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Stability of trusses with linear elastic side-supports

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Abstract

The present research is devoted to study of a lateral buckling of truss with linear elastic side-supports. The elastic support reaction in relation to force in compressed chord and coefficient of buckling length related to side-support distance are also calculated. The effect of slope of side-support on limit force is also considered. The non-linear analysis of two roof trusses are carried out. The results are compared to design code requirements [PN-90/B-03200 Steel structures. Design rules (Polish standard)]. The design sensitivity analysis of limit load due to side-support stiffness is carried out. A sensitivity of limit load due to side-support localization is calculated. The influence line of the variation of the limit load of the truss due to introducing side-supports of unit stiffness in chord joints is found. It has been found that for some side-support localization adding new side-support may cause decrease of limit load.

Keywords: Space trusses; Lateral buckling; Sensitivity analysis

1. Introduction

Roof trusses are connected with other structural elements like purlins or corrugated decking that are part of bracing system. Those elements are considered as side-supports of the truss and bear the forces of the trusses onto horizontal bracings installed at the ends of the roof. Most of earlier research, in Polish subject literature, on space trusses lateral buckling [2–4] has identified that buckling length of compressed chord is lower than side-supports distance. One of the reasons of that result is compression force distribution along the chord. Maximal force is only in the middle of the truss. Another explanation is positive influence of verticals, diagonals and tension chord in stiffening of compressed chord of the truss. This conclusion agrees with Polish code [1] recommendation where the buckling length of the truss chords in the case of lateral buckling can be assumed as distance of side-supports. Only in research [5] it was found that for short trusses buckling length of compressed chord is larger that side-support distance. The buckling length coefficient is very important in the design codes procedure so it is important for designers to define this coefficient precisely and without any doubts. To the best of the author's knowledge only in work [6] trusses with elastic side-supports were analyzed. The main purpose of this paper is to perform non-linear static analysis of two trusses with elastic side-supports and to verify code requirements. For different stiffness of elastic side-supports the limit load of the truss, the support reaction and coefficient of out of plane buckling length of the truss chords is calculated. The sensitivity analysis of limit load of one truss due to variation of side-support stiffness was also carried out.

According to the Polish steel design code [1], one can consider that the member is side-supported when the side-support is able to resist additional force F_0

$$F_0 = 0.01N_c \qquad \text{and} \qquad F_0 \geq 0.005A_c f_d, \tag{1}$$

where N_c is the normal force in the compression chord, A_c the cross section of the compression chord, and f_d the steel strength. The code [1] defines that maximal displacement of side-support should not exceed 1/200, of the side-supports distance. According to the Eurocode [7], a member can be considered as side-supported when some equivalent distributed load q can be transferred by horizontal bracing.

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2. Parametric study of trusses with elastic side-supports

2.1. Model description

The study considers two trusses. The first is a 25 m length truss binder (Fig. 1a). Its height is 1.5 m. All members in the same chord were sized equally. The compression chord consists of $2L\ 160 \times 160 \times 15$ the tension chord is made of $2L\ 150 \times 150 \times 15$. The diagonal members are made of U180 profile. It is assumed that the load is applied as concentrated forces on the top chord joints and its value corresponds to self-weight and snow loading of the roof construction. The normal compression force in chord is 2117 kN. The upper chord is additionally loaded by horizontal concentrated forces calculated from the formula according to Ref. [7]. The truss is stiffened in the upper chord by elastic side-supports of stiffness $k = 400$, 600, 800 kN/m, situated at angle $\alpha = 0°$, 15°, 30°, 45° from horizontal line.

As the second parametric study we consider the 24 m long truss shown in Fig. 1b. The height of the truss in the middle is 3.0 and 1.8 m near supports. The chords of the truss and two diagonals near supports consists of $2L\ 80 \times 80 \times 8$, the diagonals and verticals of the truss are made of U80 profile. It is assumed that the load is applied as concentrated forces on the top chord joints and its value corresponds to the self-weight and snow loading of roof construction. It is assumed that the top chord undergoes out-of-truss plane imperfection of maximum value $L/500$. The top chord is laterally braced every 3 m in joints by elastic side-supports. The stiffness of side-supports are $k = 10$, 20, 30, 40, 50, 60, 70, 80 kN/m. The case without side-supports is also considered. The normal force in compressed chord under snow and self-weight loading is 180 kN. The geometrical non-linear finite element calculations were performed by means of program [8]. Spatial beam elements were used. In the non-linear analysis the arch length method was applied.

2.2. Results of numerical simulation

For different stiffness of side-supports of truss binder a non-linear relation between normal force in compressed chord due to out of plane displacement has been calculated (Fig. 2). The load of the truss increases up to maximal value that causes lateral buckling of the truss. This value of normal force in compressed chord is considered as limit force and corresponding load is a limit load of the truss.

The limit force increases with increase of side-support stiffness and decreases with increase of angle of side-support measured from horizontal plane. For all analyzed supports the limit force of the truss is greater than normal force caused by the load exerted by the roof. For supports at angle 30° and 45° horizontal displacements are greater than allowed by code [1]. In the case under consideration elastic limit forces are greater than plastic load of chord which is 3000 kN. From the non-linear analysis one can draw the conclusion that the truss is sized correctly. The relative buckling length of compressed chord of the first of analyzed trusses is presented in Fig. 3 with side-support distance as a reference value. The relative buckling length is greater than described in code [1] and is between 1.5 and 2.1.

The relative side-support reaction due to compressed chord force and side-support stiffness and slope is presented in Fig. 4. The compressed force in upper chord of the truss is assumed to be the reference value. The side-support reaction in the middle of the truss is between −0.25% and 3.0% of compressed force in the chord.

For second truss the limit force increases with an increase of side-support stiffness. Even for supports of stiffness $k = 10$ kN/m limit load of truss is greater than force caused by statical load. In the case under consideration all forces are elastic because plastic load of chord is 750 kN (Fig. 5). All members of the truss are sized according to code [1]. From the non-linear analysis one

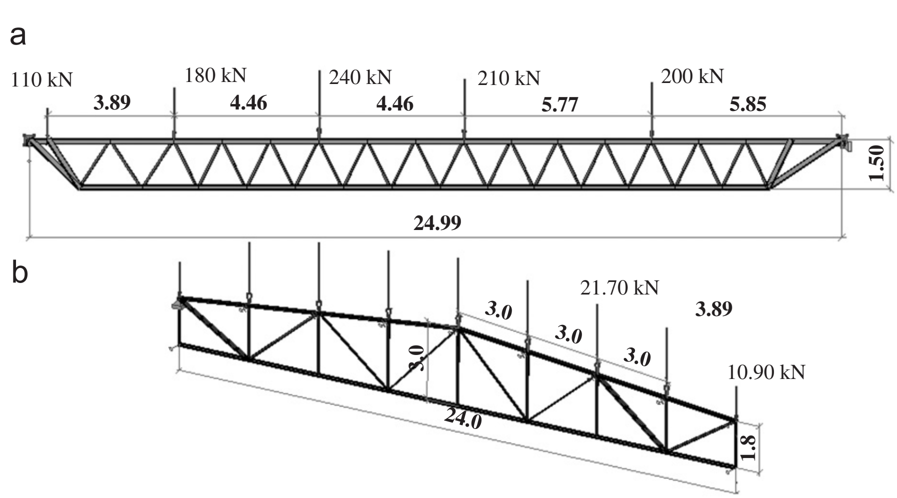

Fig. 1. Trusses with elastic side-supports.