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IIc

Comments by the General Reporter

Remarques du rapporteur général

Bemerkungen des Generalberichterstatters

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Examples of Computer-Aided Optimal Design of Structures — General Report

The main subject of Theme II is on "Progress in Structural Optimization", which was originally proposed by the Japanese National Group of IABSE, because it was intended to stimulate and encourage Japanese engineers to apply the concept and method of optimization to problems of structural design, since the structural optimization has very recently been introduced into Japan. Along this intention we are very thankful for the three excellent Introductory Reports.

Dr. Gellatly and Mr. Dupree presented a very excellent paper as an introductory report on applied structural optimization in terms of examples of computer-aided optimal design of structures. They covered two different approaches to the optimum design of complex structural systems, emphasizing the practical aspects of design problems intended for producing a useful tool for designers.

The first approach, "Optimality Criteria Approach" will be accepted by designers because of its simplicity and effectiveness. The approach to the weight minimization of fixed-geometry structures with constraints based on the use of optimality criteria, appears to offer considerable advantage over mathematical-programming based methods. At comparative studies, the present method seems to reach a similar or better design in considerably fewer iterations than most numerical search methods with the reduction of computational costs.

They presented five examples, and also Dr. Gellatly discussed this approach at his other paper[1)] at an example of "Twenty-five-bar Transmission Tower" in which, using the current program, convergence was obtained in seven iterations to get its minimum weight, although, using a numerical search method, over one hundred analyses might have been required.

These results are very encouraging us, because they indicate that some, if not all, of the difficulties encountered in large-scale optimization problems for the very large number of variables in finite element representation of real structures, can be eliminated through this type of approach. However, certain problems may still remain to be unsolved, particularly with regard to convergence characteristics.

The second approach is labeled Sieve-Search Procedure developed at Bell Aerospace Company, the guiding philosophy of which is that an optimum system is an optimum arrangement of pre-optimized components. The results obtained from the design studies on high-speed vessels and a design study on a complete bridge structure have indicated that, firstly, the method will permit the full variation of construction method, materials and configuration as well as component sizing, and secondly, this method is also an efficient cost-effective approach to automated optimum design.

Dr. Gellatly and Mr. Dupree suggested finally that the ideal solution for optimization problems would possibly appear to be a combination of the two approaches, in which the sieve-serach defines configuration and non-continuous variables and the optimality criteria method will be used for refinement of the design, expecting a considerable potential for overall system optimization at various design problems.

We have been expecting a number of papers to be presented at the Preliminary Report under the stimulus and for the discussions of the Introductory Reports. For the Sub-Theme IIc, the following five papers have been accepted:

1. The paper presented by Mr. Gurujee

The paper shouldhavebeen discussed at Theme IIa. He proposed a general optimization algorithm for a structure. A structural optimization problem can be generally solved as a sequence of analysis-programming cycles by the mathematical programming. In the optimization process which the author proposed in the form of a chart shown in Fig.1 at the Preliminary Report, p.179, the relation between the changes in the behavior variables due to a specified change in each of the design variables, is found and stored in the form of "Sensitivity Matrix". Then, the programming problem can be solved by using the penalty function method. In this paper, however, he did not show any specific examples to which his proposed method was applied.

2. The paper presented by Prof. Yamada and Mr. Furukawa

They treated the optimal design of a system of tower and pier of a suspension bridge, on the elastic foundation subjected to earthquake ground motion. They showed an example how to combine mathematical programming and dynamic structural analysis through response spectrum for a dynamic loading problem, referring to Figs. 1 and 2 at the Preliminary Report, p.184. To simplify very complicated real dynamic behavior of the system, two design variables were selected: longitudinal width of the pier and stiffness of the tower. A generalized cost was selected as the objective function, and requirements for stress of the tower and displacement of the pier at its top, and buckling of the tower, overturning of the pier, and physical limits, were constraints.

