) beam model, b) shell model

The non-linear static analyses with geometrical and material nonlinearity were performed for the imperfect double beam model and shell model of the structure. The initial geometrical imperfection shape in form of arch with magnitude L/500 [8] was implemented. The in-plane (Imperfection I - deformation perpendicular to the *y-y* axis) and out-of-plane (Imperfection II - deformation perpendicular to the *z-z* axis) imperfections were considered. The relation between loading and vertical displacements (measured at loaded point) for support stiffness equal to k = 1000 kN/m is presented in (Fig. 3). The differences between limit loads (depended on the length of the battens) for shell models with imperf. I were about 2 % and with imperf. II were up to 10 %.



a) b)

Fig. 3. The bar loading vs. vertical displacement (measured at the loaded point) for beam and shell model with: a) imperfection I (shape of imperfection - deformation perpendicular to *y-y* axis), b) imperfection II (shape of imperfection - deformation perpendicular to *z-z* axis)

The relation between limit load (magnitude of maximum loading) with respect to the support stiffness is presented in (Fig. 4) for the shell model of the bar and (Fig. 5) for the beam model. The threshold stiffness of elastic supports was depended on initial geometrical imperfection shape and it was about two times larger in case of structure with imperf. I than imperf. II. The limit load for the shell model with imperf. II was higher for the support stiffness k = 250 kN/m than for k = 1000 kN/m (battens L = 25 cm). The possible explanation might be different shape of deformation at the limit state. The bar was deformed in-plane and out-of-plane for the lower stiffness of support and only out-of-plane for the higher stiffness.
The dispersions between magnitude of limit load for the beam and shell model might be caused by differences in connection stiffness between separate members of the bar (influence of battens stiffness in 1D and 3D model). The deformation of the structure (support stiffness k = 1000 kN/m) at the limit state is presented in (Fig. 6).

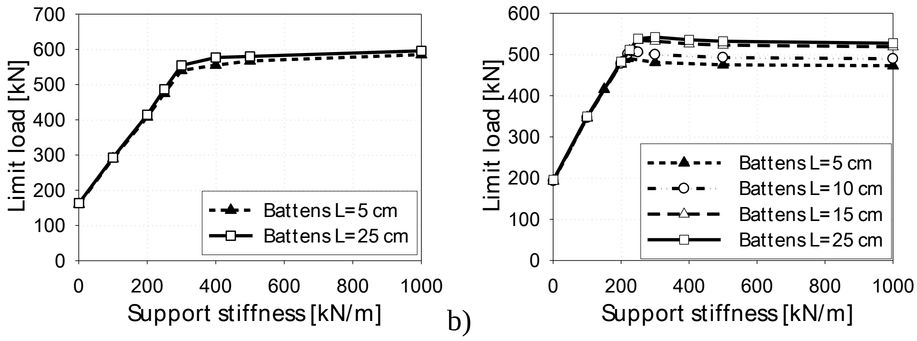


Fig. 4. The relation between the limit load for the shell model of the bar with respect to the supports stiffness: a) model with imperfection I (shape of imperfection - deformation perpendicular to *y-y* axis), b) model with imperfection II (shape of imperfection - deformation perpendicular to *z-z* axis)

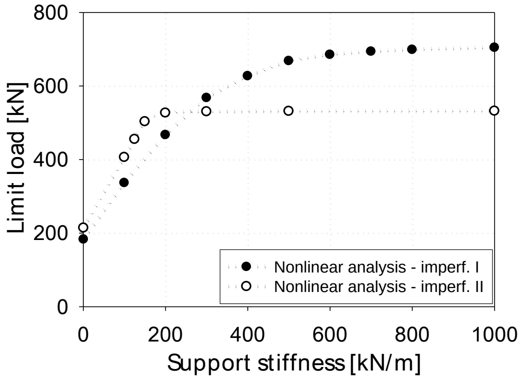
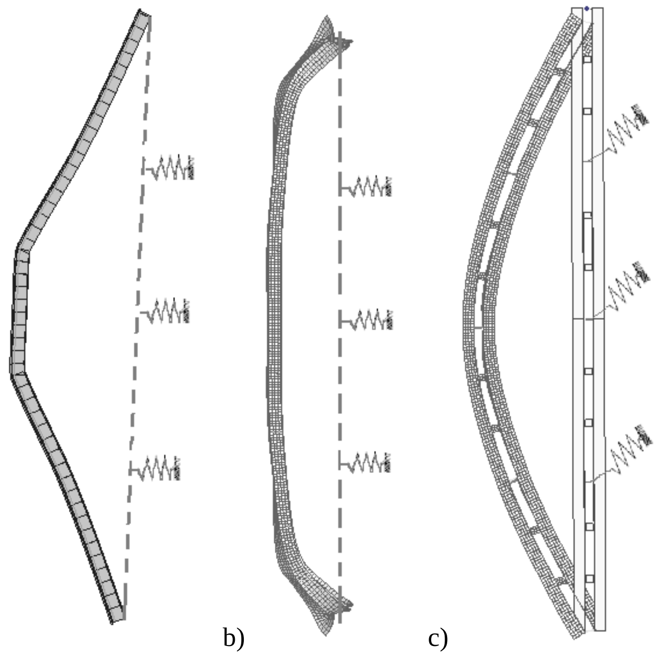


