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A Novel Approach to Expert Systems

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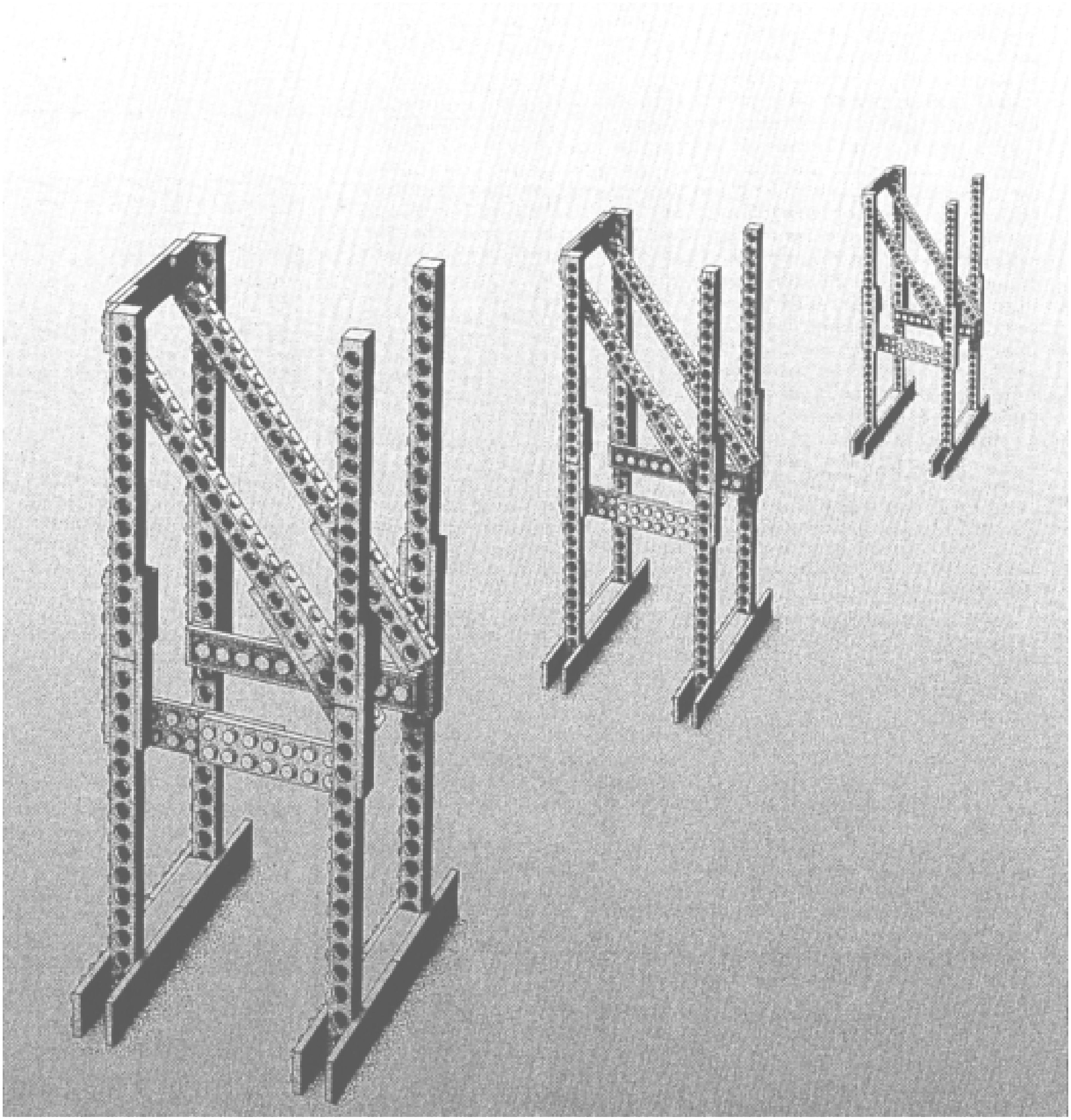

for Design of Large Structures

A novel approach is presented for the development of expert systems for structural design problems. This approach differs from the conventional expert systems in two fundamental respects. First, mathematical optimization is introduced into the design process. Second, a computer is used to obtain parts of the knowledge necessary in the expert systems in addition to heuristics and experiential knowledge obtained from documented materials and human experts. As an example of this approach, a prototype coupled expert system, the bridge truss expert (BTExpert), is presented for optimum design of bridge trusses subjected to moving loads. BTExpert was developed by interfacing an interactive optimization program developed in Fortran 77 to an expert system shell developed in Pascal. This new generation of expert systems—embracing various advanced technologies such as AI (machine intelligence), the numeric optimization technique, and interactive computer graphics—should find enormous practical implications.

Knowledge-based expert system technology has been applied most successfully to diagnostic problems. Expert systems have also been developed for fault detection, prediction, interpretation, monitoring, planning, and design problems. Design appears to be one of the most useful and, at the same time, most challenging areas for the development of expert systems. On the one hand, the heuristic nature of design should make it a suitable candidate for the application of AI techniques. On the other hand, design is an open ended problem that ultimately requires creativity.

