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Optimization of Structures with Mixed Integer Non-linear Programming (MINLP)

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Abstract : This contribution focuses on structural optimization in civil engineering using mixed integer non-linear programming (MINLP). MINLP is characterized as a versatile method that can handle both continuous and discrete optimization variables simultaneously. Continuous variables are used to optimize parameters such as dimensions, stresses, masses, or costs, while discrete variables represent binary decisions to determine the presence or absence of structural elements within a structure while also calculating discrete materials and standard sections. The optimization process is divided into three main steps. First, a mechanical superstructure with a variety of different topology-, material- and dimensional alternatives. Next, a MINLP model is formulated to encapsulate the optimization problem. Finally, an optimal solution is searched in the direction of the defined objective function while respecting the structural constraints. The economic or mass objective function of the material and labor costs of a structure is subjected to the constraints known from structural analysis. These constraints include equations for the calculation of internal forces and deflections, as well as equations for the dimensioning of structural components (in accordance with the Eurocode standards). Given the complex, non-convex and highly non-linear nature of optimization problems in civil engineering, the Modified Outer-Approximation/Equality-Relaxation (OA/ER) algorithm is applied. This algorithm alternately solves subproblems of non-linear programming (NLP) and main problems of mixed-integer linear programming (MILP), in this way gradually refines the solution space up to the optimal solution. The NLP corresponds to the continuous optimization of parameters (with fixed topology, discrete materials and standard dimensions, all determined in the previous MILP), while the MILP involves a global approximation to the superstructure of alternatives, where a new topology, materials, standard dimensions are determined. The optimization of a convex problem is stopped when the MILP solution becomes better than the best NLP solution. Otherwise, it is terminated when the NLP solution can no longer be improved. While the OA/ER algorithm, like all other algorithms, does not guarantee global optimality due to the presence of non-convex functions, various modifications, including convexity tests, are implemented in OA/ER to mitigate these difficulties. The effectiveness of the proposed MINLP approach is demonstrated by its application to various structural optimization tasks, such as mass optimization of steel buildings, cost optimization of timber halls, composite floor systems, etc. Special optimization models have been developed for the optimization of these structures. The MINLP optimizations, facilitated by the user-friendly software package MIPSYN, provide insights into a mass or cost-optimal solutions, optimal structural topologies, optimal material and standard cross-section choices, confirming MINLP as a valuable method for the optimization of structures in civil engineering.

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