Fig. 5. The relation between the limit load for the beam model of the bar with respect to the supports stiffness (imperfection I - initial deformation perpendicular to *y-y* axis, imperfection II - initial deformation perpendicular to *z-z* axis)

4. THE BAR BEARING CAPACITY ACCORDING TO EC3

According to the code [8] point 6.3 and 6.4 the maximum magnitude of loading for the analyzed structure was calculated in the case of buckling out-of-plane (deformation perpendicular to *z-z* axis). The results are presented in (Table. 1). The loading magnitude was depended on battens length and the differences were up to 5 %. The shear stiffness for bar with battens length equal to 25 cm, was calculated as for the structure with shear stiffness determined from second order theory without battens compliance, according to relation no.

6.73 [8]. It was assumed that buckling length was equal to distance between battens (L_{cr} = 0,4 m). The calculated buckling factor was constant $\chi = 1$.



a) b) c)

Fig. 6. Deformation of the bar at the limit state for supports stiffness *k* = 1000 kN/m: a) beam model and imperfection I - initial deformation perpendicular to *y-y*, b) shell model and imperfection I - initial deformation perpendicular to *y-y*, c) shell model and imperfection II - initial deformation perpendicular to *z-z*

Table 1. Maximum loading for the bar (according to EC3) for the condition $N_{ch,Ed} / N_{b,Rd} = 1$

Battens length [cm]	5	10	15	25
S_v [kN]	5325	21090	30020	30050
P_{max} [kN]	549,5	567,5	569	569,2

5. EXPERIMENTAL TEST RESULTS

Experimental tests for axially compressed bar were conducted on strength testing machine Zwick Roell Z400 (Fig. 7a). Elastic support in the form of spring with stiffness *k* = 10 kN/m or *k* = 80 kN/m (Fig. 7b) was used.

Numerical analysis results (LBA and GMNA -shell models) for the tested structure are presented in (Fig. 8). The threshold support stiffness (necessary to obtain maximum buckling load) was equal to k = 35 kN/m for the bar with battens length L = 2,0 cm and k = 77 kN/m for battens length L = 4,0 cm. Based on nonlinear static analysis results the threshold stiffness for structure with geometric imperf. I (initial arch deformation perpendicular to *z-z* axis) was about k = 500 kN/m and did not depend on battens length. In case of bar model with imperf. II threshold stiffness was equal to: k = 40 kN/m for battens length L = 2,0 cm and k = 60 kN/m for battens length L = 4,0 cm.

During experimental test it was observed that each deformation (leading horizontal displacements) of loaded bar increased in-plane (deformation perpendicular to *y-y* axis). The comparison between numerical analysis and experimental tests results is presented in (Fig. 9). The reason for large discrepancies between vertical displacements for loaded bar could be the backlash at contact joints between tested structure and handles of the testing machine. Actual and assumed imperfection shape may be the reason of differences between magnitudes of limit loads (up to 7 %) obtained from numerical and experimental test results.

a) b)

Fig. 7. Experimental set-up of the bar: a) front view of the structure placed at the strength testing machine Zwick Roell Z400, b) details at the supports

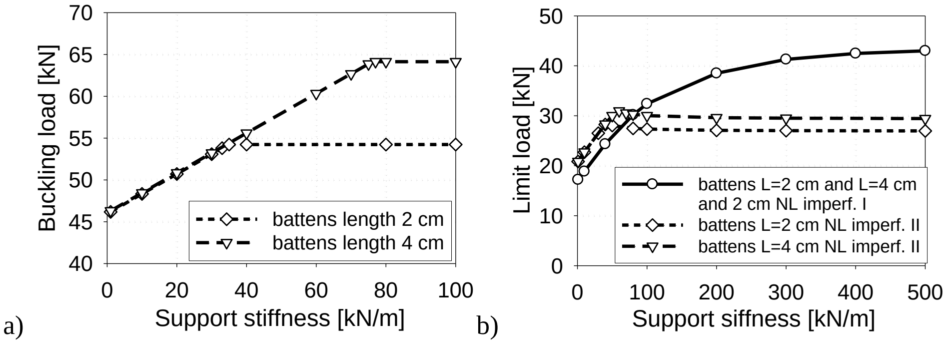


Fig. 8. The relation between: a) buckling load, b) limit load - with respect to the support stiffness, for the shell model of the structure tested experimentally

