Introducing artificial intelligence into structural optimization programs

S.F.Jóźwiak
Warsaw University of Technology, Institute for Road and Bridge Design, Poland

1 INTRODUCTION

Artificial Intelligence /AI/ is defined /Winston 1984/ as the branch of the Computer Science concerned with the study of the ideas that enable computers to be intelligent. The main purpose of the application of AI in engineering is to develop computer programs which function better as tools for engineers and designers. Many computer programs today have properties which make them inconvenient to their final users and the research carried within the field of AI provides tools and techniques so that these restriction can be removed.

The continuous progress in computer technology has lead to developing efficient computer systems which can be applied to more than simple solving sets of equations.

2 THE FIELD OF AI

The ultimate purpose of the AI is to build computer programs that are able to modify their bahaviour basing on the extracted experience. Such programs should be able to change the structure and/or the content of their knowledge base as new information becomes available. The research carried within the field of AI provides tools and techniques so that these purpose could be met. The necessity of dealing with the knowledge of non-numerical nature has lead to developing a separate part of AI known as Knowledge Engineering. Knowledge Engineering is concerned with representation of knowledge and symbolic reasoning. The concepts and techniques developed in this field allow the knowledge to be represented and handled so, that the system can exhibit intelligent behaviour. An important part of research carried within the field of AI is that concerned with machine learning as it holds the key to an improvement methods by which computers can acquire knowledge.

Although a fully intelligent computer program for practical application is not available at present, the performance of prototype programs is promising and the progress in

the field of computer science is co rapid that many concepts which seemed like science fiction yesterday are reality today.

The AI is a very large topic with many subfields and the analysis presented in the paper will therefore focus only upon the application of AI in structural optimization programs.

3 AI IN ENGINEERING OPTIMIZATION

Optimization techniques provide tools for improving the effectiveness of design activity by minimizing weight, cost or other criteria of merit for a structure. Optimization procedure finds the solution in an iterative manner and the basic function of the procedure is to carry out iterations. The main purpose of the application of AI in engineering optimization is to apply additional knowledge in order to shorten calculations as a small amount of knowledge may sometimes save an enormous amount of calculations. This statement is not quite new, but the development of techniques for knowledge representation and processing only made it possible to incorporate knowledge into computer programs in the form of program modules.

The incorporation of different classes of knowledge into computer programs was the subject of research by Gero /1986/ who considered the application of knowledge in multicriteria optimization programs. The various kinds of knowledge were encoded into a computer program in order to improve the design process. Introduction of intelligence and knowledge into optimization programs was also the subject of investigations by Brotchie et. al. /1986/ who considered the prospects of developing a general intelligent optimization program. The program would be provided, among others, with the abilities of reasoning about future actions from extracted experience, qualitative knowledge of the objective function and constraints, knowledge about search techniques etc. Incorporation of heuristics into optimization problems arising in the field of operational research was analysed by Burkard /1983/. The main feature of the mentioned programs is that the knowledge on the problem must be established by the human designer and must be encoded into the program. Knowledge engineering techniques are used to capture knowledge in a more useful way than is possible with traditional program tools.

Another concept, developed within the field of AI /Jóźwiak 1986/, is to develop computer program which shall be able to take advantage of previous results in order to improve its operation and shorten calculations.

4 TAKING ADVANTAGE OF PREVIOUS RESULTS

The main obstacle against the wider application of mathematical programming methods /MPM/ in structural design is that even medium sized, idealized examples of structural design

require vast computer resources while real life structures are very difficult to calculate in reasonable time. Thus the main purpose of the research is to shorten the total calculation time. This can be done by taking advantage of previous results. Previous results can provide numerical information concerning initial values of decision variables as well as nonnumerical information concerning the significance of constraints and possibilities of eliminating superfluous constraints in calculations.

The total computing time can be shortened by decreasing the number of iterations /i.e. the number of calculations of the values of the objective function and the constraints for given values of decision variables/ and by shortening the time necessary for single iteration. The number of iterations can be decreased by recalling relevant designs and taking advantage of previous results in appropriate choice of initial values of decision variables /the starting point/. Previous results can be used to develop empirical formulae according to which initial values of the decision variables can be estimated or can be applied directly /as initial values of design parameters/. The main problem in practical application of the concept is that structural designs are very customized i.e. different functional and aesthetic requirements, local foundation and loading conditions can change significantly stress distribution in elements of the structure. All this results in that there are no two identical structures and a criterion must be stated according to which different structural systems can be compared.

