AUTOMATED STRUCTURAL DESIGN USING IMPLICIT ENUMERATION TECHNIQUES

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by

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1 Introduction

1.1 General Remarks

Automated design is a topic of interest in every engineering discipline. The contributing factor is that design, unlike analysis, is a multivalued problem. In general, most design problems do not have a unique solution.

Early approaches to automatic design of structures focused on the automation of standard office design practices. However, this approach is useful primarily for specific cases only. It lacks flexibility and is difficult to generalize. The second approach is analysis-oriented, and is based on structural criteria. The third approach involves the application of mathematical programming ideas.

Numerous automatic design algorithms have been developed based on these approaches. However, almost all the available algorithms for the optimal automatic design of engineering structures make the assumption that design variables, such as member sizes, are continuous-valued, and that the material and its properties from which each member is made, is known in advance. In practice, however, designers rarely have the freedom to choose member sizes from a continuous range, as this implies a separate and expensive fabrication process for each member. Usually, designers are

restricted to choosing member sizes from a discrete set of available pre-fabricated sizes. Furthermore, although the range of available sizes may be large, it is common practice to pre-select a small subset of perhaps five or six of these sizes which may actually be used in design.

Designers may also find difficulty in specifying the material properties of each member before the design process starts. Typically, a particular steel section, reinforcement bar or concrete may be produced in several steel grades or concrete strengths, each with a different set of material properties and costs. Ideally, the design process itself should select the most appropriate material for each member.

Furthermore, difficulties are encountered with the design requirements and codes specifications. Many of these are developed by designers after several years of experience and successful design. Furthermore, these specifications, as presented in the codes, represent functions that are nonlinear and discontinuous. Thus, they are not easily formulated as a continuous function as required in mathematical and optimal criteria algorithms.

Also, the objective function, in the practical world, is the cost of the structure rather than weight. Cost is a function of several factors, and it is not a continuous function of the design variables; rather, it may be a function of economics (availability

and cost of the materials) and fabrication (construction methods). Thus, the discrete properties of the variables also imply that the objective functions vary in a discrete, discontinuous fashion.

Although the discrete nature of member sizes and design specifications has long been recognized, little research has been devoted to automated structural design incorporating discrete design variables and discontinuous constraints. The characteristic of these problems precludes the application of many widely used mathematical optimization and optimal criterion procedures. For example, linear programming is not directly applicable because of nonlinearity of both the constraints and the objective function. Dynamic programming is not directly applicable because there is not a sequential flow of information. Gradient search and pattern search methods are not applicable, because the objective function is neither continuous nor unimodal and because the design variables are defined only at discrete values.

Attempts have been made to add these discrete properties to existing, computationally efficient, continuous valued optimization methods. An initial approach was to replace the discrete value variable with a continuous one, to solve the resulting optimization problem with a "continuous" method, and then finally to round off the solution to the nearest available size.

This approach, while useful in some problems, is not without pitfalls.

Consider a hypothetical function with contours as shown in Figure 1.1.1. The + 's represents available combinations of d_1 and d_2. The optimal solution of the continuous problem is at O (x_1,x_2). If the values of x_1 and x_2 obtained for this solution are rounded to the nearest integer values, the result is neither an optimal nor a feasible solution. The actual discrete optimal feasible solution is represented by P, and P is not adjacent to O in each variable.

Thus, even if a continuous solution may be obtained from a continuous design algorithm, there is no way of determining a priori for each structural member whether it should be rounded up or rounded down in size. Ad hoc rounding rules may be devised for some structures, but they offer no guarantee of optimality or feasibility. One section size may in fact separate a good design from an optimal design. Even so, for practical situations, this rounding process turns out to be a combinatorial problem of immense size. Consequently, the use of continuous optimum design with some approximate rounding rules cannot be recommended, especially when the member sizes are limited to a small discrete set covering a wide range of sizes.

Unfortunately, even if there exists a continuous analog of the discrete problem, the complexity of these methods is then greatly increased and its efficiency severely reduced.

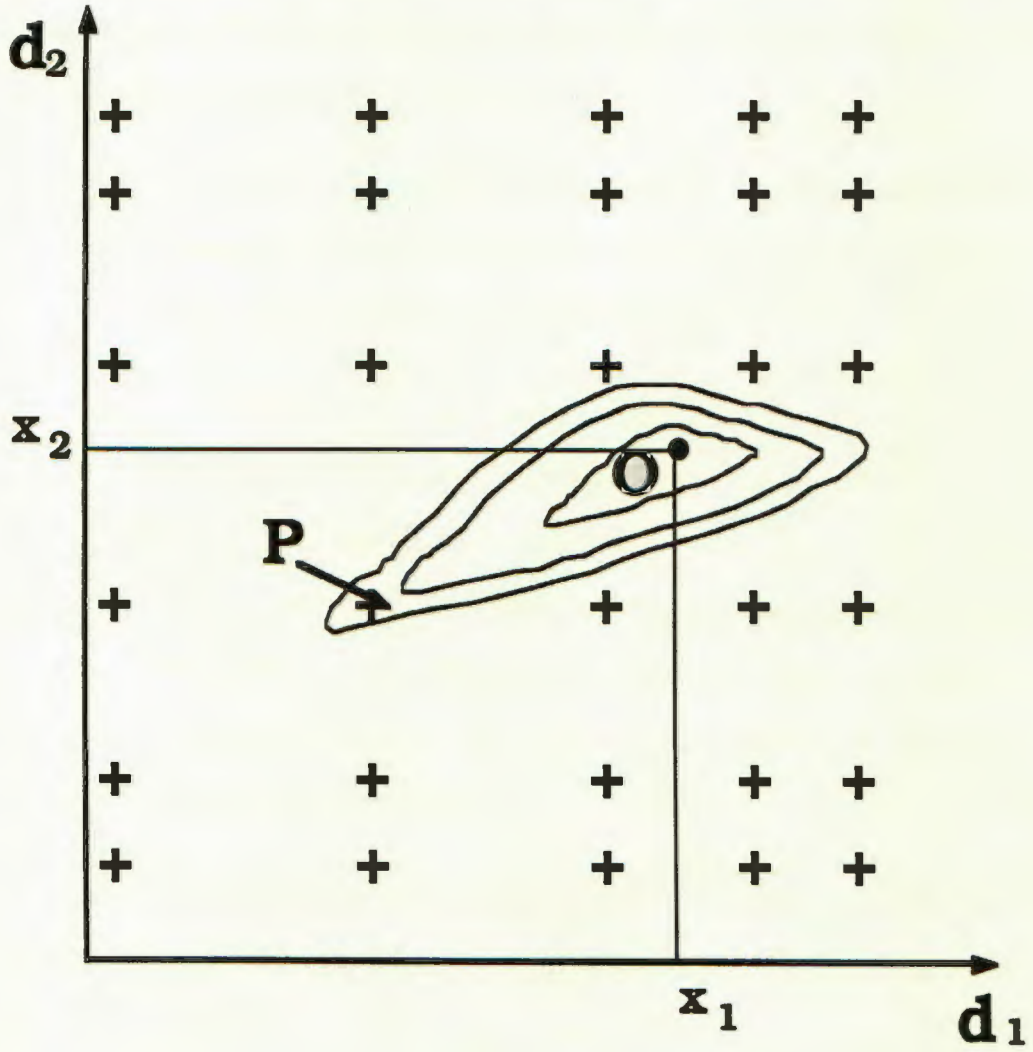

Figure 1.1.1
Continuous Solution and Discrete Solution