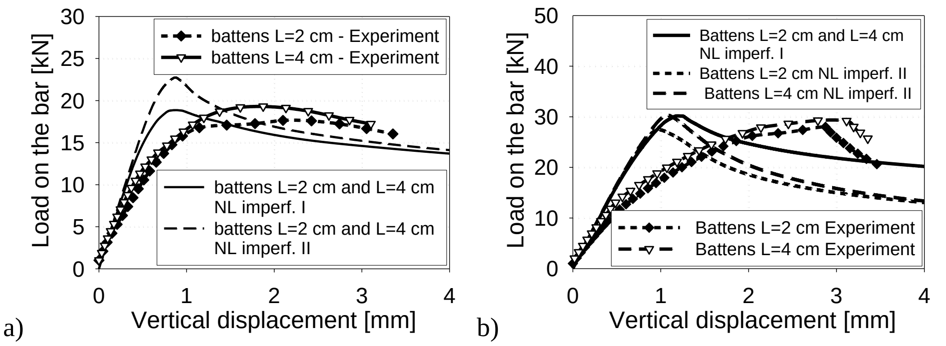


Fig. 9. The bar loading vs. vertical displacement (measured at the loaded point) for shell model and support stiffness: a) k = 10 kN/m, b) k = 80 kN/m. (Imperf. I - deformation perpendicular to y-y axis, Imperf. II – initial deformation perpendicular to z-z axis)

6. SUMMARY

Presented results obtained from LBA analysis for bars with built-up cross section confirmed that there is threshold stiffness of elastic supports necessary to obtain maximum buckling load. Above that stiffness magnitude the structure buckled out-of-plane. In this case the differences between the magnitudes of buckling load for analyzed bars (depended on battens length) were up to 20%.

Results obtained from nonlinear analysis for the structure with rigid intermediate supports showed that carrying capacity of the bar with geometric imperfection II (out-of-plane initial deformation) was depended on battens length and the differences between limit loads were up to 10 %.

In order to determine load bearing capacity for the bar with built-up cross section according to [8] the shear stiffness was calculated. The magnitude of that stiffness (depended on battens length) has significant influence on small differences between magnitudes of maximum bar loading (up to 5%).
The reason for differences between magnitude of maximum bar loading determined from numerical analysis and experimental tests (about 7 %) might be the geometric imperfections of the structure which were assumed in theoretical research and not measured from reality.

REFERENCES

1. *Autodesk Robot Structural Analysis Professional*, Autodesk Inc. 2010.
2. *Femap with NX Nastran*, Version 10.1.1, Siemens Product Lifecyde Management Software Inc. 2009.
3. Hosseini Hashemi B., Jafari M.A.: *Experimental evaluation of elastic critical load in batten columns*, Journal of Constructional Steel Research, 65, 2, (2009) 125-131.
4. Iwicki P.: *Sensitivity analysis of critical forces of trusses with side bracing*, Journal of Constructional Steel Research, 66, (2010) 923-930.
5. Krajewski M., Iwicki P.: *Badanie wpływu przewiązek na stateczność prętów* złożonych, II Kongres Mechaniki Polskiej, Poznań, Wyd. elektroniczne Politechnika Poznańska 2011.
6. Krajewski M.: *Badania nośności aluminiowego pręta o przekroju złożonym,* LVIII Konferencja Komitetu Inżynierii Lądowej i Wodnej PAN i Komitetu Nauki PZITB, Krynica, Zeszyty Naukowe Politechniki Rzeszowskiej, Budownictwo i Inżynieria Środowiska 59, (2012) 209-216.
7. Krajewski M., Iwicki P.: *Stability and load Bering capacity of a truss with elasctic braces*, Recent Advances in Computional Mechanics, London, Taylor & Francis 2014, 17-22.
8. PN-EN 1993-1-1 Eurocode 3: *Projektowanie konstrukcji stalowych, Część 1-1: Reguły ogólne I reguły dla budynków*, 2006.

BADANIA STATECZNOŚCI I NOSNOŚCI PRĘTÓW ZŁOŻONYCH Z PODPORAMI SPRĘŻYSTYMI

S t r e s z c z e n i e

Niniejsza praca poświecona jest analizom numerycznym i badaniom doświadczalnym ściskanych prętów złożonych, które są często stosowane, jako pasy górne kratownic dachowych. Istotny wpływ na nośność tego typu elementów, przy założeniu wyboczenia z płaszczyzny układu, ma odpowiedni dobór przewiązek zapewniający współpracę poszczególnych gałęzi. W pracy przedstawiono rezultaty liniowych analiz stateczności oraz fizycznie i geometrycznie nieliniowych analiz statycznych dla pręta złożonego, z którego zbudowany jest pas górny kratownicy wykonanej w rzeczywistości. Słupki i krzyżulce podpierające pas między węzłami skrajnymi zastąpiono podporami sprężystymi. Wyznaczono graniczną (minimalna) sztywność sprężystych podpór pośrednich zapewniającą maksymalną wartość obciążenia krytycznego dla modelu prętowego i powłokowego konstrukcji. Podano wartości obciążenia granicznego zależnego od długości zastosowanych przewiązek dla modeli konstrukcji ze wstępnymi imperfekcjami geometrycznymi. Zaprezentowane zostały rezultaty badań doświadczalnych osiowo ściskanych prętów złożonych z podporą sprężystą.

Słowa kluczowe: przekrój złożony, przewiązka, obciążenie krytyczne, obciążenie graniczne, sztywność podpór

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