Comments by the author of the introductory report: system and geometrical optimization for linear and non-linear structural behaviour

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Comments by the Author of the Introductory Report

Remarques de l'auteur du rapport introductif

Bemerkungen des Verfassers des Einführungsberichtes

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System and Geometrical Optimization for Linear and Non-Linear Structural Behaviour

Please accept by apologies for being unable to attend and report personally to this meeting but circumstances beyond my control have led to my absence. I offer my best wishes for the success of this session and I thank in advance Dr. Templeman for substituting on my behalf.

Many discussions at earlier IABSE sessions have considered optimization. Professor Courbon defined optimization as designing and constructing a structure at the lowest cost with the object of fulfilling a well-defined purpose. Cost consideration must be given to safety, service life, maintenance and future adaptability. Within this broad context, the speciality of structural optimization arose to provide specific design purposes and methods which will aid in reaching an optimum structure. Thus, in the same way that matrix methods or finite elements aid in structural analysis, techniques of structural optimization have been developed to improve design procedures. Its applicability depends as much on reducing the ultimate cost of the structure as on savings in time and cost for the design engineer.

Historically, optimization has used simple design rules to check optimum designs. Gradually, more sophisticated mathematical methods applied with computer programs arose to systematically search and locate optimum structures.

A description of formal optimization methods taken from fields of mathematical programming and Operations Research has been presented by Dr. Templeman in his survey paper published in the Introductory Report. Such methods have found widespread application in the design of structural elements which are described by a number of design variables and constraints determined by codes of practice.

Figure 1 of my Introductory Report shows examples of such element designs. There is an example of a welded box girder for which I have had occasion to design large numbers for crane structures. Another example, is the welded plate girder which we designed based on the rather complex provisions for unbraced members in the AISC specifications. Also shown is a prestressed concrete beam with eleven design variables. The element design is controlled by contraints on loading and prestress force and deformations. Other element designs reported include welded columns, stiffened ship plates, shear walls, prestressed plates and reinforced concrete beams.

Element optimization has led to a number of computer programs whose function is to efficiently design a variety of elements and perform the tedious calculations required by the designer in trying to proportion such elements. The programs have usually been based on penalty or geometric programming methods of optimization. Professors Ohkubo and Okumura in their Preliminary Report paper have derived the optimum design of elements such as bridge girders and truss members using the method of sequential linear programming. This was then adapted by them to a branch and bound procedure for solving discrete variables such as steel type and flange thickness. A different approach to the optimization of element, in this case concrete bridges, is presented by Ulizkij and Jegoruschkin. It uses influence factors for predicting the behaviour of the bridge and therefore simplifies subsequent optimisation.

A combination of elements as in a total structural framework requires a different approach to optimization. Any changes in the design on the path to the optimum may subsequently require complete reanalysis of the structure to determine new stresses and deflections. In Figure 2 of my Introductory Report, a grillage is shown in which redistribution of forces occurs following each design change. The optimum design procedure for this case was reported by Moses and Onoda. Other examples of system optimization are statically indeterminate trusses and frames.

A system optimization, to be efficient, requires techniques such as the sequential linear programming shown by Ohkubo and Okumura. It is important that the number of cycles of reanalysis does not become large leading to excessive demands for computer time.

Inclusion of gross geometrical variables of the structures represents an important improvement in the class of problems for which optimization may be applied. Figure 4 of my Introductory Report shows a transmission tower in which the tower shape and location of nodes is permitted to change leading to significant reductions in structural weight. The left figure is the original design while the right is an optimized case. The optimization takes place automatically with a program using methods of minimisation working with respect to the geometric or shape design variables.

Another example of geometric optimization is the arch dam reported by Vitiello and shown in Fig. 5 of my Introductory Report. The mesh shown is the finite element analysis while X_1 - X_4 are the geometric design variables. Such applications show that major improvements in structural efficiency can often come from variations in geometric design variables. This is investigated for arches and suspension bridges by Professor Hirai and Yoshimura in their Preliminary Report.

Form and type of structure represent a high level of optimization for which programs have only recently been attempted. Figure 6 from my Introductory Report paper shows a schematic diagram for optimizing the cost of single storey factory buildings. The variables include structural layout such as bay spacing and also the type of joists, girders, columns and foundation including material type and detailed design variables. The design methods, automatically performed by the computer, can lead to important structural savings and can be updated following changes in individual construction and material costs.

Bomhard in the Preliminary Report shows a comparison of structural form with an illustration of beams, arches and suspensions to cope with long-span structures. Suruga and Maeda have developed a very interesting concept of a decision matrix to compare structural forms for their application to floor systems of long-span bridges. Each type of floor system such as composite girder or orthotropic deck is rated according to cost, construction and performance before a final decision can be made. This leads to a multi-objective criteria for optimization which may have important applications to other examples such as comparing economy with safety. The inclusion of safety directly in the optimization methodology is covered by Tegze and Lenkei with an example of collapse analysis of statically indeterminate plane structures.

The inter-relationship of safety and economy of structure has been recognised by many authors, but more effort is required to bring these factors into both the code specifications and the programs for optimum design.