21st International Conference ENGINEERING MECHANICS 2015
Svratka, Czech Republic, May 11 –14, 2015
Paper #048, pp. 230–231

Stability of Stainless Steel Prestressed Stayed Columns

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Keywords: cable supported structure, cross-arm, linear analysis, nonlinear analysis, stability, stainless steel, stayed column, 3d analysis

Abstract: The paper deals with extremely slender stainless steel columns reinforced for stability by prestressed cable stays running over one central crossarm. Such columns, with the un-stayed slenderness *L*/*r* round about 300, are more and more used as the attractive exterior supports of important structures. The structural arrangement can vary according to number of stays, number of cross arms, material of structural elements etc. While some linear bifurcation 2D stability analysis (LBA) and geometrically nonlinear elastic analysis with imperfections (GNIA) were published in the years past, 3D analysis for specific boundary conditions and stainless steel were not published. The brief summary of tests with stainless steel stayed elements performed recently at the laboratory of CTU in Prague is presented. The main part of the paper describes 3D stability analysis of unstayed and prestressed stayed columns as the first part of envisaged research concerning 3D materially and geometrically nonlinear analysis with imperfections (GMNIA) to analyze the test results. FE 3D models of LBA using prestressed stays preventing any compression force are used and optimal prestressing analyzed to receive the maximal critical buckling loading. In the conclusion the comparison with tests is provided.

Tests and numerical results

Tests. The three stayed columns of 1.4301 grade stainless steel acc. to Fig. 1 were tested under various prestressing. The column and crossarms were circular tubes Ø 50.0x2.0 – 5000 and Ø 25.0x1.5-(2x250) [mm], respectively. Macalloy cables of Ø 4 mm (sliding on the cross bars) were prestressed to give the required prestress. Initial and progress deflections were measured using potentiometers and 3D scanning [1]. The collapse loads in Fig. 1 were assessed from enormous deflections, while the buckling load $N_{cr.max}$ = 27.4 kN corresponds to 3D linear buckling analysis.

