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Optimum design of semi-rigid connections using metamodels

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ABSTRACT

Considerable efforts were made in the past 15 years to develop strategies for the optimization of steel frames with semi-rigid connections, concentrating on the frames and not the connections, which were designed after the rest of the structure had been optimized. The analysis of semi-rigid connections requires the calculation of the moment-rotation curve (M_j-ϕ), which can be predicted using the Finite Element (FE) method. This is computationally expensive due to both the high number of degrees of freedom in the FE model and the nonlinear analysis required. In order to optimize such connections, a surrogate or metamodel of the FE model can be used. This paper puts forward a methodology for the optimal design of semi-rigid steel connections using metamodels generated with Kriging and Latin Hypercube, and optimized with the genetic algorithm method. This methodology was applied to two examples involving bolted extended end-plate connections, and was shown to work excellently at obtaining their optimal designs.

1. Introduction

Considerable efforts were made in the past 15 years to develop strategies for the optimization of steel frames with semi-rigid connections. This process involves minimizing the cost of the frames under specified design loads subject to stress and displacement constraints but with only the member sizes as design variables. The dimensions of the connection are not optimized, but a cost is given to them in the form of extra weight added to the steel members proportional to the rotational stiffness of that connection. Once the size of the structural profiles is obtained, what a designer currently does is to suggest an appropriate connection for the frame, which does not guarantee the resultant structure to be optimal.

Xu and Grierson [1] presented a computer-automated method to minimize the cost of the connections and members of steel frames. The cost of each member was represented by its weight, while the cost of each connection was related to its stiffness. Hayalioglu and Degertekin [2,3] presented a genetic algorithm (GA) based optimum design method for non-linear steel frames with semi-rigid connections and column bases. The design algorithm obtained the minimum total cost, using the objective function proposed by Xu and Grierson [1]. Simões [4] minimized the cost of the connections and members of the structure. He represented the cost of each member by its weight, while the cost of each connection was based on their rotation stiffness value converted into an equivalent structural weight. The weight minimization of only the structural profiles (members) of steel frames was carried out by Kameshki and Saka [5,6], Csébfalvi [7], and Liu [8]. Almusallam [9] and Al-Salloum and Almusallam [10] minimized the volume of the frame considering only the structural profiles. Pavlovčič et al. [11] presented a very detailed objective function that calculated the cost of the whole structure with rigid connections. It included all the essential fabrication costs, such as: welding, cutting, drilling, surface preparation, assembly, flange aligning, and painting, together with the steel and bolting material costs, transportation and erection costs. The cost for the connection was considered according to the beam and column dimensions and the bolt size was based on the full strength of the beam. The shop operation costs included: hole formation and welding of the stiffeners and the end-plate. The erection costs included bolting and site beam-to-column welding. Cabrero and Bayo [12] proposed a method for the optimum design of steel frames where the structural profiles and the values of stiffness and resistance for the connections were optimized. These connections were then dimensioned using these values.

In order to obtain the optimum design of steel frames, some researchers [1–12], use structural analysis to firstly obtain the rotational stiffness and moment resistance. These values are then used to determine the member sizes, after which, the connections of the structure may be optimized. Cho and Park [13] (referenced by Xu [14]) proposed an optimization model for the minimum cost design of: end-plate, bolted flange-plate and welded flange-plate beam-to-column connections. The design variables were: the number and size of the bolts, the dimensions of the end-plates, the thickness and length of the flange plates, the size and length of the welds, and the sizes of the cleats and seats. The cost function for the connection was defined by the cost of the: design variables, material, labor and fabrication.

In the case of the analysis of semi-rigid connections, there are many models to predict rotational behavior which is accounted for

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