Engineering Structures 33 (2011) 433–444

Contents lists available at ScienceDirect

Engineering Structures

journal homepage: www.elsevier.com/locate/engstruct

Multiple cardinality constraints and automatic member grouping in the optimal design of steel framed structures

Afonso C.C. Lemonge [a,*], Helio J.C. Barbosa [b], Alvaro L.G.A. Coutinho [c], Carlos C.H. Borges [d]

[a] Departamento de Estruturas, Faculdade de Engenharia, Universidade Federal de Juiz de Fora, Campus Universitário, Bairro Martelos, 36036 330 Juiz de Fora MG, Brazil

[b] Laboratório Nacional de Computação Científica, Rua Getúlio Vargas 333, 25651 075 Petrópolis RJ, Brazil

[c] Programa de Engenharia Civil, Universidade Federal do Rio de Janeiro - COPPE/UFRJ, Caixa Postal, 68506 Rio de Janeiro, Brazil

[d] Departamento de Ciência da Computação, Instituto de Ciências Exatas, Universidade Federal de Juiz de Fora, Campus Universitário, Bairro Martelos, 36036 330 Juiz de Fora MG, Brazil

ARTICLE INFO

Article history:
Received 16 January 2009
Received in revised form
29 September 2010
Accepted 26 October 2010
Available online 27 November 2010

Keywords:
Structural optimization
Cardinality constraints
Genetic algorithms
Adaptive penalty

ABSTRACT

For structural optimization problems, such as the weight minimization of steel framed structures, the sizing design variables are often defined as the cross-sectional areas of the members, which are to be chosen from commercially available tables such as those provided by the American Institute of Steel Construction. Alternatively, the cross-section dimensions, b_f, t_f, d and t_w (which may be discrete or continuous) can be defined independently for each profile. This paper discusses the structural optimization problem of framed structures involving sizing design variables where a special genetic algorithm encoding is proposed in order to establish a strategy to discover ideal member grouping of members. Advantages in fabrication, checking, assembling, and welding, which are usually not explicitly included in the cost function, are thus expected. The adaptive penalty method (APM) previously developed by the authors is applied to enforce all other mechanical constraints considered in the structural optimization problems discussed in this paper.

1. Introduction

It is a common simplifying practice in structural optimization to group certain sizing variables (associated with members carrying out a similar function, for instance) into a single design variable. This is also done when symmetry conditions are to be imposed in the final design. In both cases, the total number of design variables is decreased, leading to a computationally less expensive problem.

In a weight minimization problem, for instance, when N sizing variables are defined, the optimum solution will likely display N different values. As N grows, the cost of the material used in the optimum solution decreases, but the difficulty of the corresponding search problem also grows. Besides that, Templeman [1] has pointed out that this cost does not include the economies of bulk purchasing or fabrication arising from the use of a smaller number of different sizes or types, which are far more difficult to quantify.

It is then clear that such a grouping procedure affects the final results and that its effectiveness depends crucially on the designer's skill in allocating members/variables to a group.

As a result, it would be advantageous to the designer to be able to [2]:

1. limit the number of different design parameters (such as cross-sectional areas) in order to (a) achieve economies of bulk purchasing/fabrication, and (b) simplify construction,
2. leave to the optimizer algorithm the task of deciding how to group members and/or design variables, and
3. achieve the best possible solution within the available computational budget.

Objectives 1 and 2 can be achieved by introducing a cardinality constraint as shown in [2]. A cardinality constraint arises naturally in structural optimization when the designer, faced with the task of selecting from a large set of commercial profiles (AISC tables, for example), wishes to employ a reduced number of distinct profiles. The experiments conducted in this paper involve the structural configuration of frames and we will consider m_c and m_g as the maximum number of distinct cross-sections for the columns and girders, respectively, which will be defined by the user as input data.

Objective number 3 can only be attained with a careful formulation of the optimization problem on the part of the designer. He or she should initially group certain design variables in order to enforce the desired symmetries or any other required

* Corresponding author. Tel.: +55 32 3229 3412; fax: +55 32 3229 3401.
E-mail addresses: afonso.lemonge@ufjf.edu.br (A.C.C. Lemonge), hcbm@lncc.br (H.J.C. Barbosa), alvaro@nacad.ufrj.br (A.L.G.A. Coutinho), cchb@lncc.br (C.C.H. Borges).

0141-0296/$ – see front matter
doi:10.1016/j.engstruct.2010.10.026