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An experimental investigation into failure mechanism of a full-scale 40 m high steel telecommunication tower

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ABSTRACT

The main objective of this paper is to present and discuss failure mechanism, failure mode, as well as plastic deformation of a lattice telecommunication tower obtained during a full-scale pushover test. The manuscript consists of a detailed description of the tested structure and the experimental site. Displacements of particular nodes of the tower are presented as a function of the external load. The main conclusion is that the rigidity of joints between particular elements, which depends on thickness and diameter of connecting flanges and number and quality of bolts, determines the failure mode of the compressed tower legs. In the article, values of axial forces under compression, taken directly from the conducted test, were compared with the standard buckling resistance. On the basis of this comparison, discussion about the effective slenderness factor has been generated, and the proper determination of this coefficient has been proposed.

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1. Introduction

Experiments on full-scale engineering structures, although difficult to perform because of, both technical and financial reasons, can produce results that are impossible to obtain in a different way. Structure response searching in the context of, e.g. stresses, strains, displacements, and last but not least, failure mechanism and failure mode, may help enrich the knowledge about structures like lattice towers.

Steel lattice towers are extensively utilized in telecommunication industry as supporting structures providing services such as telephoning, wireless internet or television. The more pressing the mobile networking needs of today's customers are, the more requirements are being imposed on telecommunication devices which, in turn, causes repetitive replacements, upgrades, and modernizations. Antennas and radio units which get attached to telecommunication towers have different shapes, dimensions and weight. They are installed at various heights which considerably alters forces distribution of a supporting structure as well as carrying capacity of tower elements. Taking into consideration constant change of operating conditions, there is recurring need of determining bearing capacity of such structures. Due to the advancements in telecommunication engineering, including a growing number of new technological solutions, the scientists and civil engineers also contribute to the effort of meeting the new demands with numerous scientific publications devoted to problems in the field of telecommunication structures.

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As an example of current state of knowledge of high, slender engineering structures and, in particular, of their dynamic behavior and fatigue, the works of Repetto and Solari [1,2] may be mentioned.

One of the most practical and comprehensive scientific manuscripts dealing with communication structures is one written by Smith [3]. The author thoroughly elaborates on utilization of structures of that type, taking into account a variety of design aspects: meteorological parameters, strength, fatigue, and etc., where the conclusions coming from structural failures of masts and towers caused by external loads are particularly important. One type of load that determines cross-section size of particular elements of steel lattice towers is obviously wind load. The effect that the wind has on various engineering structures is a subject of many research articles. The comparison of results taken directly from wind tunnel tests and those predicted by Eurocode [4] for a slender tower structure can be found in [5]. Various problems in design, and analysis of telecommunication structures in particular, were published in [6] by Travanca et al. From the standpoint of engineering practice, a significant problem was tackled: the comparison of standards' records and definitions from various codes of practice, which change over time, with their impact on subsequent estimation of carrying capacity of the structures with emphasis being placed on existing object evaluation. This problem seems to be particularly significant for telecommunication towers due to changing nature of their load conditions (technological requirements). Additionally, the subject of tower strengthening and upgrading, where maintaining an object in a fair condition over years is concerned, is extremely valid. It is not uncommon that these objects are utilized for several dozen years. Hence the constant need for modernization, renovation, or upgrading to fulfill the above requirements [7]. The replacement of structure's elements with ones of larger cross-sections, manufacturing additional truss elements or adding weight to the foundations are very common, exemplary attempts of upgrading telecommunication support structures.

Reliability modeling is the next aspect of research and development in this branch of engineering. The requirements concerning the reliability are included in [8]. They impose a structural design process which ensures compliance with top quality standards.

Computational probabilistic analysis and reliability assessment of steel telecommunication towers subjected to material and environmental uncertainty can be found in author's previous works [9–12] and book of Kamiński [13].

One of more interesting and challenging problems is either analytical or numerical determination of carrying capacity of steel tower elements made of cold-rolled or hot-rolled L-sections. In particular, it involves the determination of support conditions influence, load applying manner, failure mechanism, and failure modes which results in carrying capacity estimation. Many scientific publications tackle the problem of structural elements behavior and their plastic deformation in particular [14]. An analysis of such elements often used in steel structures may involve full 3D behavior; consideration of axial, bending and shearing actions; various slenderness ratios; loading and displacement eccentricities. The comparison of numerical calculations with a full-scale destructive test may be found in the work of Lee and McClure [15]. The manuscript elaborates on highly relevant aspects of structures composed of hot-rolled single angle shapes with eccentric connections and, most importantly, allows for comparison of the obtained numerical results with full-scale, destructive test data. The authors of [15] should be also noted for pointing out that, in the context of mechanical security where the assessment of modes of failures and the confinement of failure are key, it becomes important to predict the actual strength and failure mechanism of such towers with a reasonable accuracy for failure scenarios in both static and dynamic regimes. Some consideration about non-local and local buckling and their influence on overall stability of truss and arched structures can be found in [16,17]. The use of FEM analyses with the experimental study findings considerably extends the knowledge of buckling phenomenon for structures' elements.

2. Experimental, full-scale test

2.1. Experimental study objective

One of the main objectives of the experiment was to reveal failure mechanism and failure mode of the 40 m high, steel, lattice telecommunication tower under breaking load.

The experiment has been conducted in such a manner that the external load was exerted on the tower and the maximum compression forces in its legs were created. It was achieved by applying the load in the least favorable direction for a tower of a triangular cross-section causing the maximum value of the compression stresses at one of the legs.

Particular attention was paid to the observation of the tower legs behavior. One of the goals of the performed test was the determination of their buckling resistance. Another purpose was to determine the nature of destruction of diagonal bracings comprising hot-rolled angle sections. For these purposes, a tower of a complex structure and specific bearing elements was chosen.

2.2. Tower description

The tower is a 40 m lattice structure with a triangular cross-section. It is divided into seven sections. The sections may be classified into two types, with convergent and parallel legs. The bottom part of the tower (up to 34th m) forms a pyramid frustum of convergence of 5%. The centerline dimension is 4.90 m at its base and 1.50 m at the top. The upper part of the tower is a parallelepiped of a height equal to 6.0 m with the cross-section of an equilateral triangle of side length equal

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