The process of detailed design of a structure or a mechanical system made of a large number of components is quite involved. Intuition, judgment, and previous experience have to be used for selecting the right values for the design parameters. Further, because design is an open-ended problem—that is,in general, a large number of design alternatives satisfy all the specified constraints—the selection of the optimum design becomes an extremely challenging problem. The most common criterion for selecting the optimum design is minimizing the weight or cost of the structure or mechanical system. The experience of an experienced designer is not usually sufficient to produce the minimum weight-cost structure, especially when the structure or mechanical system is large and has many components. Thus, a need exists to introduce mathematical optimization into the design process.

Expert Systems for Design Problems

Several attempts at developing design expert systems have been reported in the literature. These investigations are briefly reviewed here. For further discussion, see Adeli (1986, 1988) and Maher, Fenves, and Garrett (1988). It should be noted that the knowledge base of all these experimental expert systems for mechanical or structural design problems basically contains heuristic rules and experiential knowledge obtained from printed documents or human experts.

The first successful application of expert system technology to solution of an engineering problem appears to be SACON. Developed by Bennett and Engelmore (1979) in EMYCIN, SACON interacts with the user for the proper application of the MARC finite-element structural analysis program. SACON is intended to help the less experienced engineers use the large, general-purpose structural analysis program MARC. Rivlin, Hsu, and Marcal (1980) also attempted to develop a knowledge-based consultation system and establish a finite-element structural analysis knowledge base for the use of the MARC finite-element program in Fortran.

The application of AI in computer-aided design is a recent development. Elias (1983) reviews the possibilities of using AI techniques in the design of aerospace structures. Dixon and Simmons (1983) explore the application of expert systems in mechanical design. MacCallum (1982) discusses the development of an expert system for the design of ships. Brown and Chandrasekaran (1984) present a general approach to the creation of computer-based design expert consultants. They formulated a framework in which knowledge is decomposed into substructures; each substructure is, in turn, divided into a hierarchy of conceptual specialists. They applied this

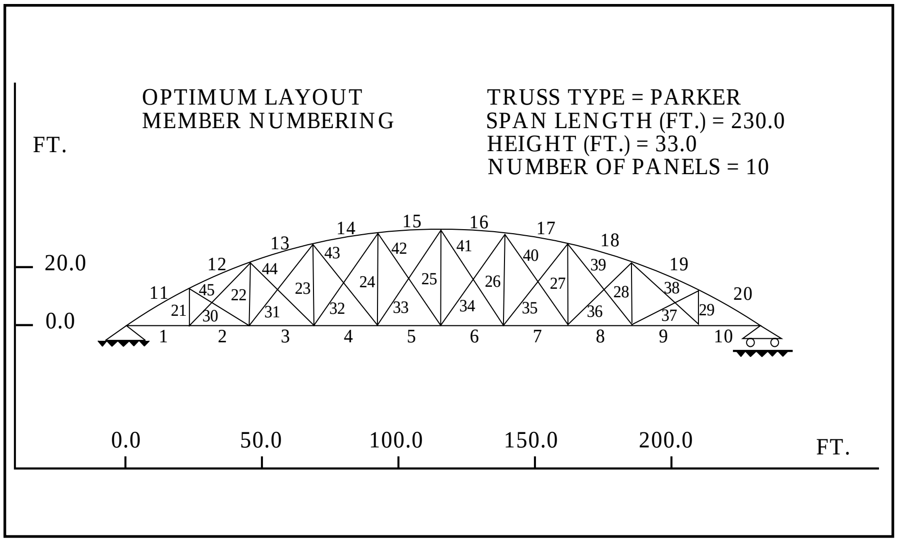

Figure 1. An example of a Parker Truss with Member Numbering Plotted by BTExpert.

methodology to the development of an expert system for mechanical design with design refinement as the central problem-solving activity.

One of the widely cited expert systems for structural design is Hi-Rise, developed by Maher and Fenves (1985) at Carnegie-Mellon University. Implemented in production schema representation language (PSRL), Hi-Rise is a knowledge-based system for preliminary design of rectangular commercial or residential high-rise buildings —those more than 10 stories high. The selection of a structural system in actual practice is usually based on a variety of factors, including aesthetics, economics, efficiency, and structural integrity. Hi-Rise uses weighing factors in a linear-evaluation factor to evaluate the merits of different structural systems. Hi-Rise selects two functional systems, that is, lateral (wind or earthquake) load and gravity load resisting systems. Hi-Rise presents all structurally feasible systems as well as the best design according to the criterion of the linear-evaluation function. The Hi-Rise knowledge base is obtained from textbooks.

Sriram, Maher, and Fenves (1985) present a small knowledge-based system for checking structural steel members for compliance with the American Institute of Steel Construction (AISC) specification (American Institute of Steel Construction 1980). A framework for detailed structural design is presented by Maher, Fenves, and Garrett (1988) in a recent article, using a Hearsay-II–like (Erman et al. 1980) blackboard architecture. Sriram (1986) presents a conceptual model for integrated structural design called Destiny. Destiny is also based on a blackboard architecture. The knowledge base of Destiny has a three-level hierarchical structure.

