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Strengthening under Load: Numerical Study of Flexural Buckling of Columns

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Abstract

The paper refers to the strengthening of doubly symmetric columns under load by welded plates. A validated numerical study containing more than 500 models was performed to question the currently used design procedures. These procedures are not unified but vary greatly in different countries. The overly conservative design approach used in the Czech Republic contrasts with the approach completely neglecting the effect of preload commonly used in the USA. The effect of various parameters on the flexural buckling resistance of columns strengthened under load was investigated. The selected parameters were the thickness of the strengthening flange, the column length, the initial bow imperfection, the preload magnitude and the direction of the axis which is pinned while the other axis is fixed. Several conclusions were reached from provided results and a simple analytical method is proposed. The load under which the column is strengthened weakens the column but only slightly.

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Keywords: Column; experiment; finite element analysis; parametric study; steel; strengthening under load

1. Introduction

This paper investigates strengthening of steel members under load using welded plates. It focuses on flexural buckling of doubly symmetrical axially loaded columns. The paper contains a description and results of experimental research performed in years 2015 and 2016 which served to study the feasibility of column strengthening under high magnitudes of preload (the load under which the column is strengthened), the temperature changes raised by welding

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process and the size of affected area, and to validate the numerical models used for parametric study. The results are compared with two vastly different analytical approaches.

The first, used in the USA [1], presumes that the strength of columns strengthened under preload and under no load is identical. This claim is supported by various researchers, e.g. O'Sullivan [2], Nagaraja Rao and Tall [3], Tide [4], Wu and Grondin [5]. The second approach does not allow the steel of the base section to yield in the case of members susceptible to buckling. It was introduced by Spal [6] and later adopted by Czech technical recommendations [7] and other authors, e.g. Vašek [8]. This safe approach is supported by e.g. Brown [9] and Ricker [10]. The design of a member under high preload magnitude according to the first or second approach leads to completely different cross-section and use of material. This big discrepancy may be caused by only several experimental studies in this area.

To author's knowledge, experiments of strengthening steel compressed members under load are very scarce and were conducted by O'Sullivan [2] (2 specimens strengthened under compressive load, bolted plates, very low effect of buckling), Kolesnikov [11] (3 specimens, high preload magnitudes, no comparison with member strengthened under no load), Nagaraja Rao and Tall [3] (1 specimen, complemented with stub column tests), Marzouk and Mohan [12] (7 specimens, high preload magnitudes, no comparison with member strengthened under no load) and authors [13, 14] (6 specimens, torsional-flexural buckling and local buckling).

The authors believe that the load resistance of steel members strengthened under load is decreased by the effect of preload but only slightly. There are two factors that should be accounted for in the structural design:

- Increased initial deflection caused by lower stiffness of the base section compared to the strengthened section as suggested by Unterweger [15]; distortion caused by asymmetric welds [16] added to this increased bow imperfection.
- Residual stress caused by welding (hardly predictable) and preload.

The exact solution is difficult and contains some hardly predictable variables for practical design. Therefore, a simple solution with a coefficient *k* is introduced.

Nomenclature

A_0	area of a base cross-section
A_z	gross area of a strengthened cross-section
L	column length
N_1	preload magnitude
$N_{b,0,Rk}$	load resistance of a base member
$N_{b,z,Rk}$	load resistance of a strengthened member
$N_{s,R}$	load resistance of a member strengthened under preload
f_y	yield strength of used material
k	coefficient adjusting the effect of preload magnitude
χ_0	buckling reduction factor of the base section
χ_z	buckling reduction factor of the strengthened section

2. Methods

2.1. Experimental research

Experimental research took place at the laboratory of the Institute of Metal and Timber Structures at Brno University of Technology in years 2015 and 2016. Hot rolled steel section HEA 100 was selected as the base section and strengthening plates with cross-section dimensions 120×10 mm were used. The cross-sections along with strain gauges and draw-wire sensor positions are shown in Fig. 1. All columns were 3 m long and all steel was grade S235 (yield strength from coupon tests: 309 ± 4 MPa – base section, 294 ± 6 MPa – strengthening plates; modulus of elasticity was not measured and was estimated 210 GPa). The boundary conditions were determined by knife-edge