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OPTIMIZATION OF MAIN GIRDERS OF OVERHEAD TRAVELLING CRANES BY EXPERT SYSTEMS*

Károly,JÁRMAI, assoc.prof.,PhD.,***Zsolt,SOMOGYI,*** PhD.student,***László,MÉSZÁROS,***sci.res.fellow
University of Miskolc, H-3515 Miskolc, Hungary

SUMMARY

Artificial Intelligence techniques are the best utilized in identifying and evaluating design alternatives and there relevant constraints while leaving the important design decisions to the human. Expert system shells, the Personal Consultant and the LEVEL 5 OBJECT are used. The connection of the optimization techniques and the expert shells make it possible to find the best solution among several alternatives. The Rosenbrock Hillclimb procedure is used at LEVEL 5 OBJECT and five single-objective and seven multiobjective optimization techniques are used at Personal Consultant. We show the benefits of these systems in the optimum design of main girders of overhead travelling cranes. At the example the double crane girders are welded and stiffened box ones, with one trolley on it. We've used the British Standard for the structural analysis.

1. INTRODUCTION

The emerging fields of AI and knowledge engineering offer means to carry out qualitative reasoning on computers. Advanced programs that can solve a variety of new problems based on stored knowledge without being reprogrammed, are called knowledge-based systems. If there level of competence approaches that of human experts, they become expert systems, which is the popular name for all knowledge systems, even if they do not deserve the name.

AI techniques provide powerful symbolic computation and reasoning facilities that accommodate intuitive knowledge used by experienced designer. AI techniques, knowledge engineering in particular, can be used in conjunction with numerical programs to serve as an interface between the alternatives and constraints and the designer. AI should be used in the following context [1]

- to track the available design alternatives and relevant constraints and to infer candidate modifications in order to improve the design,
- to observe the relationship - intuitive or numerical - between specifications and decision variables, and give advice on how to formulate the problem for optimization, in particular, to identify the limiting constraints and specifications.

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2. CAPABILITIES OF EXPERT SYSTEMS

Depending on the application, an expert system can perform ten type of projects as follows: *interpretation, prediction, diagnosis, design, planing, monitoring, debugging, repair, instruction, control.* We've used the expert systems for design.

3. COMPONENTS OF AN EXPERT SYSTEM

The three basic components of an expert system are

- the knowledge base,
- the inference engine,
- the user interface.

There are three main streams at expert systems

- rule-based expert systems can be backward or forward chaining,
- object-oriented systems,
- hybrid systems, which combine object-oriented techniques with rule-based ones [2,3,4].

There were some attends to connect the expert systems and structural optimization. One of them is an expert system for finding the optimum geometry of steel bridges [5].

The connection of single- and multiobjective optimization made it possible at the structural optimization to form a decision support system. At the multiobjective optimization there are several so called weighting coefficients for the designer to give the relative importance of the objective functions [6,7]. The decision support systems (DSS) and the expert systems (ES) are close together, but it is necessary to build an inference engine. The key concept in our approach is to give the user control of important design decisions.

Therefore, our approach in applying AI to engineering design is to use AI techniques for keeping track of all the design alternatives and constraints, for evaluating the performance of the proposed design by means of a numerical model, and for helping to formulate the optimization problem. The human designer evaluates the information and advices given by the computer, assesses whether significant constraints or alternatives have been overlooked, decides on alternatives, and makes relevant design decisions.

4. OVERVIEW ON PERSONAL CONSULTANT EASY [8]

Personal Consultant Easy (EASY) is an EMYCIN-like program developed by Texas Instruments to run on PC-s. Fact are represented as object-attribute-value triplets with accompanying confidence factors. Production rules represent heuristic knowledge. Personal Consultant can build systems of up to about 400 rules. A rule tests the value of an O-A-V fact and concludes about other facts. The inference engine is a simple back-chainer.

Control is governed primarily by the order of clauses in the rules. Uncertain information is marked by confidence factors ranging from 0 to 100. Personal Consultant accepts unknown as an answer to its questions and continues to reason with available information. There are explanation facilities in the program as well as trace functions for knowledge base debugging. Personal Consultant uses questions to prompt the designer to enter the initial information into a knowledge base. The tool provides several programming aids for debugging.