Composites design assistant (CDA), an expert system for design of a sandwich panel made of a honeycomb or foam core bonded to metallic or composite face sheets, was developed by Pecora, Zumsteg, and Crossman (1985). CDA consists of a backward-chaining expert system shell written in Prolog, a relational database manager written in Fortran, a laminate analysis program also written in Fortran, and a rule-based knowledge base. Honeycomb core material, as well as various metallic and composite material properties, is obtained from the relational database manager. The analysis program can take into account the hygrothermal effects, mechanical loading, viscoelasticity, and various failure modes. The knowledge base in CDA was acquired from two composites handbooks. CDA interacts with the user iteratively through a sequence of menus in order to produce a satisfactory design.

Zumsteg and flaggs (1985) describe a proof-in-concept system to be used during the preliminary design of stiffened cylindrical composite panels and shells. The knowledge base of this expert system, called the buckling expert, contains knowledge of various analysis methods, when and how to use them, and how to interpret the results. The knowledge in the system was acquired from a journal article that summarizes the experience of an expert in the field.

Chehayeb, Connor, and Slater (1985) report the development of a general engineering problem solving environment (GEPSE), in C. The choice of the C language was based on its transportability and efficient numeric processing. Engineering knowledge is divided into static and active knowledge. *Static knowledge* includes the physical description of an engineering system. *Active knowledge* is defined as scientific laws and heuristic rules that must be satisfied in a particular domain. GEPSE has been used for description and verification of a simply supported reinforced concrete beam subjected to a uniformly distributed load.

Adeli and Al-Rijleh (1987) present a coupled expert system—the roof truss expert (RTExpert)—for the design of roof trusses. RTExpert can advise the user on the appropriate type of the roof truss, selection of the layout of the truss (such as the pitch of the truss and the number of panels), and the loading. The design basis is the AISC specification (American Institute of Steel Construction 1980). The truss is designed for dead, live, snow, and wind loads in accordance with the American National Standards Institute (ANSI) specification (American National Standards Institute 1982).

A novel part of RTExpert is the automatic computation of nodal forces due to various loads. The user needs to indicate only the types of materials used as roof covering and the location of the structure in the United States. RTExpert automatically generates all the nodal forces. The knowledge base and explanation facility of RTExpert were developed using the Insight2+ expert system shell. The mathematical computations, graphic algorithms, and data-file manipulation routines were developed in Turbo Pascal. RTExpert has a comprehensive graphic interface for displaying the truss configuration, cross sections, loading, and deformed shape. Information about individual members is presented through multiwindow graphics-text displays.

Paek and Adeli (1988a, 1988b) developed a structural design language (SDL) in the Interlisp environment for building coupled knowledge-based expert systems for the integrated design of structures. The complex body of knowledge needed for the detailed design of a structure is fractionated into smaller and manageable knowledge sources that are organized into a hierarchy of cooperating conceptual specialists. SDL has been used to develop an expert system, called Steel Design Expert (Steelex), for the integrated design of steel building structures consisting of moment-resisting frames. Steelex designs the beams and columns making the frame as well as the moment-resisting connections. Steelex has a multiwindow graphics interface that can display orthographic and isometric views of the structure and moment-resisting connections.

A New Approach to Expert Systems for Structural Design

The fundamental method of knowledge acquisition recommended in practically all the recent books on expert systems is to find one or several human experts in the problem domain and use their knowledge in the expert system (Hayes-Roth, Waterman, and Lenat 1983; Weiss and Kulikowski 1984; Waterman 1986). In fact, this approach was used in developing the most celebrated expert systems in the fields of medical diagnosis (for example, Mycin), mineral exploration (Prospector), and computer configuration (XCON).

Our approach to expert systems for design in general, and structural design in particular, is novel in at least two respects. First, mathematical optimization is introduced in the expert system. Second, we use the machine to obtain parts of the knowledge necessary in the expert systems. We are, thus, extending the current prevalent concept of expert systems by incorporating machine intelligence into the expert system.

As an example of our approach to expert systems for design problems, a prototype expert system—the bridge truss expert (BTExpert)—was developed for the optimum (minimum weight) design of bridge trusses. The scope of BTExpert is currently limited to the optimum design of four types of bridge trusses, that is, the Pratt, Parker, parallel-chord K trusses, and the curved-chord K truss for a span range of 100–500 feet. An example of a Parker truss with member numbering as plotted by BTExpert is shown in figure 1. Design constraints and the moving loads acting on the bridge are based on the American Association of State Highway and Transportation Officials (AASHTO) specifications (American Association of State Highway and Transportation Officials 1983). The design of such a structure is highly complicated in part because of the complex nature of AASHTO moving loads.

