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PAUL GRUNDY, ALAN HOLGATE & BILL WONG
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Application of expert systems in the optimum design of tubular trusses of belt-conveyor bridges

K.Jármai & J.Farkas
University of Miskolc, Hungary

ABSTRACT: Expert system shells, the Personal Consultant Easy (EASY) and the LEVEL 5 OBJECT (L5O) are used. The connection between the optimization techniques and the expert shells makes it possible to find the best solution among several alternatives. The Rosenbrock Hillclimb procedure is used in L5O and five single-objective and seven multiobjective optimization techniques are used in EASY. The benefits of these systems in the optimum design of belt-conveyor bridges are shown. In an example the main truss girder of a belt conveyor bridge is designed with different heights and different numbers of columns to find the optimal topology. The Eurocode 3 standard is used for the structural analysis.

KEYWORDS: Structural optimization, expert systems, belt-conveyor bridges, tubular structures.

1 INTRODUCTION

Computer programs using AI techniques to assist people in solving difficult problems involving knowledge, heuristics and decision-making are called expert systems. Artificial Intelligence techniques are the best utilized in identifying and evaluating design alternatives and their relevant constraints while leaving the important design decisions to the human designer. The emerging fields of AI and knowledge engineering offer means to carry out qualitative reasoning on computers. There were some attempts to connect the expert systems and structural optimization (Adeli 1988). One of them is an expert system for finding the optimum geometry of steel bridges (Balasubramanyan 1990).

The connection between single- and multiobjective optimization made it possible in the structural optimization to form a decision support system. In the multiobjective optimization several so called weighting coefficients serve for the designer to give relative importance of the objective functions (Jármai 1989,1990). 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 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.

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

2 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 in 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 (Harmon 1990), (Dym 1991), (Garrett 1990).
- 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).