Personal Consultant is implemented in IQLISP. Sources of data can be other language programs or procedures such as FORTRAN, C, C++, data bases such as DBASE, LOTUS. The program has some graphics functions as well (DR HALO). The tool uses an Abbreviated Rule Language, ARL, to write the rules.

5. OVERVIEW THE LEVEL 5 OBJECT [10,11]

LEVEL 5 OBJECT (LO5) is an object-oriented expert system development and delivery enviroment. It provides an interactive, windows-based user interface integrated with Production Rule Language (PRL), the development language used to create L5O knowledge bases. The PRL Syntax Section provides syntax diagrams to follow logically when writing a knowledge base. System classes are automatically built by L5O when a new knowledge base is created, thereby providing built-in logic and object tools. The developer can use system classes in their default states or customize them. In this way, the developer can control devices,files, database interactions and the inferencing and windowing enviroments.

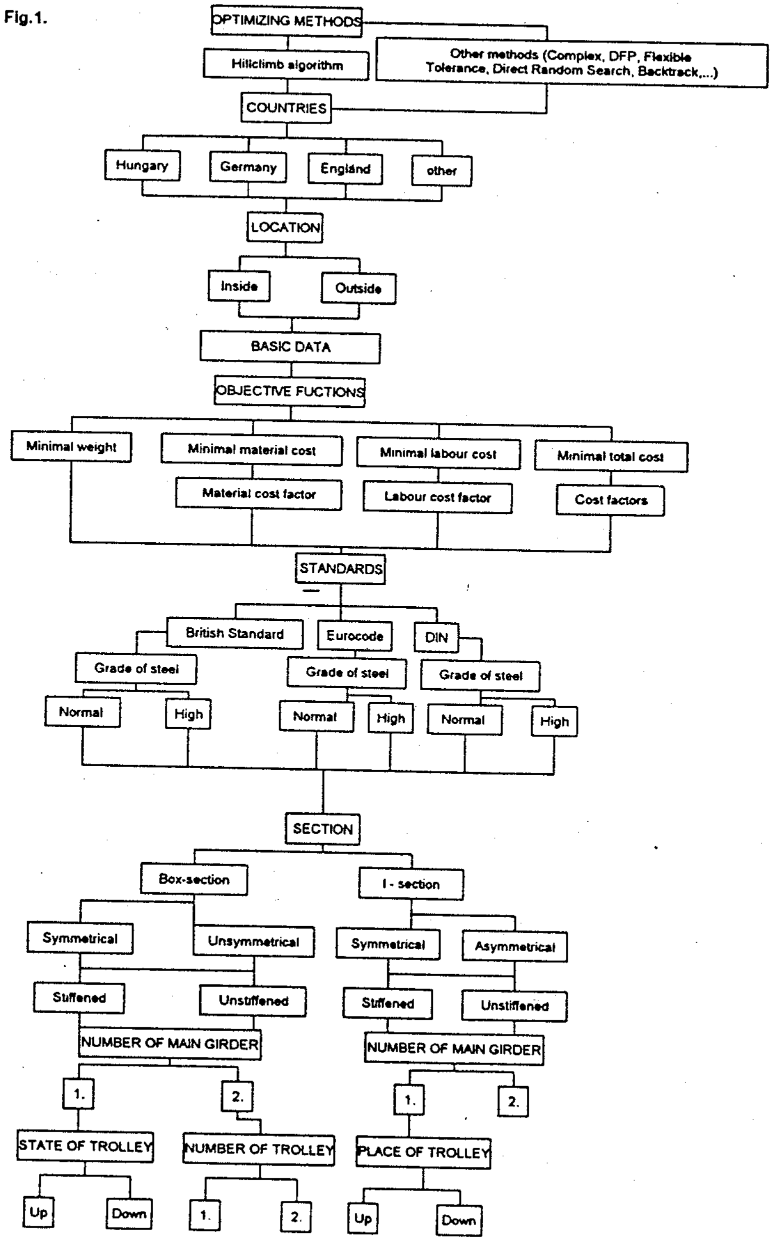
The most remarkable tools of LO5 are:

- object oriented programming (OOP),
- relational database handling (RDB),
- computer aided software engineering (CASE), and
- graphical development system.

