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OPTIMUM DESIGN OF MAIN GIRDERS OF OVERHEAD TRAVELLING CRANES USING AN EXPERT SYSTEM

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ABSTRACT

Artificial Intelligence (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 design alternatives and constraints and the designer. Expert system shells, the Personal Consultant Easy (1987) and the LEVEL 5 OBJECT (1990) are used. The connection of the optimization techniques and the expert shell makes it possible to find the best solution among several alternatives. The Rosenbrock Hillclimb procedure is used at L5O. We show the benefits of this system 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.

KEYWORDS

Structural optimization, expert systems, crane girder, welded structures..

INTRODUCTION

AI should be used in the following context (Harmon, Sawyer 1990):
- 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 (Garrett 1990).

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.

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 (Balasubramayan 1990).

LEVEL 5 OBJECT (1990) is an object-oriented expert system development and delivery environment. 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 (Benke et al. 1993). 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 environments.

Personal Consultant Easy (1987) is a rule based expert shell, which is very useful, but from an earlier generation of shells.

The aim was to develop an expert system, which is able to find the optimum dimensions of the welded box girder of the overhead travelling crane considering different geometries, loadings, steel grades and design codes (Fig. 1.).

The total number of variants is about 30000 and it can be increased if we take into account other aspects and constraints in a modular way (Fig. 2.).

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 tree system and the optimum computation part is build into the expert shell.

The Rosenbrock's Hillclimb algorithm is a direkt search technique, using rotating coordinate system and penalty functions in the boundary zone. Other techniques could be also useful finding the optimum (Jármai 1989). We have written the Hillclimb procedure into the expert shell in PRL language. We gave the objects, the system classes, rules, default values and help messages (Fig. 3.). The expert system is under development. It takes a long time to built all parts of the system, to give the important knowledge to the expert system.

The characteristics of the optimum design of a crane girder are as follows (Jármai 1990):

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 a fillet weld, L_w is the length of weld, k_c is the difficulty factor of welding, which depends on the position of welding. k_w is the specific welding cost.
- 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 simple box 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 (1983) and BS 5400 (1983) is expressed by

$$\frac{M_x}{W_x} + \frac{M_y}{W_y} \le \alpha_d P_s, \qquad (1)$$

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

$$\frac{M_{xf}}{W_x} + \frac{M_y}{W_y} \leq P_{ft}, \tag{2}$$

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

- local flange buckling constraint is

$$\frac{\sigma_{1f}}{P_s K_{1f}} + \left(\frac{\sigma_{bf}}{P_s K_{bf}}\right)^2 \leq 1, \tag{3}$$

where $\sigma_{1f} = M_x/W_x$; $\sigma_{bf} = M_y/W_y$, the K_f factors depend on the slenderness of the flange plate

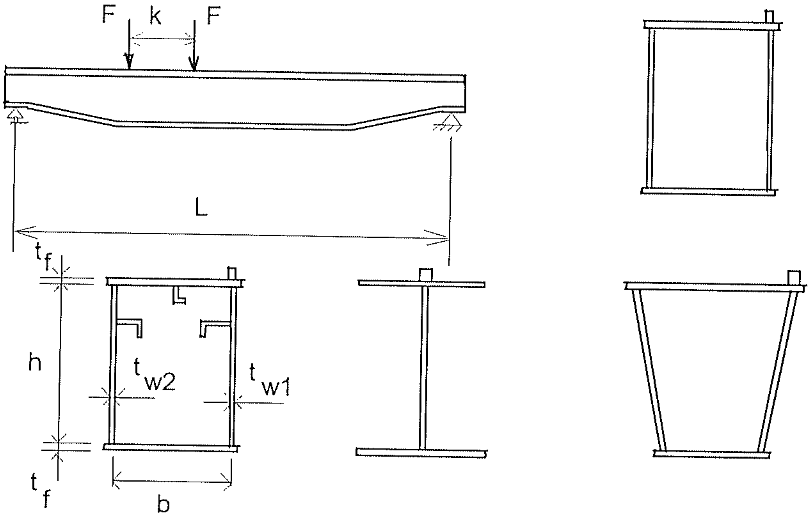

Fig. 1. An overhead travelling crane and different cross sections of the main girder

$$\lambda_f = (b/t_f)\sqrt{R_{yf}/355}, \tag{4}$$

where R_{yf} is the yield stress of the flange plate

- local web buckling constraint is

$$\sqrt{\left(\frac{0.8\sigma_{1f} + \sigma_{bw}}{P_s K_{1w}}\right)^2 + \left(\frac{\sigma_{cw}}{P_s K_{2w}}\right)^2 + \left(\frac{0.2\sigma_{1f}}{P_s K_{bw}}\right)^2 + 3\left(\frac{\tau_q}{P_s K_{qw}}\right)^2} \leq 1 \tag{5}$$