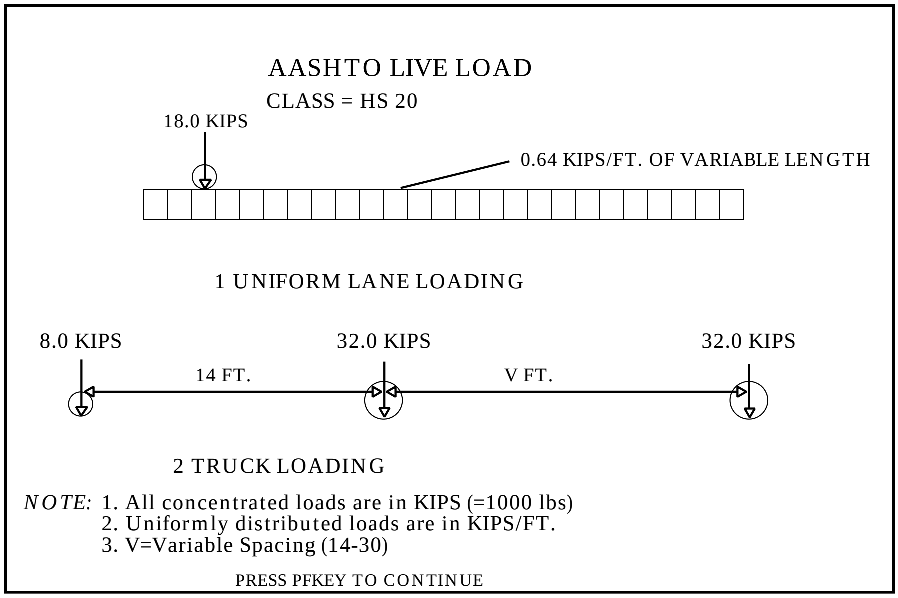

Figure 2. Example of an AASHTO Live (moving) Load Generated by BTExpert.

A Heuristic Approach for the Analysis of Bridges under Moving Loads

Bridges are to be designed for combined dead and live (moving) loads.(Bridges must be designed for moving loads such as the one shown in figure 2). Live loads are usually specified by design specifications. AASHTO live loads are used in BTExpert. These loads can be classified into three categories: two-axle truck (H 15 and H 20), two-axle truck plus one-axle semitrailer (HS 15 and HS 20), and uniform lane loadings consisting of a distributed load of uniform intensity but variable length and a single, moving concentrated load (figure 2).

The process of finding the maximum forces as a result of live loads acting on a bridge structure is not straightforward because of the complexity of AASHTO live loads. A heuristic approach was developed for finding the maximum compressive and tensile forces in the members of a bridge truss based on the shape classification of the *influence line diagrams* (ILDs) and the type of AASHTO live loads (Adeli and Balasubramanyam 1987a). ILD is defined as a figure showing the variation of some behavior functions of the structure (axial forces in the case of trusses) when a unit load moves across the structure. ILDs are used to find the maximum forces in the truss members as the load moves across the bridge.

The heuristic procedure uses information about the shape of ILDs for the bridge truss type under consideration. For statically indeterminate trusses, this information is obtained through machine experimentation for any given type of truss. The ILDs for member axial forces of a bridge truss are classified according to their shapes. For Pratt trusses, for example,

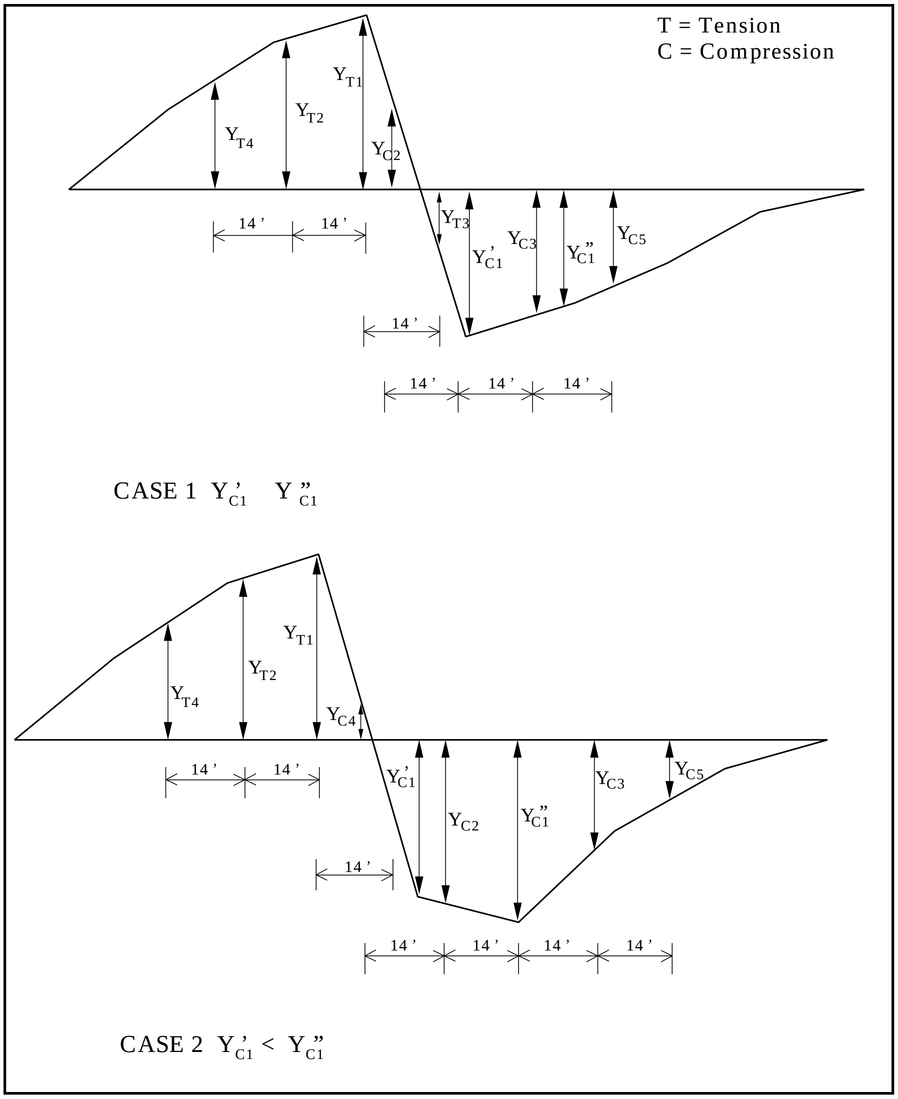

Figure 3. General Shape of Influence Line Diagram Type 2 with Its Characteristic Ordinates.

a careful examination of some 5400 ILDs generated by computer for various layouts and truss member sizes guided us to conclude that all ILDs can be classified into four types. Figure 3 shows ILD type 2 as an example. (ILD is a diagram showing the variation of the axial force in a truss member when a unit vertical load moves across the structure.)