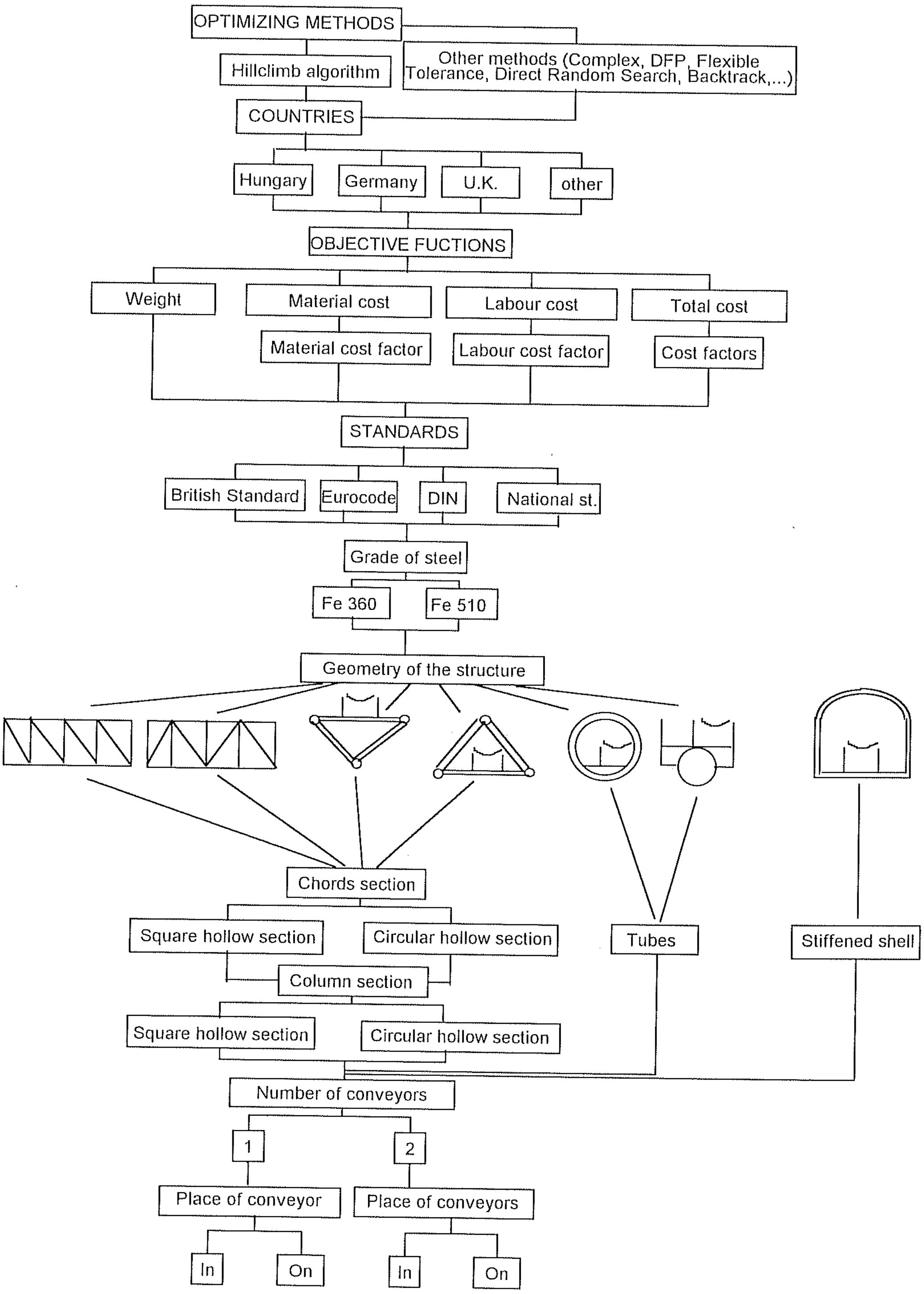

Fig. 1 Logical construction of the expert system in LO5 for belt-conveyor bridges

3 OVERVIEW OF PERSONAL CONSULTANT EASY (1987)

EASY is an EMYCIN-like program developed by Texas Instruments to run on PC-s. Facts are represented as object-attribute-value triplets with accompanying confidence factors. Production rules represent heuristic knowledge. EASY 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. EASY accepts unknown as an answer to its questions and continues to reason with available information. Explanation facilities in the program as well as trace functions are used for knowledge base debugging. EASY uses questions to prompt the designer to enter the initial information into a knowledge base. The tool provides several programming aids for debugging.

EASY 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.

4 OVERVIEW OF LEVEL 5 OBJECT (1990)

LO5 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. 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.

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, offers 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 their 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 (Gero 1987)

- 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 to give advice on how to formulate the problem for optimization, in particular, to identify the limiting constraints and specifications.

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, L5O was found suitable for development of 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 (Harmon 1990).

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

The aim was to develop an expert system, which is able to find the optimum version of belt-conveyor bridges due to different geometry, loading, steel grades and design codes. The different variants can be seen in Fig. 1. The truss structures can be constructed with four or three chords. The belt-conveyor can be placed on or in the bridge. Instead of a truss structure a tube or a stiffened shell can be used as the main girder.

The total number of variants is about 14000 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, contains five various single-objective and seven various multiobjective optimization techniques. These techniques are able to solve nonlinear optimization problems with practical nonlinear inequality constraints.

