A Knowledge-Based Approach to Preliminary Design of Structures

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Computers have been used extensively for the analysis, detailed design and drawing production of structures. However, they have not been utilized effectively in the preliminary design stage. During this stage, the structural framing schemes that are likely to offer an optimum solution for the given design constraints are identified. Once an appropriate framing scheme is selected, an analytical model which requires initial member sizes is developed to investigate the behavior and performance of the structure under the design loads. An engineer may have to perform an approximate analysis to select the preliminary member sizes; however, experienced engineers may be able to make a reasonable estimate of the required sizes using their past experience with similar structures. A prototype computer-based design tool that utilizes past engineering experience for selecting initial member sizes of structures has been developed and is described in this paper. This tool is applicable to the design of various types of structures through the use of knowledge base techniques.

Introduction

Structural design is a creative process that requires a combination of knowledge of engineering principals, understanding of design specifications and experience with similar structures. Normally, there are many feasible schemes that satisfy the design constraints of a structure, of which one solution is usually considered the most appropriate. The success of a structural designer in selecting an efficient structural scheme depends on his relevant past experience. A novice designer may have to evaluate many alternate schemes before arriving at a satisfactory solution. This lack of experience may often lead to a design that is far from optimum. Furthermore, once a framing scheme has been selected, a novice designer will normally rely on the results of an approximate analysis to select initial member sizes. An experienced engineer will normally be able to recognize situations where the strength of a member is not the controlling design criterion and will be able to select initial member sizes based upon his past familiarity with similar structures.

The structural design process can be divided into the following tasks: preliminary design, analysis, detailed design and drawing production. Each of these tasks are described in the following:

Preliminary Design: This task has two main goals. The first goal is the conceptual design. This is where the framing scheme for the proposed structure is selected. During the early stages of this process, more than one scheme may be selected and evaluated; however, before the next phase is started, one scheme is usually selected. The second goal for this phase is preliminary member sizing. Once a framing scheme has been developed, the sizes of the various components in the structure are determined. Sometimes an approximate analysis is used to estimate the forces in the components, and these forces are then used to determine the preliminary sizes. On the other hand, some experienced engineers will use knowledge obtained from designing similar structures to estimate the required sizes.

Analysis: In this phase the performance of the framing scheme selected during the preliminary design phase is evaluated. Normally a numerical analysis is performed to determine the structure's behavior when subjected to the various loads that it is required to resist. If any problems are found with the performance of the structure that cannot be corrected, the design process will revert back to the preliminary design phase to select an alternative framing system.

Detailed Design: The selection and proportioning of all component sizes is performed at this phase. All components are evaluated so that the applicable design constraints are satisfied. The results of the analysis phase are used to select the required sizes, and since the sizes of many of the components will change from the original estimate, the analysis phase may have to be repeated.

Drawing Production: The ultimate goal of any structural design is to produce the documents that are required to build the structure. The majority of these documents are the drawings that provide the locations and sizes of all components of the structure as well as details that indicate how the various members and components are to be connected.

Although computers have been employed to perform the analysis and detailed design of structures as well as the production of working drawings, they have not been utilized effectively in the preliminary design stage. This stage includes both the conceptual design and the preliminary sizing of various structural components. Until now the use of computers

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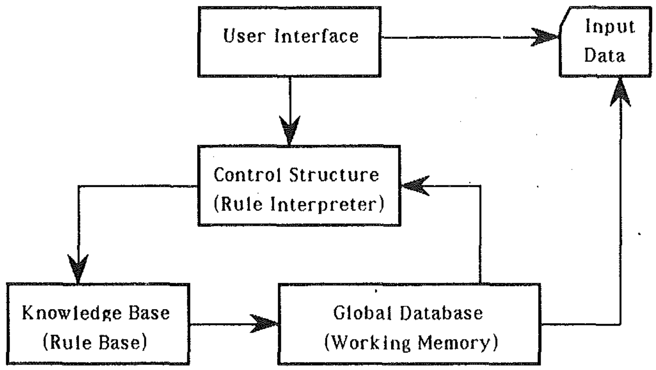

Fig. 1 Components of an expert system

in this stage has been limited to the evaluation of different framing schemes developed and modeled by the engineer. If they can be used to help in developing the framing schemes and/or in the preliminary sizing of members, more framing schemes can be studied in a shorter time. Therefore, the overall design procedure can be made more efficient.