The total time necessary to find the optimum depends i.a. on the time needed for a single determination of values of the objective function and the constraints /i.e. the analysis of the optimization model/. Thus the total computing time can be decreased by shortening the time needed for a single analysis of the optimization model. This can be done by eliminating superfluous constraints and rearranging the remaining ones. In practical engineering design neglecting any constraint can be dangerous, as this may result in the violation of a constraint and diqualify the design. To avoid this, the following procedure can be suggested: basing on the previous results superfluous constraints are eliminated and optimization is carried out with the reduced set of the constraints; for the optimal values of the decision variables all constraints are checked taking into account the neglected ones. The time necessary for the single analysis can be also shortened by rearranging the constraints. A set of the decision variables can be the solution of the optimization problem only if all constraints are complied with.Thus in a case of a group of constraints, each of them requiring approximately the same amount of time to be calculated, more strict constraints should be checked first. If tolerance is not met, remaining equations can be neglected and another set of decision variables is generated. Similarly as in the case of neglecting superfluous constraints, the information on the constraints that were critical in former design of analogious structures is very useful and should be extracted and stored.

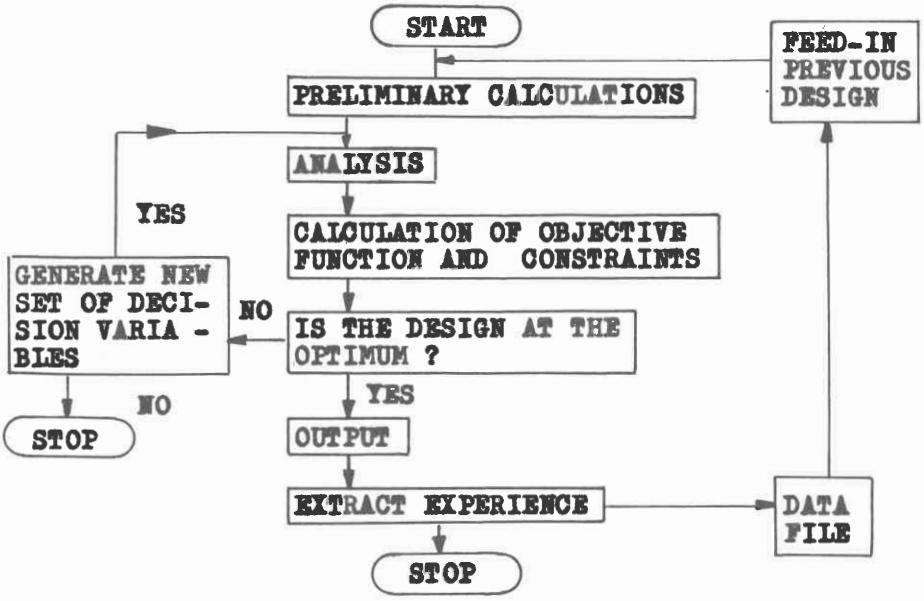

Figure 1. Structural optimization program taking advantages of previous results

A computer program for structural optimization, taking advantages of previous results, is presented in Figure 1. In comparison with a conventional optimization program, following aditional elements have been introduced:
- the module that incorporates previous experience,
- data base, where the data concerning previous designs are stored,
- the module that extracts experience from the results produced by the program.

In case of more complex problems special data-management modules for data retrieval may be necessary to improve calculations.

5 NUMERICAL EXAMPLE

Basing on the above considerations, a computer program has been developed for the optimization of truss structures. The optimization problem is stated as follows:

find a vector of decision variables $X = \{x_1, x_2, \ldots, x_n\}$, which minimizes the weight of the structure

with the following constraints imposed

(1) $\quad x_i^{min} \leq x_i \leq x_i^{max}$,

(2) $\quad u_j \leq d_j$,

(3) $\quad F_k \leq R_k$,

where x_i - i-th decision variable, x_i^{min}, x_i^{max} - given

values, u_j - j-th joint displacement, d_j - allowable value of j-th joint displacement, F_k - internal stresses in k-th element, R_k - allowable value of stresses in k-th element.

Unless a sufficient number of data are stored in the data file, the program acts as an ordinary optimization program i.e. the initial values of decision variables must be estimated by designer.