Decision trees and heuristic rules were developed for finding the maximum compressive and tensile forces in the members of a given truss type. As an example, in order to find the maximum tensile forces in the members of a Pratt truss whose ILD is type 2, the ILD ordinates corresponding to the location of wheel loads W_1 (the 32 Kips load in figure 2 {1 Kip = 1000 pounds]) and W_2 (the 8 Kips load in figure 2) are needed. The decision tree for finding these ordinates is presented in figure 4. This heuristic procedure, which is based on the pattern recognition of ILDs, results in substantial savings in structural analysis computations. For details of this procedure, see Adeli and Balasubramanyam (1987a).

Mathematical Optimization

The optimum design of a bridge truss consists of selecting the right combination of the cross-sectional areas of the truss members to satisfy all the design constraints and produce a least weight truss. To create the optimum design, a hybrid optimization algorithm was developed for minimum weight design of bridge trusses subjected to moving loads (Adeli and Balasubramanyam 1988b). In this algorithm, an efficient zero-order explicit approximation is combined with a more accurate but less efficient explicit stress-constraint formulation.

First, optimization is performed using the zero-order explicit approximation until the objective function attains a stationary value; then, the control is transferred to the explicit stress-constraint formulation. This transfer control is performed automatically by BTExpert using heuristic rules. Note that BTExpert finds the optimum detailed design of relatively large structures subjected to the nonlinear and discontinuous constraints of the AASHTO specification. This optimization process requires substantial central processing unit (CPU) time. The hybrid algorithm was developed in order to minimize the CPU time for the mathematical optimization process.

Architecture of BTExpert

BTExpert was developed using the expert system development environment (ESDE) (IBM Corporation 1986b, 1986c) and the expert system consultation environment (ESCE) (IBM Corporation 1986a, 1986b) implemented in Pascal/VS. The first program is used to develop expert systems and, in particular, the knowledge bases. The second program provides facilities for executing them. The two programs are collectively referred to as the expert system environment (ESE). The analysis and optimization algorithms were coded in Fortran 77. A schematic representation of the architecture of BTExpert is shown in figure 5. The various components of BTExpert are briefly described in the following subsections.

(Most components of BTExpert are described in the text. [Note the box marked truss geometry in figure 5.] The truss geometry is generated automatically [the user does not have to input the coordinates of the truss joints]. Display algorithms are developed for displaying the AASHTO live loads [for example, figure 2], the truss configuration with node or member numbering [for example, figure 1], ILDs, and the convergence history of the objective function and design variables. The W-sections database contains the cross-sectional properties of all the 187 wide-flange steel shapes commonly used in steel structures and given in the AISC manual.)

User interface is provided in the form of visual edit screens and menus in which the user types the values of the required parameters into the appropriate field. Further, using the graphical data display manager (GDDM) (IBM Corporation 1984), a graphic interface was developed for displaying the truss configuration with joint or member numbering (figure 1, for example), the design AASHTO live loads (figure 2, for example), and ILDs for various member axial forces (figure 3, for example).

The explanation facility helps the user to examine the reasoning process. The explanation consists of both the RULE text and RULE comments coded by the knowledge base builder. The explanation facility commands follow:

1. EXHIBIT—It displays the current value(s) of a specific parameter.
2. HOW—It displays an explanation of how the system determined a value for a parameter. An example of the explanation generated by BTExpert in response to the HOW command during a sample consultation is given in figure 6.
3. Why—It displays an explanation of why the system is asking a given question. An example of the explanation generated by BTExpert in response to the WHY command during a sample consultation is presented in figure 7.
4. What—It displays more information about a given parameter.

Knowledge Acquisition. In BTExpert, domain knowledge is obtained in part from textbooks, design manuals, design specifications (for example, American Association of State Highway and Transportation Officials 1983), and research papers and journal articles. In addition to these sources, to bridge the gaps in the knowledge base, a detailed numeric machine experimentation in the problem domain was undertaken to obtain the optimum values of primary design parameters.