Objectives of Study. The objective of the research was to establish a computer-based procedure which employs the knowledge gained from past engineering experience to aid in performing appropriate preliminary structural design. A system named PREDES was developed to aid the engineer in the selection of preliminary member sizes for different classes of framing systems. The methods utilized by the system can be classified as knowledge-based system techniques. These techniques allow PREDES to be applicable to a wide variety of structures.

Characteristics of Knowledge-Based Systems. Knowledge-based (KB) systems, also known as expert systems, have been given many definitions; however, the following characteristics are found in most definitions:

- KB systems must be able to solve problems that are normally solved by experts in the field.
- KB systems deal with problems which are difficult if not impossible to solve by traditional programming techniques.
- KB systems generally separate the control strategy from the knowledge base, (i.e., facts, rules and computational procedures) (Ortolano and Perman, 1987).
- KB systems can function with incomplete data. This is normally accomplished through the use of certainty factors.
- KB systems also allow for prototyping of proposed ideas and methods. Subsets of the knowledge base can be implemented and tested before the system is finished.

Figure 1 shows the architecture of a typical knowledge-based (expert) system. The knowledge base consists of facts and heuristics which are used to solve the problems in the system's domain. The control structure, typically called the inference engine, applies the knowledge contained in the knowledge base. The global database, which contains the current problem status, is referred to as the working memory and has been compared to the short-term memory of a person (Firebaugh, 1988).

Survey of Related Studies

Many expert systems have been developed in the field of structural design. HI-RISE (Mather, 1987), DESTINY (Sriram, 1986), EIDOCC (Sacks and Buyukozturk, 1987), STRUPLE (Zhao and Maher, 1988), RUBHY (Jones and Sauoma, 1988) and BTEXPERT (Adeli and Balasubramanyam, 1988a) are just a few of the many prototypes previously developed. HI-RISE and STRUPLE are systems developed as aids for preliminary design. EIDOCC is an example of a hybrid system that combines expert system technology with more traditional numerical programs. This prototype was developed to design concrete columns under various loading conditions. DESTINY, RUBHY and BTEXPERT are also hybrid systems that offer capabilities for the preliminary design, analysis and detailed design of structures. RUBHY was developed specifically for the analysis and design of concrete frames, while BTEXPERT is a prototype that combines preliminary design and numerical optimization for trusses. DESTINY is a complex system that interfaces several different expert systems. Each individual system has a separate domain such as preliminary design or detailed design. The different expert systems, called knowledge modules, communicate through a blackboard and are controlled through an inference mechanism. The blackboard is used for communicating the project status with the different modules. The status includes information stating whether a specific process is ready to start, has been successfully completed or even failed. Of the prototypes listed here, HI-RISE, BTEXPERT and STRUPLE are related to the proposed work and will be discussed in detail.

HI-RISE. HI-RISE was one of the first expert systems developed for structural design. Its domain is the preliminary design of high-rise commercial or residential buildings. This system was developed using PRSL, a combination of a production system and frame representation system. HI-RISE generates alternate framing schemes for a proposed building. Declarative knowledge which defines the different structural schemes known to the system is contained in a combination of PRSL frames and production rules, while procedural knowledge such as that needed to propose specific schemes is represented by LISP functions. The original prototype was restricted to rectangular structures from 5 to 50 stories. The input to HI-RISE includes the following:

1 The structural frame description includes the spatial requirements for the building defined by a three-dimensional grid, the topology of the grid defined by the number of bays in each direction, as well as the number of stories, the horizontal dimensions of the grids defined by the bay sizes, the location of service shafts, elevator shafts and any internal spaces.
2 Architectural requirements include the occupancy type and minimum floor-to-floor clearance.
3 Engineering requirements include the definition of the live and wind loads and the preferred locations of columns, walls and beams.

HI-RISE divides the preliminary design into two primary tasks. These tasks are the generation of the lateral load resisting system and the gravity load resisting system. Each of these tasks is further subdivided into:

1 Component Synthesis: Generates the different framing schemes. This includes the generation of the different lateral and gravity load resisting systems that are known by HI-RISE. Production rules are used to eliminate schemes that are not acceptable.
2 Analysis: Provides information on the performance of each proposed framing scheme. During this stage an approximate analysis is performed so that the preliminary sizes of key components in the frame may be estimated.
3 Evaluation: Each proposed system is evaluated and ranked using the information generated during the analysis stage. The different attributes that are used during the evaluation include the cost of the proposed systems, the displacement of the proposed systems, and the structural integrity and efficiency of the proposed systems.
4 System Selection: Finally, HI-RISE lists all of the systems that satisfy the initial constraints for the building and indicates the preferred system.

