Available online at www.sciencedirect.com
SCIENCE DIRECT®
Comput. Methods Appl. Mech. Engrg. 193 (2004) 3493–3521
Computer methods in applied mechanics and engineering
www.elsevier.com/locate/cma

Improved sequential linear programming formulation for structural weight minimization

Luciano Lamberti *, Carmine Pappalettere [1]

Dipartimento di Ingegneria Meccanica e Gestionale, Politecnico di Bari, Viale Japigia 182, Bari 70126, Italy

Received 29 May 2003; received in revised form 28 November 2003; accepted 2 December 2003

Abstract

This paper presents an optimization algorithm for weight minimization of structures. The algorithm—denoted as LSTRLP (line search trust region linear programming)—combines sequential linear programming (SLP) and Trust region methods (TRM). LSTRLP solves a linearized sub-problem in each design cycle and accepts or rejects intermediate designs based on a line-search strategy which detects if the eventual improvement in cost is actually the largest possible. It is to be noticed that the present work is the closure to several studies carried out by the present authors in order to improve the overall efficiency and robustness of the sequential linear programming method.

The LSTRLP algorithm is implemented by an optimization code written in Fortran 90. The optimization code is tested in eight cases of weight minimization of bar truss and frame structures. The test cases include examples of large-scale and configuration optimization. The results obtained here are compared to those presented in literature. The optimizations are run also with sequential quadratic programming (SQP) routines implemented in commercial software. The results indicate that LSTRLP is competitive with recently published algorithms and commercial software.

Keywords: Structural optimization; SLP; Trust region; Line-search

1. Introduction

Sequential linear programming (SLP) is very popular in practical engineering since the linear solvers utilized to solve the linearized sub-problems are easily available to designers. In optimum design of structures, SLP is more attractive than other optimization methods because it requires structural analysis only for computing gradients of the cost function and constraints. Trust region methods (TRM) are universally acknowledged robust and versatile optimization algorithms because of their excellent global

* Corresponding author. Tel.: +39-0805962774.
E-mail address: lamberti@poliba.it (L. Lamberti).
[1] President of the Italian Society for Stress Analysis (AIAS). Chairman of the European Association for Experimental Mechanics (EURASEM).

doi:10.1016/j.cma.2003.12.040

Nomenclature

N number of optimization variables
j counter of optimization variables
NC number of inequality constraint functions
m counter of inequality constraints
NC_{act} number of active constraint functions
m_{a} counter of active constraints
NCV number of violated constraint functions
v counter of violated constraints
$\mathbf{X}(x_1, x_2, \ldots, x_N)$ design vector containing the optimization variables
$W(\mathbf{X})$ cost function of the optimization problem
$G_m(\mathbf{X})$ nonlinear inequality constraint functions
x_j^{l} lower bound of the jth optimization variable
x_j^{u} upper bound of the jth optimization variable
i iteration counter of the current design cycle
$\mathbf{X}_i(x_1^i, x_2^i, \ldots, x_N^i)$, $\mathbf{X}_{\mathbf{SOL}}^i$ design vector found in the ith optimization cycle by solving the current linearized sub-problem
$\mathbf{X}_{\text{OPT}}(x_{\text{opt},1}, x_{\text{opt},2}, \ldots, x_{\text{opt},N})$ optimum design vector updated each time the current iteration results in design improvements
P_0^i linearization point used in the ith optimization cycle: point of the design space about which the nonlinear problem is linearized
$\mathbf{X}_0^i(x_{0,1}^i, x_{0,2}^i, \ldots, x_{0,N}^i)$ design vector defining the linearization point P_0^i used in the ith design cycle
$\boldsymbol{\delta}\mathbf{X}_{\text{TR}}(x_1 - x_{0,1}^i, x_2 - x_{0,2}^i, \ldots, x_N - x_{0,N}^i)$ search direction vector originating from the linearization point P_0^i of the current design cycle
X generic point of the design space: it is defined by the $\mathbf{X} = \mathbf{X}_0^i + \boldsymbol{\delta}\mathbf{X}_{\text{TR}}$ vector where the N design variable values are stored
$\rho(X)$ trust region parameter computed at the X point of the design space
$W_{\text{APP}}(X)$ approximate cost function computed at the X point of the design space
$\varepsilon_{\text{LIN}}^i(X)$ linearization error computed at the X point of the design space in the ith optimization cycle
$\varepsilon_{\text{LIN}}^{\text{LIM}^i}$ allowable linearization error computed in the ith design cycle
$\varepsilon_{\text{LIN}}^{\text{SOL}^i}$ linearization error computed at the intermediate solution of ith design cycle
$\varepsilon_{\text{LIN}}^{\text{INV}^i}$ linearization error computed for the intermediate solution obtained in the $(i-1)$th design cycle $(\mathbf{X}_{i-1})$ if the nonlinear functions are linearized about the current intermediate design point $(\mathbf{X}_i)$
$\mathbf{S}_k$ descent directions defined by perturbing the kth design variable
k counter of perturbed variables and search directions $\mathbf{S}_k$
$\mathbf{S}_{\text{LIM},r}$ limit directions orthogonal to the gradient of cost function in the linearization point P_0^i
$\mathbf{S}_{\text{des},r}$ descent directions obtained from the limit directions $\mathbf{S}_{\text{LIM},r}$
r counter of the limit directions orthogonal to the gradient of cost function in P_0^i
p counter of the feasible sub-segments (i.e., parts in which the solution step size $\|\mathbf{X}_{\mathbf{SOL}}^i - \mathbf{X}_0^i\|$ is divided) actually found when the check on local non-convexity of the constraint domain is performed
∇ gradient operator