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REINFORCEMENT OF LATTICE TOWER LEGS MADE OF ANGLE SECTIONS

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ABSTRACT: The main goal of this paper is to present the results of the buckling resistance analysis of two types of unconventional reinforcement of legs of a telecommunications tower by means of equal-leg angle sections. The key reinforcing elements are round solid bars that are connected with the angle section in various ways. Two types of connection between an existing leg and reinforcing elements were considered: stiff (welded) and frictional (based on friction between round solid bars and sheet plates around them). The reinforced element was loaded by a surface force applied at the upper end of the angle section. The paper discusses the impact of how the reinforced and reinforcing elements were connected on the value of the critical force. For the frictional connection, it was also shown how environmental conditions (wet or dry) and the resulting friction coefficient influence the form of buckling and the failure mechanism. Calculations were made with FEM numerical analysis using the FEMAP software.

Keywords: telecommunications tower, FEM, reinforcement, angle section, solid rod, buckling.

1. INTRODUCTION

1.1. Reinforcing steel structures

The lifetime of a building structure can be extended at a relatively small cost by increasing the structure's load-carrying capacity and protection against corrosion by means of reinforcements. The need to provide a reinforcement can be based on a number of reasons (Masłowski and Spiżewska 2002, Skwarek et al. 2013). For steel telecommunications towers, the most common reason to reinforce a structure is a change in its operating conditions as a consequence of its load having been increased. Adding new or retrofitting existing antennas affects the distribution of load exerted by devices and support structures located on the tower. An increased number of antennas results in higher upwind surface area or a modified aerodynamic drag factor, which leads to increased actions on a structure (Juszczyk-Andraszyk 2020). Technological advancements are often accompanied by an alteration or an upgrade of parts of support structures used for mounting antennas or service platforms that are required to access and maintain telecommunications equipment. If a tower structure's load-carrying capacity is inadequate, a comprehensive extension project has to be designed to reinforce the structural parts whose load-carrying capacities are exceeded in the current state or will be exceeded following the installation of planned telecommunications devices on the building structure.

For steel telecommunications towers, legs are the structural elements that most often require reinforcement (Skwarek et al. 2013). To improve the stability of compressed rods, the buckling length of the legs can be shortened by using an additional bracing or by extending the cross-section. If the cross-section is to be extended, adequate operation of the reinforced element with the reinforcing ones has to be ensured. The extension can be provided by adding one or more additional elements or by creating a two-branch cross-section. Some means that can be found in real-world constructions and were supposed to reinforce a steel tower structure raise questions as to their effectiveness or economic justification (Szafran et al. 2018).

1.2. Means of reinforcing an equal-leg angle section considered in the paper

One of the means of reinforcing a steel lattice tower that is discussed in this paper was implemented in 2005 (Fig. 1). The archived reinforcement project contains no information on the expected operating characteristics of the reinforcement, its impact on the existing structure, and how it would improve the structure's load-carrying capacity. The completed reinforcement was interpreted as an attempt to extend the cross-section of the tower legs by linking them with existing angle sections and increasing the buckling resistance of the legs at the same time. The applicable standard (PN-EN 1993-3-1. Part 3-1) and regulations that were in force when the actual reinforcement was designed (PN-90/B-03200:1990) provide no conditions for calculating the resistance of complex elements to cross-section compression and no guidelines for calculating complex cross-sections with unequal branches or with branches connected with each other in a way other than by means of their interface, spacers, batten plates placed in a crosswise manner, bracing or batten plates (Skwarek et al., 2013). The second means of reinforcing a leg made of an angle section consists in using two solid rods welded on the outer part of the angle section at the midspan of the leg's side (Fig. 2).

Fig. 1. View of the actual reinforcement — reinforcement no. 1.

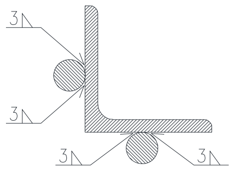

Fig. 2. Drawing of reinforcement no. 2.

2. THE CALCULATION MODEL CONSIDERED IN THE ANALYSIS

A section of the leg made of an equal-leg angle section L100×100×10 mm with assumed length of 1600 mm including the reinforcement was analyzed in the study. Reinforcement no. 1 (Fig. 3) includes sheet plates that hold in place two Ø25 mm round solid bars. The sheet plates covering the angle section are connected with each other by means of M16×72 screws, and the sheet plates covering the bars by means of M12×45 screws. Reinforcement no. 2 (Fig. 4) consists only of solid Ø25 mm bars. Both the reinforcements were mounted to a base plate measuring 200×200×20 mm.

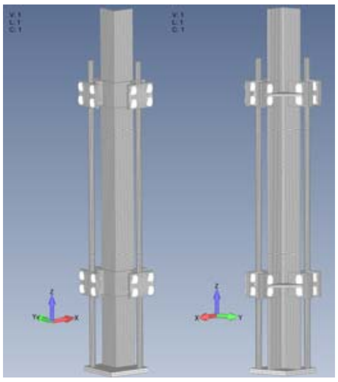

Fig. 3. A computer model of reinforcement no. 1.

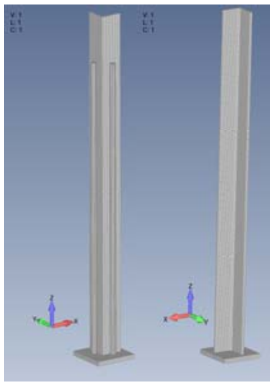

Fig. 4. A computer model of reinforcement no. 2.