The most remarkable tools of LO5 for IBM compatible PCs are:

- Microsoft Windows,
- programming with an object-oriented language (Borland C++),
- direct connection with dBase,
- direct connection with the fourth generation FOCUS data handling system,
- EDA/SQL interface to relational and non-relational databases,
- Rdb/SQL interface to VAX RDB/VMS databases, and
- own worksheet handling system (similar to LOTUS 123).

Fig.1.



Using LO5 there are two ways of developing programmes: they can be generated either by word processors or in the developing environment. Taking these capabilities into account, LEVEL5 OBJECT was found suitable for development expert systems for structural engineering.

There are a great number of expert shells available such as ART (Automated Reasoning Tool, Inference Corporation), KEE (Intellicorp), Intelligence Compiler (Intelligence Ware Inc.), Symbologic Adept (Symbologic Corporation), GURU (Micro Data Base Systems), etc. They are available on APOLLO or SUN workstations or on PC-s [2].

We've developed the optimization package on PC and we've found the previously described two softwares to be efficient expert shells, so we've made our development using these tools.

6. APPLICATION OF AN EXPERT SYSTEM FOR THE OPTIMUM DESIGN OF THE MAIN GIRDERS OF OVERHEAD TRAVELLING CRANES

The aim was to develop an expert system, which is able to find the optimum sizes of the welded box girder of the crane due to different geometry, loading, steel grades and design codes. The different variants can be seen in Fig. 1.

The total number of variants is about 60000 and it can be increased if we take into account other aspects and constraints in a modular way.

The decision support system, which was connected to the expert one, constraints 5 various single-objective and 7 various multiobjective optimization techniques. These techniques are able to solve nonlinear optimization problems with practical nonlinear inequality constraints. It could contain finite element procedures to compute the mechanical behaviour of the structures. The DSS system is described in [6].

7. ECONOMIC DESIGN OF BOX GIRDERS OF OVERHEAD TRAVELLING CRANES

Objective functions

- material cost of the girder, $C_m = k_m * \rho * V$ [kg], where ρ is the material density, V is the volume of the girder, k_m is the specific material cost.
- labour cost contains welding cost and surface preparation cost $C_l = C_w + C_s$,
- welding cost, $C_w = k_w*(a^2_w/\sqrt{2})*L_w* \rho *k_c$ [\$], where a_w is the effective size of weldment, L_w is the length of weldment, k_c is the difficulty factor of welding, which depends on the position of welding.
- surface preparation and painting costs, $C_s = k_s*(2*b*L+2*h*L)$ [\$], where b and h are width and height of the girder, k_s is the specific cost of manufacturing.
- total cost contains material and labour costs $C_t = C_m + C_l$

Design constraints

- constraint on the static stress at midspan due to biaxial bending according to BS 2573 and 5400 [9,10] is described by

$$M_x/W_y + M_y/W_y \leq \alpha_d * P_s$$

where M_x, M_y are the bending moments, W_x, W_y are section moduli, P_s is the permissible static stress, α_d is the duty factor.

- constraint on fatigue stress is as follows

$$M_{xf}/W_x + M_y/W_y \leq P_{ft}$$

where M_{xf} contains the live load multiplied by the impact, factor and the spectrum factor. P_{ft} is the fatigue stress.

- local flange buckling constraint is

$\sigma_{1f}/(P_s*K_{1f}) + ((\sigma_{bf}/(P_s*K_{bf}))^2 \leq 1$, where $\sigma_{1f} = M_x/W_x$; $\sigma_{bf} = M_y/W_y$, the K factors depend on the slenderness of the plate

$\lambda_f = (b/t_f)*\sqrt{R_{yf}/355}$, where R_{yf} is the yield stress of the flange plate

- local web buckling constraint is

$$\sqrt{\{(0.8.\sigma\sigma_{lf} + \sigma_{bw})/(P_s.K_{1w})\}^2 + \{(\sigma_{cw}/(P_s.K_{2w})\}^2 + \{(0.2.\sigma_{lf}/(P_s/K_{bw})\}^2 \cdot 3.(\tau_q/P_s/K_{qw})^2} \leq 1$$

where $\sigma_{bf} = \sigma_{bw}$; $\sigma_{cw} = F/(t_{1w}*a_w)$; $a_w = 50 + 2(h_r+t_f-5)$

the K factors depend on the slenderness of the plate

$\lambda_e = (h_w/t_{w1})*\sqrt{R_{yw}/355}$, where R_{yw} is the yield stress of the web plate.

h_r is the height of the rail.