To conduct machine experimenta-

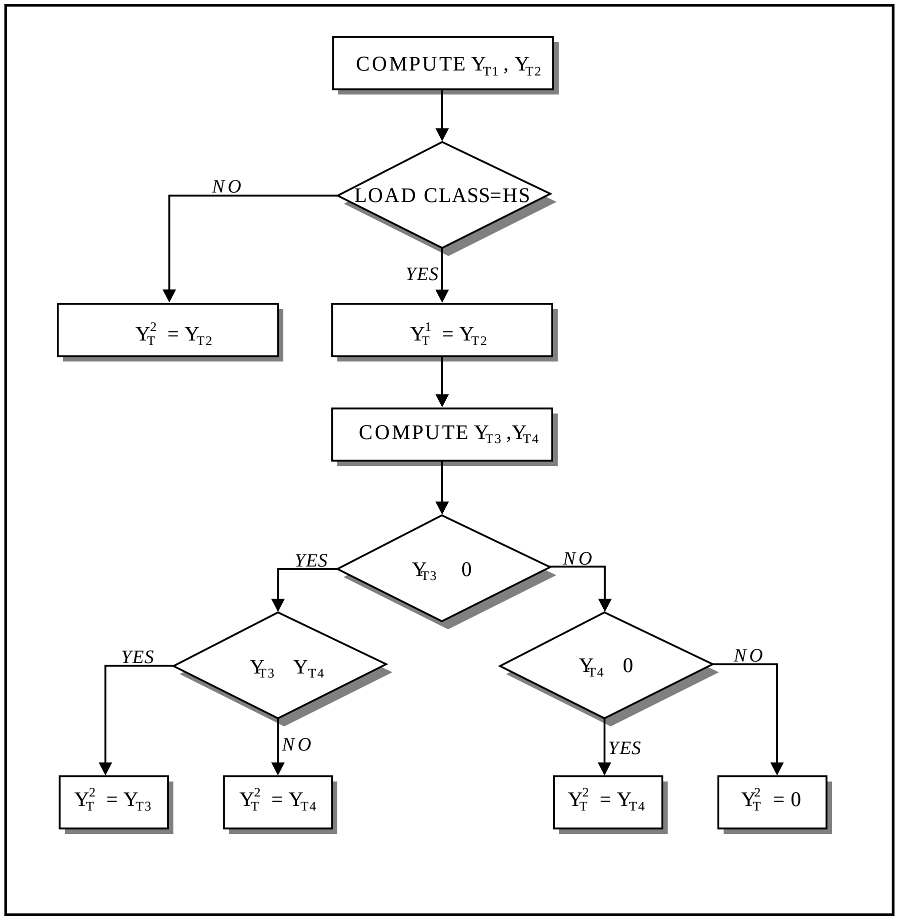

Figure 4. Decision Tree for finding the Maximum Tensile Forces $Y_T{}^1$ and $Y_T{}^2$ Corresponding to the Location of the Wheel Loads W_1 (the 32 Kips load in figure 2) and W_2 (the 8 Kips load in figure 2). 1 Kip = 1000 lbs.

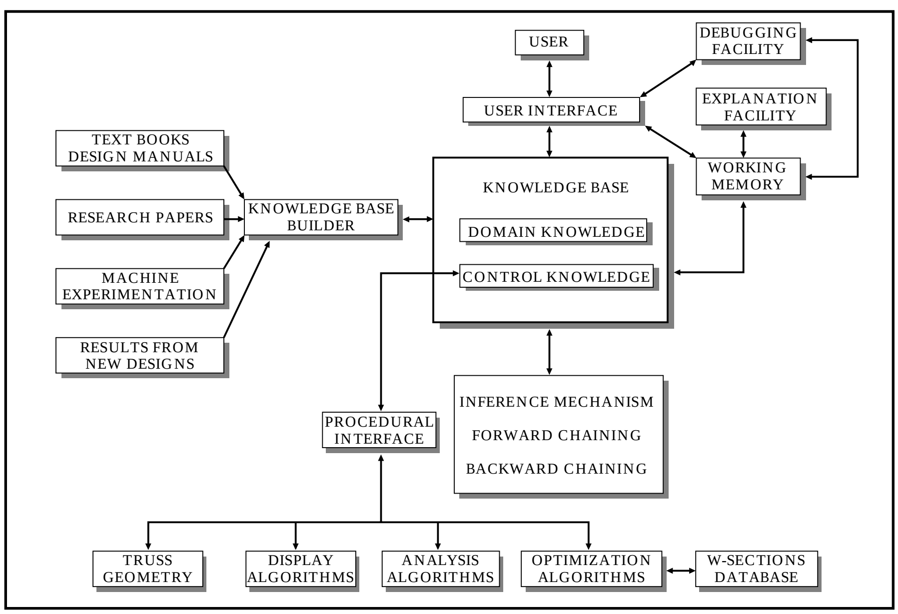

Figure 5. The Schematic Architecture of BTExpert.

Focus: FCB13

— How —

I assigned value to TERMINATE DESIGN of GLOBAL by

1. The default constraint: assigned = ‘False’ (1).

2. Rule RULE0141 of GLOBAL (4) which states that

If Optimization formulation is ‘Explicit Stress Constraints’
and Iteration number > Maximum number of zero order explicit approximation iterations + 1
and (iteration number > (Maximum number of zero order explicit approximation iterations +
Maximum number of explicit stress constraints
formulation iterations) or Percentage change in the value
of the objective funtion
<Tolerance on percent change in the objective function)
Then TERMINATE DESIGN is ‘True’.

This rule is a test for stopping the iterative cycle of analysis/optimization of the indeterminate bridge trusses when the displacement constraint is not active.

As a rusult of this rule
TERMINATE DESIGN assigned = ‘True’ (1).