Since the problem is non-linear and undifferential, the Sequential Unconstrained Minimization Technique by Powell's direct search method was applied to optimization, probably because the method is more reliable in terms of guaranteed convergence if the first derivatives or no derivatives are available. At a numerical example, the authors found out that the generalized cost is greatly affected by the modulud of elasticity of the foundation. This problem is overall system optimization of a simple tower-and -pier system. Shape and geometry optimization and combination with detailed element optimization will be a future problem.

3. The paper presented by Prof. Konishi and Prof. Maeda

The paper on "Total Cost Optimum Design of I-Section Girders for Bridge Construction" treated examples of detailed design optimization of main elements of girder bridges. Generally, at the problem of bridges, cost optimization is selected as the objective function, but the cost used to be defined material cost only or material plus overall fabrication cost. At the present paper, the objective function consists of material and fabrication costs, which cover costs of full-scale drawing, machining, shop welding, shop assembly and shop painting base on actual detailed informations obtained at fabricating shops in Japan.

A computer-aided optimum design of girders by the method of "Sequential Linear Programming" was illustrated at I-shaped, deck-type, welded plate girders with five different span lengths, and sixteen design variables including material selection (See Fig.2 at the Preliminary Report, p.192). The influence of material and size selections on the total cost was discussed in detail, to help designers carry out a detailed element design efficiently from the point of optimization, taking into consideration not only material cost, but also shop fabrication cost.

For a specific or individual bridge, it would be required to study on an overall optimization design including transportation and erection costs for a system of main girders, laterals and decks.

4. The paper presented by Professor Schindler

He proposed an optimization method to combine design-oriented approach and computer-oriented approach, in which a designer can search for a range of approximation near an optimum value with a design program, within the capacity of a computer, not spending so much money and time for computer calculation.

He illustrated his method at the optimum design of a railway truss bridge shown in Abb.1 at the Preliminary Report, p.196, taking into account three kinds of deck system , two kinds of steel, two kinds of bridge class, five kinds of span length. The objective function was total steel weight, and the design variables were span length, number of panels, height of the truss, and width of chord members. For various truss heights, steel weights were calculated by a computer with parameters of span length and number of panels. By comparison of each steel weight, the minimum weight was found out for a certain value of span length and of number of panels.

This approach is not straightforward, but rather comparative or selective. Sometimes depending on a problem, this approach may save the time and money for a computer more than mathematical programming methods. This kind of approach could be examined in contrast with a study presented by Prof. Ohkubo at Theme IIb [2)] who proposed a sub-optimizing method for trusses.

5. The paper presented by Messrs. Tanaka, Kamemura and Maruyasu

They introduced the total computer-aided design system for girder bridges. which has recently been developed at Nippon Kokan Company, Japan. Automated computer techniques for design have advanced so that various types of detailed element design and selection among alternatives for minimum cost can be carried out. In this sense, the proposed computer system is a well advanced method for automated design of a girder type bridge in its element and overall system.

As the authors pointed out, such a computer program could be used for lowering cost, increasing standardization of elements and also evaluating the effects of changing constraints on weight, cost and behavior. The authors discussed conceptually the interaction between optimum design and automated design, but they did not show concretely with an illustration how to incorporate optimization into the automated design program.

The proposed computer system should be examined in contrast with the flow chart of Sieve-Search Optimization for bridge design proposed by the Introductory Reporters, Dr. Gellatly and Mr. Dupree [3].

As a concluding remark, at the Prepared Discussion nore demonstrations of structural optimization are welcome in terms of examples to encourage designers to utilize optimization techniques at their routine office practice, and also to discuss what kinds of problems have been encountered at practical designs.

References:

1) R.A. Gellatly & L. Berke, "Optimality-criterion-based Algorithms", Optimum Structural Design, ed. by Gallagher & Zienkievicz, John Wiley, 1973, p.44.
2) S. Ohkubo & T. Okumura, "Structural System Optimization Based on Sub-optimizing Method of Member Elements", Prel. Rept. 10th Congress, IABSE,1976.
3) R.A. Gellatly & D.M. Dupree,"Examples of Computer-Aided Optimal Design of Structures", Introductory Rept., 10th Congress of IABSE, 1975.

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