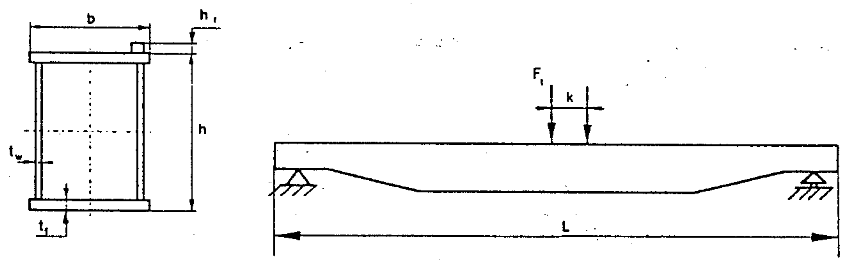


Fig. 2. Cross section of the welded main girder of overhead travelling crane

- local web buckling constraint on the secondary web is similar to the main web one, but we have to use t_{w2} instead of t_{w1} and there is no local compression, so $\sigma_{cw} = 0$.
- deflection constraint due to wheel load can be expressed as $w_{max} \leq L/(800\text{-}1000)$, where L is the span length.

8. EXAMPLE

Main data of an example solved by Personal Consultant

Hook load is H = 240 kN, length is L = 25 m,

mass of trolley is G_t= 30kN, distance between the trolley axes is

k = 2.5 m, height of rail is h_r = 50 mm, mass of the rail is p_r = 80 kg/m,

the Young module is E = 2.06 GPa, class of the crane is A7,

steel grade is Fe 430, stiffeners are 120*80*8 mm angle profiles.

The program is made in MS FORTRAN 5.0 on IBM PC/AT 386 type computer. In the expert system one part of the rules are concerning to the selection of the crane (see Fig. 1.). The second part is concerning to the selection of optimization techniques.

The weighting factors at the multiobjective optimization system and the uncertainty parameters at the expert system for the various objective functions are the same. There ranging is from 0 to 100 percent. It means the relative importance of the objective function.

The third part of the rules are concerning to the results of the optimization, to choose the smallest objective function value, where the ratio of web height and flange width and the ratio of the two web thicknesses are acceptable. For the first ratio it is given to be near to the golden ratio, for the second ratio it has technological reasons.

$$0.4 \le b/h \le 0.8; \qquad t_{w1}/t_{w2} \le 1.5$$

The result for a crane girder is determined with box girder section, unsymmetrical section, stiffeners on the webs, two main girders, one trolley and the degree of interest of total cost = 0.4 , material cost = 0.3, labour cost = 0.3. Specific costs are: material cost k_m = 1.[\$/kg], welding cost k_w = 10. [\$/kg], surface preparation cost k_s = 100. [\$/m^2] .

web height is	h = 1260. [mm],
main web thickness is	t_{w1} = 6. [mm],
secondary web thickness is	t_{w2} = 5. [mm],
width of the flange is	b = 700. [mm],
thickness of the flange is	t_f = 18. [mm],
total cost of the structure is	C_t = 16677.04 [\$]

The discrete value ranges of the variables are as follows: for h and b the step sizes were 20 [mm], for the thicknesses step sizes were 1 [mm]. Further development can be the installation of the new Eurocodes in the analysis to build the system in Borland C++, to use the Object Oriented Programming (OOP).

9.CONCLUSION

The main differences using the Personal Consultant and the LEVEL 5 OBJECT expert shells were, the at EASY all values for the computation should be given in advance, so the program goes on a given way bordering by the rules, but LO5 asks for the unknowns during the computation, it knows

what to ask for, more easy to jump from one level to another on the rules' tree and the optimum computation part is build into the expert shell. It means, that the second application is much close the original aim of artificial intelligence.

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Dr.Jármai could use the Personal Consultant (R) software during his stay in Sweden at Chalmers University of Technology in Gothenburg in 1991.