2.1. Computer analysis

Tests were completed in the FEMAP software, version 2020.2 MP2, using a 3D finite element model. Parts of the reinforcements include areas with curved contours, which is why isoparametric elements were used. The models were discretized using 8-node hexahedral finite elements. The side length was taken as 10 mm for the base plate element and 5 mm for other elements.

Table 1. The number of finite elements

Reinforcement number	The number of finite elements	Node count
1	94762	144591
2	72240	97523

A stiff external support was introduced in the calculation program to eliminate any movement of the stiff arrangement. The support was located at the bottom surface of the base plate. Stiff conditions of internal supports between elements of the reinforcing arrangements were used with the exception of round solid bars in reinforcement no. 1, where a frictional connection transferring loads from the sheet plates around the angle section was added. This was included in the program by using a non-dimensional friction coefficient of the mating surfaces. The friction coefficient was related to ambient conditions (Tab. 2).

Table 2. Static friction coefficients taken for materials used in the structure

Ambient conditions	Static friction coefficient
Dry	0.74
Wet	0.16

The load from upper segments of the tower is transferred through the legs across their entire surface, so the load applied is a surface load distributed on the upper side of the angle section.
The linear buckling analysis in FEMAP, supported by the built-in NX Nastran solver, is based on the Lanczos method. For reinforcement no. 1 and the frictional connection, a matrix reflecting the stiffness of the latter is also included and added to the linear stiffness matrix.

3. RESULTS OF THE ANALYSES

The elements included in the reinforcements of the angle section extend its cross-section. Despite this, the mechanism of stability loss was not changed in principle. What changed, however, was the value of the critical force which was determined through buckling analyses. Based on this result, the buckling resistance of the angle section with reinforcing elements was calculated. For angle sections, Eurocode (PN-EN 1993-3-1 – Part 1-1) classifies sections that meet the following condition as class 3:

$$\frac{h}{t} \le 15\varepsilon; \frac{b+h}{2t} \le 11{,}5\varepsilon, \tag{1}$$

where *h* and *b* are width and height of a cross-section, respectively, and ε is a factor depending on yield strength. The angle section considered in the analysis satisfies these conditions. For class 3 cross-sections, the cross-section buckling resistance takes the form:

$$N_{b,Rd} = \frac{\chi \cdot \mathrm{A} \cdot f_y}{\gamma_{M1}}, \tag{2}$$

where χ is a buckling factor reflecting the actual form of buckling, A is the cross-sectional area, f_y is yield strength, and γ_{M1} is a partial factor equal to 1.0.
For the same external forces used in the model with and without the reinforcement, it was found that the upper section of the model with the reinforcement deforms to a lesser extent.
The results of the analyses for the first form of buckling are listed in tables below.

Table 3. The critical force, the buckling resistance for the two means of angle section reinforcement and improved buckling resistance as percentage compared to the model without the reinforcement

Reinforcement number	Environment	Critical force [kN]	Buckling resistance [kN]	Buckling improvement [%]
1	Wet	175.05	146.23	26,6
	Dry	182.74	151.90	31,6
2	Not applicable	170.77	143.05	23,9

4. SUMMARY AND CONCLUSIONS

The paper discusses the effect of using round solid bars on the buckling resistance of the structure considered. Based on the results of analyses performed in FEMAP, the following conclusions can be drawn:

– the reinforcements significantly improve the buckling resistance of the reinforced angle section.
– for reinforcement no. 1 with the frictional connection between round solid bars and sheet plates embracing the reinforced angle section, the result is strongly affected by the friction coefficient used.

Reinforcement no. 2 is a solution that uses less steel per meter length of the structure. It must be noted, however, that installation works designed to reinforce steel lattice towers are usually performed at significant heights. If welding work is planned, personnel with special qualifications and experience in working at height needs to be involved. Welding work is also more difficult in adverse weather conditions. Using reinforcement no. 1 is faster and, given the costs, can prove less expensive even though it requires more steel. The noticeable advantage of selecting round solid bars as unconventional elements to reinforce an angle section argues for further research, which is the intent of the authors of this paper. What is important is that the improvement in the buckling resistance of an angle section should be confirmed through studies on a physical model.

REFERENCES

Juszczyk-Andraszyk, K. 2020. *Dynamika smukłych konstrukcji stalowych pod obciążeniem o charakterze stochastycznym.* Rozprawa doktorska, Politechnika Łódzka, Wydział Budownictwa, Architektury i Inżynierii Środowiska, Katedra Mechaniki Konstrukcji.

Masłowski, E., Spiżewska, D. 2002. *Wzmacnianie konstrukcji budowlanych.* Warszawa: Arkady.

PN-90/B-03200:1990: *Konstrukcje stalowe – obliczenia statyczne i projektowanie.* 1990.

PN-EN 1993-3-1:2008. *Design of steel structures. Part 1-1: General rules and rules for buildings.* 2008.

PN-EN 1993-3-1:2008. *Design of steel structures. Part 3-1: Towers, masts and chimneys – Towers and masts.* 2008.

Skwarek, M., Tomska, D., Hulimka, J. & Kozłowski, M. 2013. *Problemy wzmacniania stalowych kratowych wież telekomunikacyjnych.* XXVI Konferencja Naukowo-Techniczna Awarie Budowlane.

Szafran, J., Kamiński, M., Juszczyk-Andraszyk, K. 2018. *Reinforcements of tower structures: effective and economic design engineering.* XXIV LSCE. Łódź.