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Optimization of tall guyed masts using genetic algorithms

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ABSTRACT

The aim of the article is to describe the procedure for mixed topology-size optimization of tall guyed masts, seeking the minimal mast weight with stochastic genetic algorithms. Given the height, geometrical in-plan and bracing schemes of the mast, loading and material data, the optimization procedure renders the explicit design of the mast including dimensions of all mast elements, attachment points of the guys, distances of the guys' foundations from the mast, etc. The constraints of the problem include typical strength, slenderness, and local and global stability requirements according to the Eurocodes. The value of the objective function is obtained and all the constraints are checked via statical analysis with a finite element program. The influence of the guys on the behavior of the mast is modeled by linear springs. The design obtained may serve as a hint for more precise nonlinear dynamic analysis. This article provides the results of the optimization of a practical 50 m broadcasting antenna mast with two clusters of guys.

1. Introduction

Guyed towers are used frequently to support telecommunication antennas. They consist of a slender tall mast that is supported laterally by several sets of inclined pre-tensioned guys attached at a few levels along its height. The guys around the mast are usually spaced at equal angles. The optimization of these structures may be a complex task since the structural behavior of guyed towers is complicated due to the inherent nonlinearity of the guys, and since turbulent wind is the dominant loading that essentially determines the design of the towers.

Despite the fact that few typical designs prevail in the engineering practice (e.g., see Figs. 1 and 2: triangular plan of horizontal cross-section of mast, triangular bracing with lateral stiffeners at the guys attachment levels, etc.), there are many factors that can be chosen to optimize a tower design that seeks to preserve all the safety and serviceability requirements while maintaining a minimal mass of the whole structure. For example, the set of design variables may consist of the number of guys' clusters, the heights of their attachment positions along the height of the mast, pre-tension forces in the guys, distances of the guys' foundations from the axis of the mast, width of mast in the cross-section, height of the typical section of the mast, and, finally, of all dimensions of mast elements. Such an optimization problem can be categorized as the mixed topology-sizing optimization.

Evidently, the objective function cannot be expressed in a closed form in terms of design variables. Moreover, it may present a large number of local minima points; therefore global optimization methods capable of finding the global minimum or at least a rational solution are needed. If more than several design variables are considered, only the stochastic global optimization algorithms may render satisfactory results.

Engineers have worked to optimize slender structures subjected to the wind loading for many years. Bell and Brown [1] optimized guyed towers using the deterministic global optimization technique on the basis of the Branch-and-Bound algorithm. However, it led to only local optimum points since each design variable was considered separately. Thornton et al. [2] developed a computer program for the mass optimization of towers under deflection constraints-static wind loads were treated. Uys et al. [3] proposed a procedure for optimizing steel towers under dynamic wind loading after the Eurocode 1 [4]. Venanzi and Materazzi [5] proposed a multi-objective optimization method for wind-excited structures based on a stochastic simulated annealing algorithm. The objective function involved two competing factors: the sum of the squares of the nodal displacements and the in-plan width of the structure. However, only three factors were included in the set of design variables.

The optimization of masts and towers is a complicated global optimization problem. Therefore, considerable attention has been given to the development of effective stochastic problem-oriented optimization algorithms. Zhang and Li [6] combine the shape and sizing optimization of a transmission tower structure in two levels using the ant colony algorithm (ACA). Luh and Lin [7] employed

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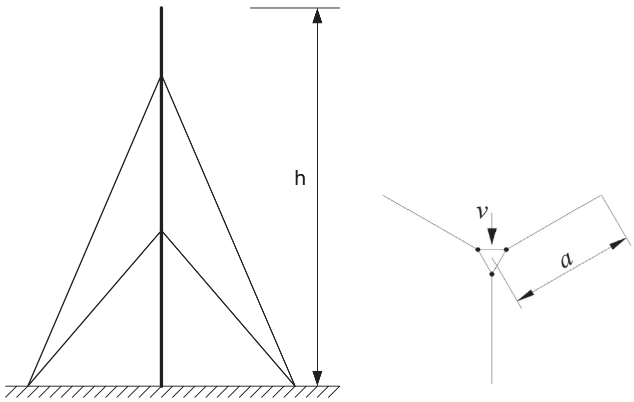

Fig. 1. Schematic of the mast with two clusters of guys. Horizontal plan of the structure.