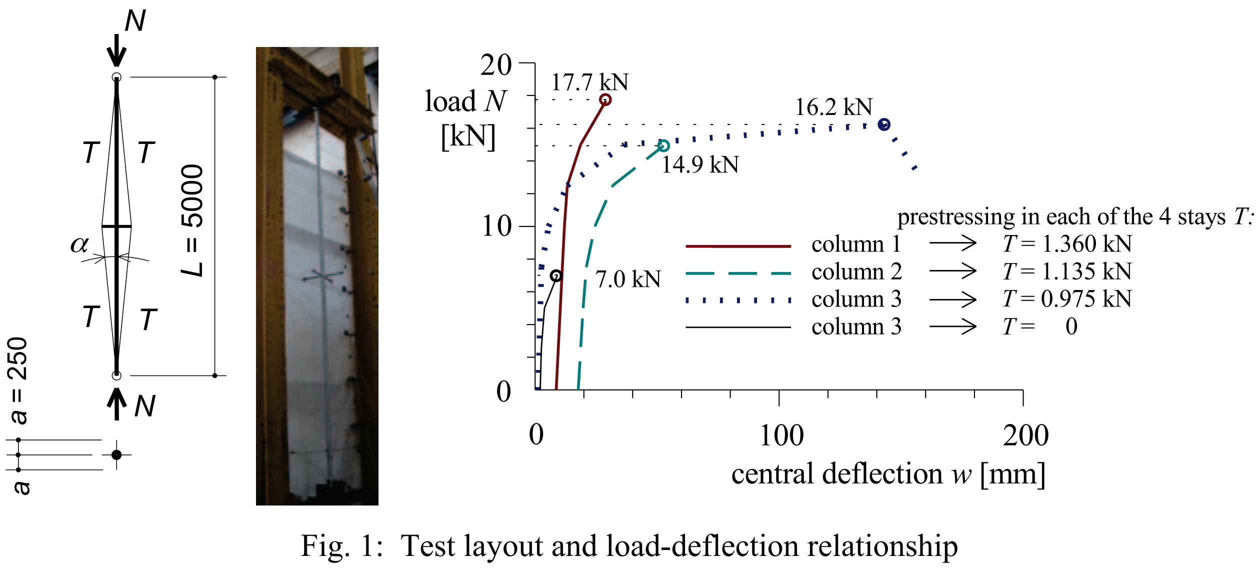

Fig. 1: Test layout and load-deflection relationship

The amplitudes of initial deflections (with shapes approaching to half sine wave) of the columns 1, 2 and 3 were 8.5 mm (i.e. $L/588$), 18.4 mm (i.e $L/272$) and 1.6 mm (i.e. $L/3125$) respectively. At collapse the deflection modes were symmetrical.

3D stability analysis. Euler's critical load of the tested column without prestressing (linearized E = 200 GPa, I = 87010 mm^4, L = 5000 mm) is $F_E = F_{cr,1}$ = 6.87 kN, the second critical load $F_{cr,2}$ = 27.48 kN. Analytical formulas based on elastic behavior, hinged joints of stays to crossarms and buckling in the plane of the crossarm member [2] give T_{min} (total pretension of stays small enough for buckling load equal to Euler load) and T_{opt} (total pretension of stays giving maximal buckling load $N_{cr,max}$). Based on axial (K_c, K_{ca}, K_s) and bending (B_c, B_{ca}, 0) stiffnesses of the column, crossarm and stay, the values are:

$$T_{min} = C_1 N_E = \frac{\cos\alpha}{2K_c\left(\frac{1}{K_s} + \frac{2\sin^2\alpha}{K_{ca}} + \frac{2\cos^2\alpha}{K_c}\right)} N_E = 0.0354 \cdot 6.87 \cdot 10^3 = 0.24 \cdot 10^3 \text{ N} \quad (1)$$

$$N_{cr,max} = \frac{(kl)^2 E_c I_c}{(L/2)^2} = \frac{(3.635)^2 \cdot 2 \cdot 10^5 \cdot 87009.6}{2500^2} = 36.79 \cdot 10^3 \text{ N} \quad (2)$$

$$T_{opt} = C_1 N_{cr,max} = 0.0354 \cdot 36{,}79 \cdot 10^3 = 1.30 \cdot 10^3 \text{ N} \quad (3)$$

in which symmetrical mode of buckling acc. [2] gives (kl) = 3.78 and predominant asymmetrical one - on the contrary to tests, (kl) = 3.635. The buckling load according to 3D nonlinear buckling analysis (NLBA using SCIA Engineer soft.) *with the optimal prestressing* of the 4 stays was performed with two boundary conditions: i) the stays joined with the crossarms as ideal hinges, ii) the stays sliding on the crossarms (which is convenient arrangement for the structure assembly). The first case gives $N_{cr.max}$ = 36.6 kN, the second one $N_{cr.max}$ = 27.4 kN.

Maximum load-carrying capacity. The experimental results were compared with analytical formulas according to [3], based on nonlinear analysis (ABAQUS soft.). Asymmetric buckling modes were considered according to the analysis. The values for columns 1, 2 and 3 were received taking into account amplitudes of the initial deflections conservatively as $L/400$, $L/200$ and $L/1000$ and result into N_{max} = 15.5, 15.6 and 20.0 [kN] respectively. Therefore, in comparison with tests (Fig. 1), the recommended procedure with safety factor $\gamma_M = 1$ is for *stainless steels* rather unsafe.

Summary

The brief insight into test behavior, analysis and design of steel prestressed stayed column is provided. Experimental results give global path of the behavior and indicate predominant influence of initial imperfections which decrease the load-carrying capacity in respect to critical loading received from 3D LBA. Optimum prestressing and the design capacity using 3D GMNIA for a spectrum of stainless steel stayed columns is under investigation.

Acknowledgment: The support of the Czech Grant Agency GACR grant No. 103/13/25781S is gratefully acknowledged.

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