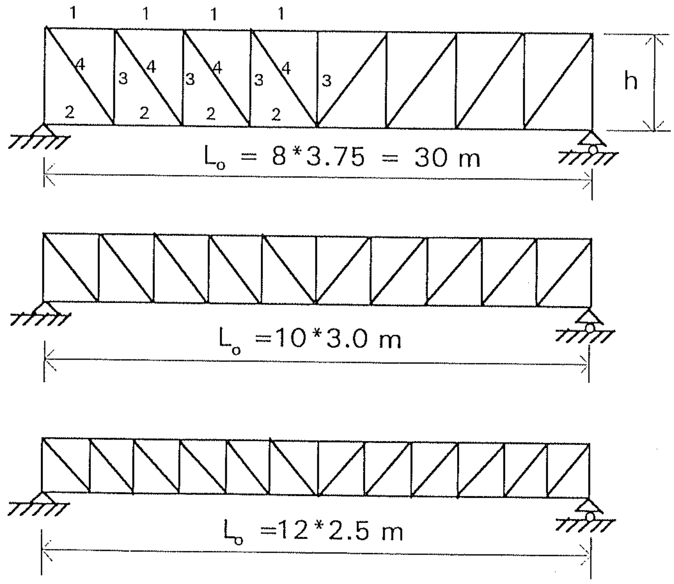

Fig. 2. Various topologies of the main tubular truss girder.

The DSS could contain finite element procedures to compute the mechanical behaviour of the structures. The DSS is described in (Jármai 1989).

We have investigated only some variations and our aim is to build the program according to Fig. 1. in all details.

5 NUMERICAL EXAMPLE

To illustrate numerically the effect of some structural parameters on the minimum weight design of tubular trusses for belt-conveyor bridges, the optimum topology is sought for a simply supported N-type truss (Fig. 2.). The belt-conveyor is placed inside the bridge.

The total volumes of the planar main truss girder are calculated for three values of node distance 'a'.

The span length is kept constant L_o = 30 m. For each 'a' the ratio $\omega = h/a$ is varied and the optimal ω giving the minimum volume is determined.

The loads are as follows:

Uniformly distributed vertical loads for a main truss girder:

self-weight	$p_G = 3.7$ kN/m,
imposed load	$p_{Q1} = 0.5$ kN/m,
snow	$p_{Q2} = 1.0 * s/2 = 1.2$ kN/m,

where s is the width of the bridge.

Load on foot path for maintenance is p_{Q3} = 0.5 kN/m.

Factored vertical load with safety factors according to the Eurocode 3 is

$$p_v = \gamma_G \, p_G + 0.9 \, \gamma_Q \, (p_{Q1} + p_{Q2} + p_{Q3}) =$$

$$1.35*3.7 + 0.9*1.5 \, (0.5 + 1.2 + 0.5) = 7.965 \text{ kN/m}.$$

Horizontal wind load for one horizontal wind girder is

$$p_{wo} = 0.8 \, h/2,$$

the safety factor is γ_w = 1.5, the factor for simultaneous effects is 0.9, then the factored horizontal load is

$$p_w = 0.9*1.5*0.8 \, h/2$$

Four different square hollow sections are considered: for upper chord(1) , lower chord(2) , inside columns(3) and diagonal braces (4). The outside columns are not treated, since they should be constructed as transverse frames and designed also for bending moments caused by the horizontal wind load.

The maximal forces in truss members are as follows:

Upper chord: $N = N_v + N_h$ (compression)

Force from vertical load $N_v = \dfrac{p_v L_o^2}{8h}$

and from horizontal load $N_h = \dfrac{p_w L_o^2}{8s}$.

Lower chord: $N = N_v + N_h$ (tension)

and from the horizontal load $N_h = \frac{p_w L_o^2}{8s}$.

The forces from the vertical load are given in Table 1.

Table 1. N_v forces from the vertical load p_v

a	lower chord	inside columns	diagonals
$L_o/8$	$7.5\, p_v a/\omega$	$2.5\, p_v a$	$4\, p_v a\sqrt{1+\omega^2}\,/\,\omega$
$L_o/10$	$12\, p_v a/\omega$	$3.5\, p_v a$	$5\, p_v a\sqrt{1+\omega^2}\,/\,\omega$
$L_o/12$	$17.5\, p_v a/\omega$	$4.5\, p_v a$	$6\, p_v a\sqrt{1+\omega^2}\,/\,\omega$