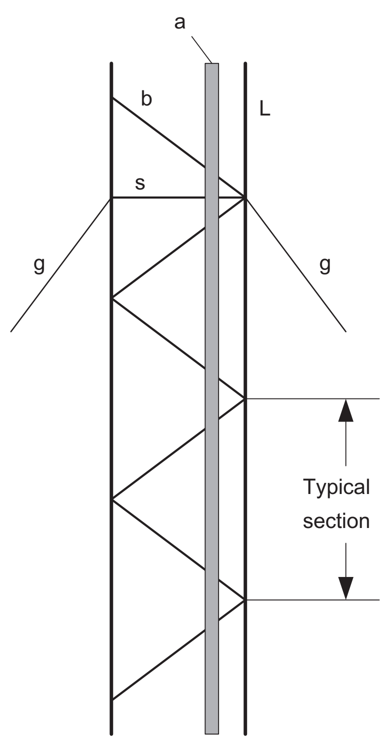

Fig. 2. Side-view of the mast structure and typical section: *L* – leg, *b* – bracing, *s* – stiffener members; *g* – guy, *a* – auxiliary equipment.

modified binary particle swarm optimization (PSO) for the topology optimization of truss structures, and subsequently the size and shape of members were optimized using the attractive and repulsive particle swarm optimization. Kaveh and Talatahari [8] find that the PSO is more effective than ACA and the harmony search scheme for optimizing truss structures. Deng et al. [9] and Guo and Li [10] proposed several successful modifications of genetic algorithms (GA) to optimize tapered masts and transmission towers.

This paper poses the topology-sizing optimization problem of guyed mast as a single-level single-objective global optimization problem using the genetic algorithm to determine the minimum weight design. The set of the design variables may contain up to 10 parameters of different natures. The genetic algorithms [11] have been chosen due to their effectiveness in different engineering application areas [12] and ease of implementation. Another advantage of GA is its stochastic character: the optimization problem has to be solved a sufficient number of times, each time starting from a randomly formed population of individuals in order to exclude the influence of deviation of the results. This usually leads to several optimum points with close objective function values but corresponding to different topologies of the mast; the designer now can choose the relevant topology.

The additional problems, e.g., low deformability of the mast, are considered "difficult constraints" and are handled by a penalization technique-a penalty term is added to the objective function if the restraint is not satisfied. Therefore, a penalized design has little chance to leave its off-springs.

The following sections introduce the idealizations on the analysis of mast behavior and pose the optimization problem. Next, the optimization method is explained in detail. Then, the paper will present and discuss the numerical application of the proposed technique to the case study of a two-level guyed mast subjected to turbulent wind.

2. Idealizations and optimization problem

The structural behavior of guyed masts is extremely complicated; the guys especially exhibit a nonlinear behavior, more at low pre-tensioning levels. Increasing the pre-tension forces decreases the nonlinearity and enhances the lateral stiffness at the cost of increased compressive loads, and therefore, a higher buckling probability of the mast. The mast itself can be geometrically nonlinear due to its slenderness and substantial wind loading. In addition to the wind loads, we should account for the loads due to the self-weight of the tower with all auxiliary equipment, and possible icing.

The use of global optimization algorithms, either deterministic or stochastic, inevitably requires analyzing the computational scheme of the structure for thousands and millions of times; therefore a very fast and reliable analysis tool is a pure necessity. For that reason, we restrict the analysis to the linear stage, substituting the guys by the springs of equivalent horizontal stiffness and corresponding vertical compressive forces [13]. In this paper, we evaluate the statical wind loads, multiply them by the coefficients of turbulent loading according to the patch load method (Eurocode 1, Part 1-4 [4] and Eurocode 3, Part 3-1 [14]), and solve statical problem, despite the fact that wind forces are of a dynamic nature, and consideration of equivalent statical loads is not always adequate. According to the Eurocodes, the designer has to consider several other loadings in addition to the wind loading of different directions, including icing and several their combinations. In this paper we choose to optimize the mast for the most critical and determinant case of wind loading, when the direction of wind is at the right angle to one side of the mast, and when the load constituent due to turbulent wind is added only to the top zone of the mast. The loads due to the self-weight of the structure and equipment are accounted for, but not the ice loads. In our country, simultaneous heavy icing and extreme winds are not usually the critical combination. Simultaneous icing and wind loading is more topical for Nordic and mountainous countries. However, our mast analysis program has the straightforward capability of including icing loads. The evaluation of the most critical icing loading is cumbersome. Research on the impact of icing loading on the mast structures revealed [15,16] that the most dangerous icing is usually non-symmetrical icing. Also, the European standard of icing loading evaluation ISO 12494 [17] distinguishes two icing types: glaze and rime, adding more complication. The glaze loading in turn is divided into 6 ICGx classes, while the rime loading is divided into 10 ICRx classes. The drag coefficients of iced mast elements and the factor for the combination of wind loading and icing depend