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Move limits definition in structural optimization with sequential linear programming. Part II: Numerical examples

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Abstract

A variety of numerical methods have been proposed in literature in purpose to deal with the complexity and non-linearity of structural optimization problems. In practical design, sequential linear programming (SLP) is very popular because of its inherent simplicity and because linear solvers (e.g. Simplex) are easily available. However, SLP performance is sensitive to the definition of proper move limits for the design variables which task itself often involves considerable heuristics. This research presents a new SLP algorithm (LESLP) that implements an advanced technique for defining the move limits. The linearization error sequential linear programming (LESLP) algorithm is formulated so to overcome the traditional limitations of the SLP method. In a companion paper [Comput. Struct. 81 (2003) 197] the basics of the LESLP formulation along with a guide to programming are provided.

The new algorithm is successfully tested in weight minimisation problems of truss structures with up to hundreds of design variables and thousands of constraints: sizing and configuration problems are considered. Optimization problems of non-truss structures are also presented. The numerical efficiency, advantages and drawbacks of LESLP are discussed and compared to those of other SLP algorithms recently published or implemented in commercial software packages.

Keywords: SLP; Move limits; Linearization error; Trust region

1. Introduction

In practical optimization, the sequential linear programming (SLP) method [1–4] is very popular because of its simple theoretical foundation and because reliable linear solvers are readily available (i.e. Simplex packages). Although SLP performs very well in convex programming problems with nearly linear objective and constraint inequality functions, the method is not globally convergent. Moreover, numerical problems like convergence to local or infeasible optima and objective function oscillations may occur if the method is not well controlled. Therefore, SLP is often considered a "poor" method by many theoreticians. However, SLP techniques may be enhanced by using move limits which are additional side constraints that define a region of the design space where the solution of the linearized sub-problem will lie.

An efficient and robust approximate method for structural optimization should define the move limits so that the approximate sub-problem portrays the original non-linear problem well. Besides, high accuracy of the approximation will eliminate cost function oscillations and will avoid that the optimizer gets stuck in infeasible

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regions. Wujek and Renaud [5] stated that a proper choice of the move limits should ensure that the objective function improves monotonously, that each intermediate solution is feasible, that the design variable movement is controlled in order to maintain the approximation error at a reasonable level.

The aforementioned requirements were fulfilled by the move limit definition strategy proposed by Lamberti and Pappalettere [6]. The resulting algorithm (LEAML) was superior over other SLP techniques but involved some heuristics. Hence, the original formulation of Ref. [6] has been substantially modified in this research. The new algorithm, called linearization error sequential linear programming (LESLP), is formulated so to avoid any uncertainties and guesswork in the SLP procedure. The move limit domain is built based on the linearization error ε_{LIM} introduced with the linear approximation: LESLP uses a combination of "low-fidelity" and "high-fidelity" models that, respectively, evaluate the cost function only or all the non-linear functions. Also, line searches are performed to enforce the move limit domain to lie in regions of the design space where the cost function is very likely to improve. Furthermore, the move limits are accepted or rejected and recalculated based on trust region models that enhance the robustness of the procedure. Finally, LESLP provides schemes to accept, improve or reject intermediate designs. Even infeasible designs can be handled because LESLP tries to find regions where the constraints are satisfied or violated the least.

The basics of LESLP formulation and a basic guide to programming have been presented in a companion paper [7]. The present paper discusses in detail the numerical efficiency of LESLP in solving a large variety of design optimization problems.

2. Test problems

The efficiency and the reliability of the LESLP algorithm described in the companion paper [7] were tested solving 20 problems of weight minimisation of bar truss structures. Sizing as well as shape optimization problems are considered. The truss structures are designed to carry multiple loading conditions under static constraints on the nodal displacements, stresses in the members and critical buckling loads. This class of problems was chosen because truss structures are widely diffused in practical engineering. Also, examples of truss structure design optimization are extensively used in literature to compare the efficiency of optimization algorithms. In order to draw more general conclusions, four examples of non-truss optimization problems including mathematical programming (Barnes' problem) and structures to be designed under static constraints (cantilevered beam, frame structure, speed reducer) were considered.

LESLP was implemented by a numerical code written in Fortran 90. The code has a built-in FEM routine for structural analysis and a standard Simplex package as the linear solver. The optimizations were run on a DEC-Alpha 4100 Unix platform. Initial designs were taken from studies presented in literature. Optimizations were very often started from unconservative designs in order to test the capability of LESLP to quickly enter a feasible domain.

2.1. Truss design problems

The 20 problems are relative to 10 different structures. The first five structures have respectively 10 (Fig. 1), 20 (Fig. 2), 25 (Fig. 3), 72 (Fig. 4), and 200 members (Fig. 5); these structures are usually presented in literature as benchmark tests. The dome structure with 444 elements (Fig. 6) and the antenna structure with 720 elements (Fig. 7) are presented as examples of large scale structures. The cantilevered bar trusses (Fig. 8) and the power line (Fig. 9) respectively have 18, 45 and 47 elements; these structures are presented as examples of

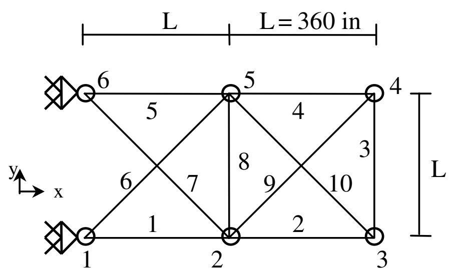

Fig. 1. Schematic of the 10 bar truss structure.

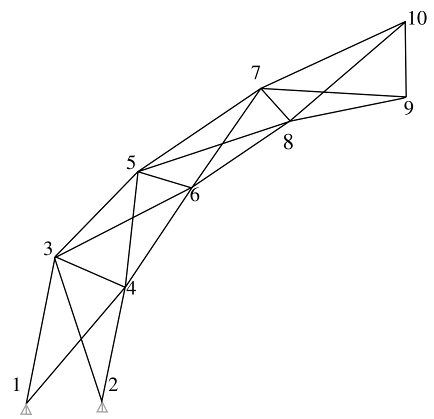

Fig. 2. Schematic of the 20 bar truss structure.