PF1	Help
PF2	Review
PF3	End
PF4	What
PF5	Question
PF6	Unknown
PF7	Up
PF8	Down
PF9	Tab
PF10	How
PF11	Why
PF12	Command

Figure 6. An Example of the Explanation Generated by BTExpert in Response to HOW It Arrived at the Value of the Parameter Terminate_design.

Focus: FCB2 4

— Why —

I am asking about Bridge loaction of FCB2
to find Recommended AASHTO live load of FCB2 which I am trying to determine.

These rules are used for this line of reasoning.

— RULE RULE0014 —
If Bridge location is ‘Interstate’
Then Recommended AASHTO live load = ‘HS 20’

(Choose one of the following)

— State road
— Trunk highway
— Interstate
— Main highway
— Arterial highway

PF1	Help
PF2	Review
PF3	End
PF4	What
PF5	Question
PF6	Unknown
PF7	Up
PF8	Down
PF9	Tab
PF10	How
PF11	Why
PF12	Command

Figure 7. An Example of the Explanation Generated by BTExpert in Response to WHY It Is Asking the Value of the Parameter Bridge_location.

tion, a software for layout optimization of trusses, called Interactive Optimization of Trusses (IOTRUSS), was developed in Fortran 77 (Adeli and Balasubramanyam 1987b). The layout optimization in IOTRUSS is based on changing certain key dimension(s) of the truss and performing optimization for each layout by taking advantage of the interactive environment of the computers with graphic facilities. In contrast to formal shape-optimization procedures that are computationally expensive and can produce impractical designs, the synergic man-machine approach used in IOTRUSS is an effective method for practical layout optimization of trusses.

The software IOTRUSS was used as a knowledge-acquisition tool to find the optimum values for the height, number of panels, and initial cross-sectional areas of truss members for various span lengths, AASHTO live loads, and grades of steel (figure 8). The information obtained through the machine experimentation was subsequently used in the knowledge base of BTExpert.

The optimum layout optimization parameters (that is the optimum height of the bridge and optimum number of bridge panels, as well as initial approximate cross-sectional areas) are obtained through interactive numeric machine experimentation. For each type of truss, this knowledge is obtained for different AASHTO loadings and various types of steel.

Knowledge Base. The domain knowledge of BTExpert is represented in the form of parameters and rules, and the control knowledge is represented in the form of focus control blocks (FCBs). Each FCB can own some parameter(s) or rules of the knowledge base. Because FCBs are the driving mechanism for problem solving, each parameter and rule should be referenced in some FCB. If a parameter is associated with multiple FCBs in a hierarchy, each association is treated as a separate instance. The control knowledge of BTExpert is classified into 17 FCBs. The main idea of using FCBs is to express the complex optimum design process into distinct steps and identify the intended use and application sequence of rules and external procedures.

As an example, FCB1 owns the rules for selecting the right type of truss for a span length inputted by the user. A sample rule in this FCB is as follows: If Span_length > 300 and Span_length <= 400 Then Recommended_truss_type is `Parallel-chord K truss’

FCB2 contains the rules for selecting the right type of design live loads for the bridge under consideration. A sample rule in this FCB is as follows:
If Bridge_location is `State road’ and Traffic_intensity is `Light’ Then AASHTO_live_load = `H 15’
The FCB3 contains the rules for obtaining the yield stress and the relative cost of the steel used in the truss bridge. If Steel_type is `M 183’ Then Yield_stress = 36 and Relative_cost = 1.0
Another FCB calculates the thickness of the deck slab, and so on (Adeli and

Balasubramanyam 1988a).

Procedural interface. For numeric processing and graphics interface, BTExpert uses procedures implemented in Fortran 77. Therefore, an interface was developed in PASCAL/VS interfacing the knowledge base of BTExpert implemented in ESE to the interactive bridge truss optimization program implemented in Fortran 77. The interface consists of a number of procedures written in PASCAL/VS and uses ESE utility functions. They act as a buffer between the knowledge base and ESE, and the numeric and graphic processors of BTExpert. In other words, they transfer information from ESE to numeric and graphic processors and acquire information from the numeric processors and transfer it to ESE. This information can be in the form of control parameter values, the knowledge about the application sequence of the numeric algorithm, or the results obtained from the numeric processors. The PASCAL procedures in the procedural interface of BTExpert are invoked by FCBs using the PROCESS or ACQUIRE control command. For details, see Adeli and Balasubramanyam (1988b).

Final Comments

It must be noted that the layout optimization by BTExpert is based on the knowledge learned from machine, through machine experimentation. BTExpert, however, performs mathematical optimization for finding the optimum cross-sectional areas after selecting the optimum layout from its knowledge base. With these optimum areas and heuristic rules, wide-flange sections are selected for truss members from a database containing the W sections given in the AISC manual (American Institute of Steel Construction 1980).

BTExpert presents a practical optimum solution for the bridge truss. This solution is obtained iteratively. At each iteration, the user can interrupt and interrogate the expert system. BTExpert provides extensive explanation. At the end of each iteration the user can request that the convergence history of the objective function (the weight of the structure) and any selected number of design variables be displayed. Nonlinear mathematical optimization algorithms sometimes produce unstable results. The kind of in-depth information and explanation provided by BTExpert increases the confidence of the user in the design software. In other words, one of the objectives is to have a "glass box" software rather than a traditional black-box program.