If previous design results are to be used for the proper selection of initial values of decision variables and rearranging of the constraints, a rule or a criterion must be stated according to which different structural systems can be compared. The criterion adopted in the paper is based on the following relation,

$$c_j = \frac{1}{K} \sum_{k=1}^{K} \frac{s_k}{s_{jk}} , \tag{4}$$

in which s_k - value of k-th parameter which has been used to compare different structural systems, s_{jk} - value of kth parameter of j-th structure which has been previously designed and dimensions of which have been stored in the data file, K - number of parameters.

To estimate the effectiveness of taking advantage of previous results the results obtained by the application of conventional program and by the application of modified optimization program were compared. The numerical analysis was performed for the structure presented in Figure 2. Cross sectional areas were taken as decision variables and the number of decision variables was equal to 3. Eight different data sets concerning previous succesful designs were stored in the data file at the beginning of the analysis. Each structure was designed twice: first with the application of the conventional approach and then - with the application of the modified approach.

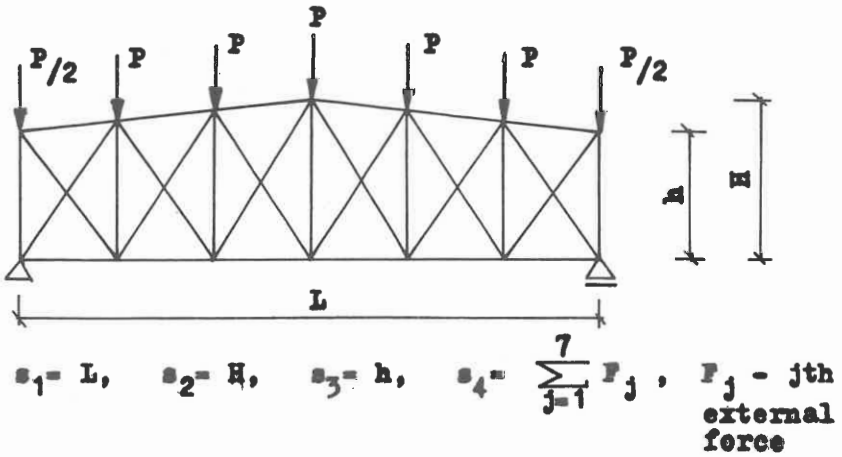

Figure 2. Plane truss

In four design problems, the average number of iterations necessary to find the optimum by the application of conventional approach /N_c/ is 411. For the improved program, the average number of iterations N_i is 171. As the computation time is approximately proportional to the number of iterations, the average time necessary to find optimum is 2.4 times shorter for modified approach than the time needed to find optimum by conventional approach.

This result was obtained by taking advantage of previous results only and neglecting other possibilities of shortening calculations discussed in the paper.

CONCLUDING REMARKS

The central issue considered in the paper is the possibility of improving structural optimization programs by introducing additional information /knowledge/ which can be encoded in the form of program modules. The techniques developed within the field of AI enable the knowledge to be represented and applied. The knowledge may concern the optimization problem, solution techniques, existing solutions etc. This can significantly shorten analysis, as a small amount of additional information can sometimes save an enormous amount of numerical analysis. Application of AI concepts in optimization programs can improve the design process and the value of the resultant design. Although the performance of the prototype programs is promising, further research is necessary.

REFERENCES

Winston P.H. 1984. Artificial Intelligence, Cambridge; Addison-Wesley.

Gero J.S. Balachandran M. 1986. Knowledge and design decision process, in: Sriram D. Adey R. /eds./ Application of Artificial Intelligence in engineering problems, Proceedings of Int. Conf., Berlin: Springer V.

Brotchie J.F. Sharpe R. Marksjo B. 1986. Introducing intelligence and knowledge into CAD, in: Sriram D. Adey R./eds./ Application of Artificial Intelligence in engineering problems, Proceedings of Int. Conf., Berlin: Springer V.

Burkard R.E. Bonniger T. 1983. A heuristic for quadratic boolean programs with application to quadratic assignment problems, European J. Operational Research, 13, 374-386.

Jóźwiak S.F.1986. Artificial Intelligence - the means for developing more effective structural optimization programs, in: Yagawa G. /ed./ Proceedings of Int. Conf. on Computational Mechanics, Tokio: Springer V.