where

$$\sigma_{bf} = \sigma_{bw}, \quad \sigma_{cw} = \frac{F}{t_{w1} s}, \quad s = 50 + 2(h_r + t_f - 5) \quad [\mathrm{mm}] \tag{6}$$

the K_w factors depend on the slenderness of the web plate

$$\lambda_e = (h_w/t_{w1})\sqrt{R_{yf}/355}, \tag{7}$$

where R_{yw} is the yield stress of the web plate.

h_r is the height of the rail,

τ_q is the shear stress.

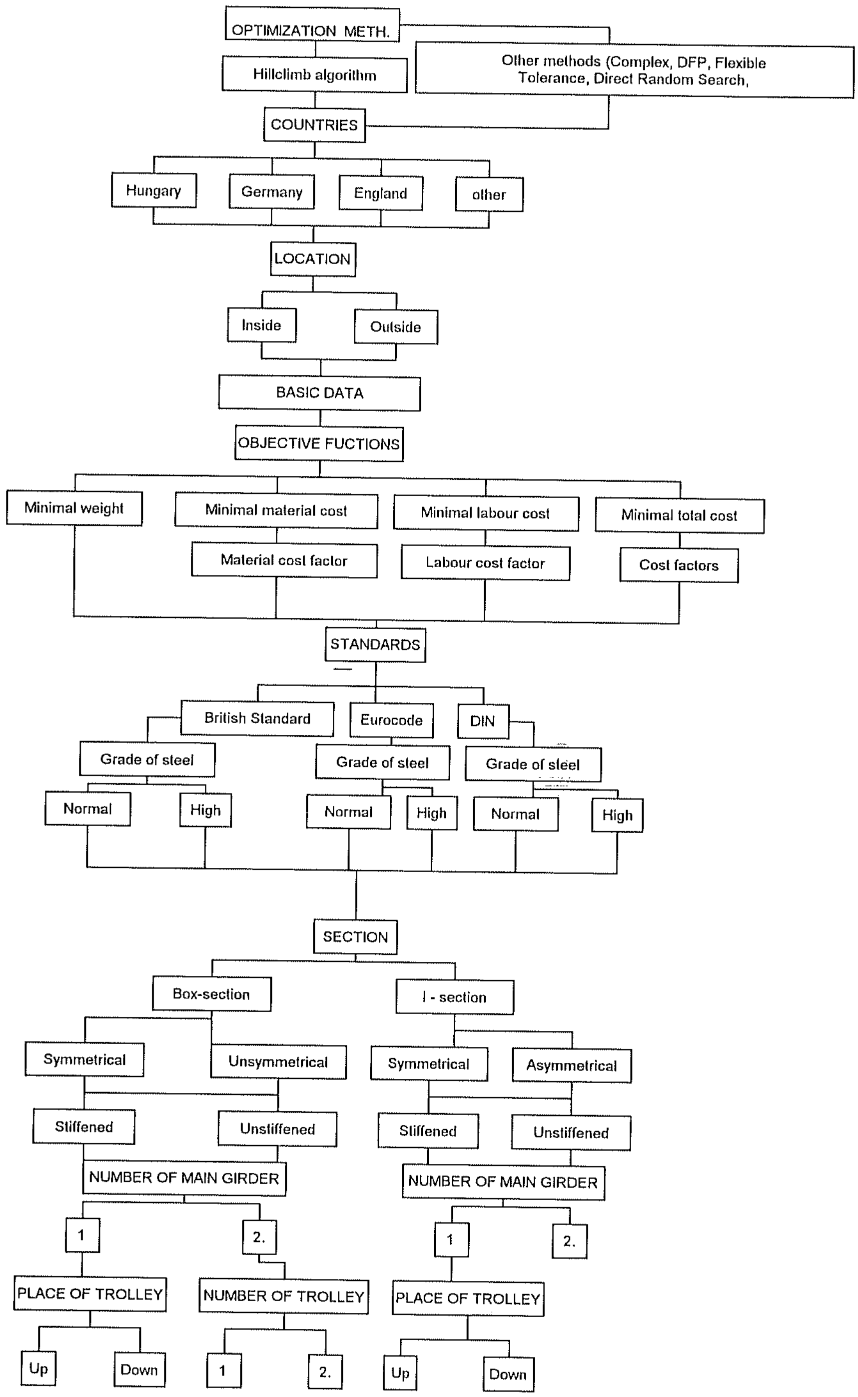

Fig. 2. Logical construction of the expert system in L5O for crane girder design

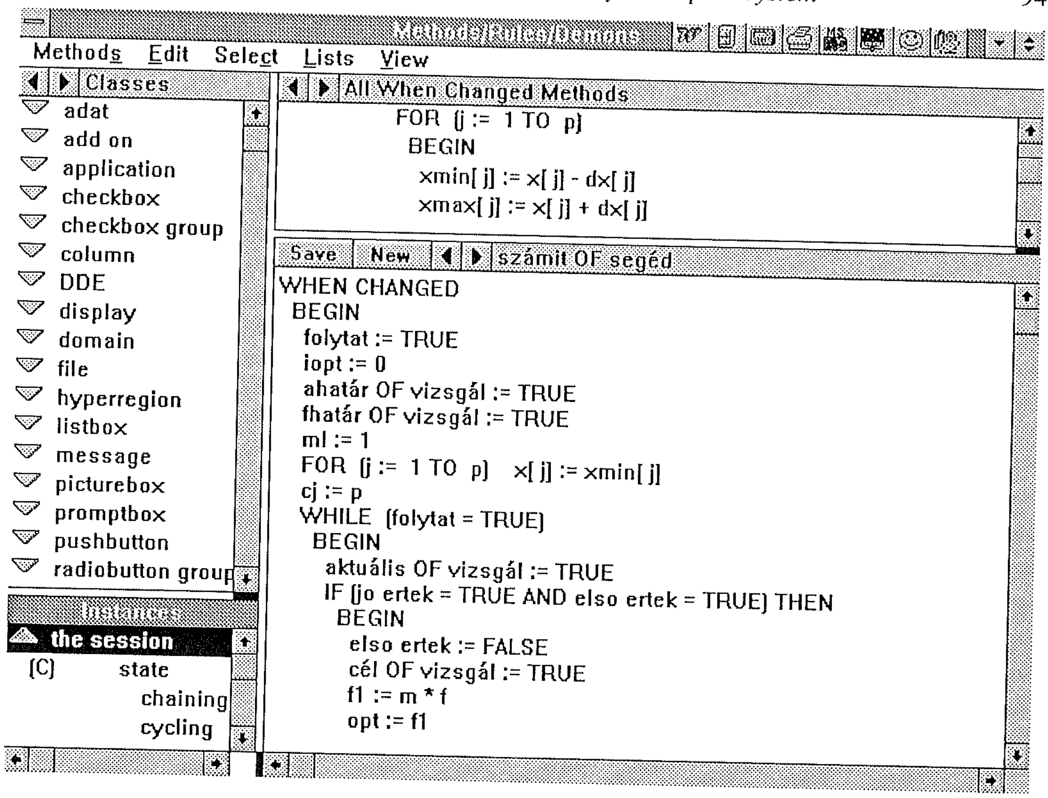

Fig. 3. The development screen of L5O for system classes and methods

- 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
  $w_{max} \leq L/(600\text{-}1000)$, where L is the span length (Farkas 1984).

NUMERICAL EXAMPLE OF RECTANGULAR BOX SECTION

Hook load is $H = 240$ kN, spanlength is $L = 25$ m, mass of trolley is $G_t = 30$ kN, 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 modulus is $E = 2.06$ GPa, class of the crane is A7 according to BS 2573, steel grade is 43, the permissible fatigue stress $P_{fl} = 167$ [MPA], stiffeners are 120*80*8 mm angle profiles, which are welded to the upper part of the web, the distance is $h/5$ from the top flange (Fig. 1.).
The discrete value ranges of the variables are as follows: for h and b the step size is 20 [mm], for the thicknesses step size is 1 [mm].

RESULTS

web height is	$h = 1180$	[mm],
main web thickness is	$t_{w1} = 8$	[mm],
secondary web thickness is	$t_{w2} = 6$	[mm],

width of the flange is b = 420 [mm],
thickness of the flange is t_f = 14 [mm],
total cost of the structure is C_t = 14159 [$].

If we take into account other constraints, like fabrication ones, we can force the program to modify the result, that the *h/b* ratio should be suitable for welding the inside diaphragms etc.

CONCLUSION

The main differences using the Personal Consultant and the LEVEL 5 OBJECT expert shells were, that 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 construction logical tree and the optimum computation part is build into the expert shell. It means, that the second application is closer to the original aim of artificial intelligence.

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