The compressed members are designed for overall buckling according to Eurocode 3 (1992) using the buckling curve b for SHS struts and the limiting local slenderness according to CIDECT (Packer et al. 1992) $\delta_{SL} = (b/t)_{\lim} = 35$ for steel of yield stress f_y = 235 MPa. It is shown in our another paper (Farkas & Jármai 1994) that the relationship between the radius of gyration (r) and the cross-sectional area (A) can be expressed as

$$r = a_S\sqrt{A} = \sqrt{\frac{\delta_{SL}}{24}}\sqrt{A} = 1.2076\sqrt{A}$$

The design formula for overall buckling is

$$\frac{N}{A} \le \chi f_y\,, \qquad \frac{1}{\chi} = \Phi + \sqrt{\Phi^2 - \bar{\lambda}^2}$$

$$\Phi = 0.5[1 + \alpha(\bar{\lambda} - 0.2) + \bar{\lambda}^2]$$

$$\bar{\lambda} = \frac{\lambda}{\lambda_E} = \frac{KL}{r\lambda_E}\,, \qquad \lambda_E = \pi\sqrt{\frac{E}{f_y}}$$

Using the symbols

$$c_o = \frac{100K}{\lambda_E},\; x = \frac{10^4 N}{L^2},\; y = \frac{10^4 A}{L^2}$$

the design formula can be written as

$$\frac{x}{f_y} \le \frac{y}{\Phi + \sqrt{\Phi^2 - \frac{c_o}{a_S^2 y}}}$$

$$\Phi = 0.5[1 + \alpha(\frac{c_o}{a_S\sqrt{y}} - 0.2) + \frac{c_o^2}{a_S^2 y}]$$

where L is the strut length, α = 0.34 for buckling curve b, K is the end restraint factor for chord members K = 0.9, for inside columns K = 0.75. For f_y=235 MPa it is $\lambda_E = 93.91$. For a given compressive force N and strut length L (or x) the required cross-sectional area (or y) can be calculated by using a computer program.

The results of calculations are summarized in Table 2 and in Fig. 3. It can be seen that the optimal $\omega = h/a$ ratios are different for various a-values. The absolute optimum is $\omega = 1$ for $a = L_o/8$.

Table 2. Total volumes of a main girder of belt-conveyor bridge constructed from SHS members $10^{-6}\,V$ (mm^3).

$\omega=h/a$	0.8	1.0	1.2	1.4	1.6
$a=L_o/8$	144.1	137.7	138.6		
$a=L_o/10$		143.8	140.2	141.7	
$a=L_o/12$		153.9	146.1	144.1	148.0

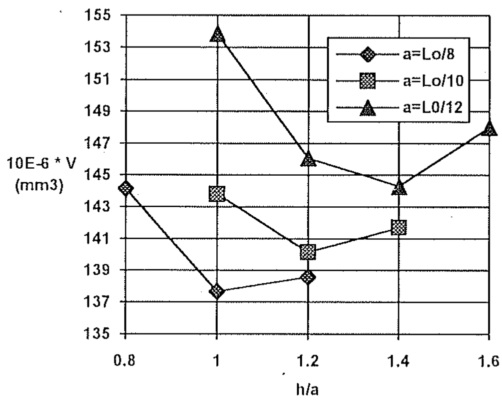

Fig. 3. Total volumes of a main girder of belt-conveyor bridge constructed from SHS members.

Although the sensitivity of the volume function is small, the difference between the V-values for $\omega = 1$ is 100*(153.9 - 137.7)/153.9 = 10 %, thus, 10% savings in weight can be achieved by using the optimal $a = L_o/8$ version instead of $a = L_o/12$ version. This optimal version is also advantageous regarding the fabrication costs, since it is constructed with less number of nodes.

6 CONCLUSIONS

The main differences using the EASY and the L5O expert shells were, that in 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, easier to jump from one level to another on the rules' tree and the optimization part is built into the expert shell. It means that the second expert system is much close to the original aim of artificial intelligence.

The numerical example shows that it is important to include the optimum design in an expert system to make it possible to select the most suitable structural versions.

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