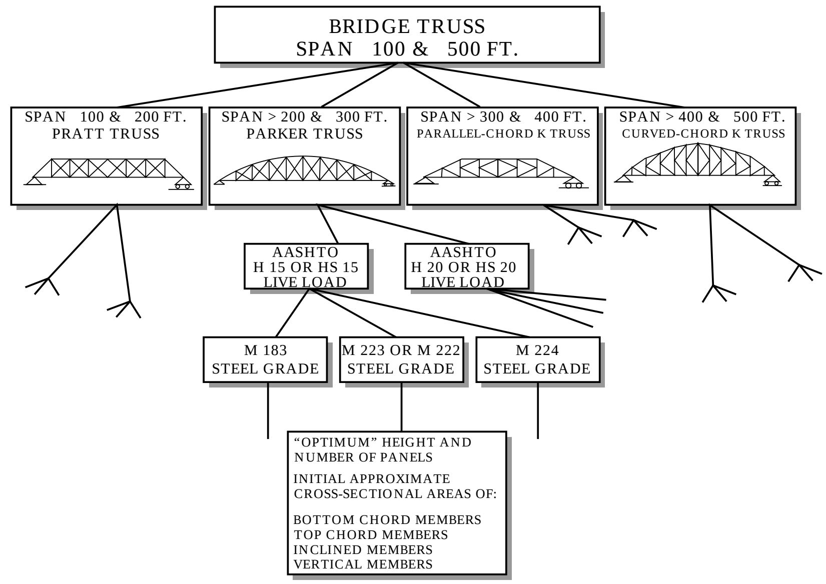

Figure 8. Decision Tree for the Knowledge Obtained Using Machine Experimentation.

To summarize, the approach used in developing BTExpert is not based merely on heuristics and experiential knowledge. It uses sophisticated mathematical optimization techniques and knowledge obtained using machine experimentation and learning (much of the knowledge of BTExpert did not exist anywhere and had to be created interactively). BTExpert can be considered a prototype for a new generation of expert systems for structural design (Adeli and Balasubramanyam 1988b). The approach used in BTExpert is not limited to the design of a particular class of structures and can be applied to other types of structures. This new generation of expert systems embracing various advanced technologies such as AI (machine intelligence), mathematical optimization techniques, and interactive computer graphics should find enormous practical implications.

BTExpert is a coupled expert system integrating AI-based symbolic processing and sophisticated conventional numeric processing. Since the original version of this article was first submitted to *AI Magazine* in January of 1987, several coupled expert systems have been presented in the literature (Kitzmiller and Kowalik 1987; Lee et al. 1987; Selig 1987). Selig (1987) presents a coupled expert system called the automated beam line expert (ABLE), for automating error-finding in particle accelerator facilities. It is developed in the KEE3.0 expert system programming environment on a Symbolics 3600 LISP machine. Although ABLE is not a design expert system like BTExpert, it combines mathematical optimization techniques with AI techniques and symbolic reasoning. In addition, part of the knowledge base of ABLE was developed interactively by solving simulated problems.

It must be pointed out that the expert system technology so far has been applied mostly to problems that are readily solved by human experts and domains where knowledge is readily available or acquired from human experts. Consequently, the performance of such systems can be compared to human experts. The multifacet research presented briefly in this article, however, attacks a problem for which a single human expert does not exist. Thus, the performance of BTExpert cannot be compared to human experts. In other words, in a sense, BTExpert outperforms human experts because it uses mathematical optimization techniques and the knowledge obtained using interactive machine experimentation.

BTExpert addresses a realistic design problem. Therefore, a question arises about why no single human expert exists to solve the bridge design problem. Of course, there are many bridge designers who can design truss bridges. For given design and loading conditions, each bridge designer will come up with a different design, and most probably, no one will come up with the optimum design. However, there are university researchers who are knowledgeable about mathematical optimization algorithms. These researchers usually apply their optimization algorithms to the solution of academic problems. The practicing engineers, however, are not familiar with mathematical optimization algorithms. In fact, the detailed optimization of realistic structures (such as bridge trusses) subjected to realistic design constraints (which are usually implicit and discontinuous functions of design variables) is a highly nonlinear problem, with the associated problems of efficiency, convergence, and stability. These problems explain why practicing engineers shy away from mathematical optimization algorithms. BTExpert attempts to bring mathematical optimization techniques to the reach of practicing engineers and designers.

BTExpert is a prototype expert system developed in an academic environment. We used the minimum weight as our optimization criterion. A more realistic criterion would be the minimum cost. In this case, the labor cost must be added to the cost of materials. However, for large steel structures, the cost of materials (steel) is the primary cost of the structure. BTExpert can be modified and extended to incorporate the cost of the structure instead of the weight. However, this modification is more a development issue than a research issue.

BTExpert is currently being extended. Heuristic rules and procedures are being developed to improve the efficiency, robustness, and accuracy of the optimization process. For example, heuristic rules are being developed for the choice of the right optimization algorithm and appropriate control parameters using machine learning. Other heuristic rules are being developed for the classification of constraints into inactive, partially active, active, and violated constraints. The inactive constraints will not be included in the optimization cycle through a constraint deletion process. This strategy will result in a more efficient optimization algorithm. Finally, a sample consultation with BTExpert is presented in a forthcoming book by Adeli and Balasubramanyam (1988b). The example presented here covers an entire chapter of this book.

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