BTEXPERT. BTEXPERT is an example of a hybrid expert system that combines knowledge processing with algorithmic numerical processing. BTEXPERT's domain is the design of bridge trusses. Three phases of the design process are addressed by this system. These phases are the preliminary design, analysis and detailed design of bridge trusses.

The preliminary design capabilities of BTEXPERT include both the conceptual design as well as the preliminary member sizing. The conceptual design consists of determining the truss type, panel spacing and truss height. These parameters are determined using rules defined in the knowledge base of the system. Some of the attributes required by these rules include the truss span length, live loads, and material grade. Once the conceptual design has been completed, the preliminary member sizes are determined. To obtain the initial member sizes, the different components in the trusses are grouped into one of the following four categories: top chord, bottom chord, vertical and diagonal members. The member group type along with the truss type and span length are then used by heuristic rules to define the initial member sizes.

Once the preliminary design task is completed, the loads that are required for the analysis and detailed design stages are determined. The magnitudes of the live loads are defined by the AASHTO specification (1983). The moving loads are applied to the truss using a heuristic procedure that has been developed to produce loadings that typically cause the maximum and minimum forces of the members in the truss (Adeli and Balasubramanyam, 1988b). After the design loads have been defined, the analysis and detailed design stages are performed simultaneously by formulating and solving a numerical optimization problem. The design constraints for the optimization problem are based upon the AASHTO specification and the design variables are the cross-sectional areas of the members in the truss.

When the optimum members sizes have been determined, the results of the design can be used to modify or add to the existing rules used during the preliminary design stage. This capability allows BTEXPERT to add to its knowledge base as more trusses are designed. This feature should improve the accuracy of the preliminary design as more trusses are designed with the system.

STRUPLE. STRUPLE is a prototype that aids an engineer in the preliminary design of buildings using analogical reasoning. According to Carbonell (1986), analogical reasoning consists of using knowledge obtained from previous solutions to construct new solutions to problems that share significant aspects with the previously solved problems. STRUPLE attempts to use knowledge of previously designed buildings to generate framing schemes that satisfy the current design constraints for the proposed building. STRUPLE generates a design vocabulary that can be used by a frame synthesis program. The design vocabulary is defined as a set of design elements that can be used to generate components of the desired entity. For example, a design element may be a beam that is part of a frame in the structure being designed. In STRUPLE, the design vocabulary will contain the different components that make up the lateral load resisting system, the gravity load resisting system and the foundation system.

To generate the design vocabulary, STRUPLE uses a set of criteria to find similar buildings stored in a database. The different criteria are classified as either required or desired. Examples of the required criteria are the number of stories above grade, number of stories below grade, intended use of stories above grade, building shape and typical bay size. Examples of desired criteria are location of the building, wind load for structures under 30 stories and unit cost of the building. The user also has the choice of changing the classification of some of the attributes.

Once a set of matching buildings is located, STRUPLE builds the vocabulary for the current design by using a hierarchical abstraction of the different components of a structure. The levels of abstraction include the lateral framing system, gravity framing system and the foundation. The components are divided into additional levels to further simplify the problem. These levels of abstraction are shown in Fig. 2. STRUPLE identifies the different components used in the set of matching buildings and ranks them using a heuristic procedure. The components with the highest rankings are then used in the design vocabulary for the new structure.

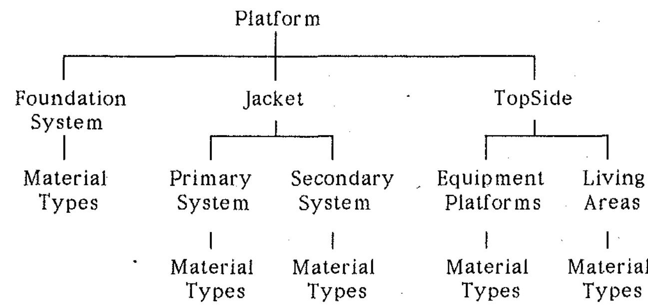

Fig. 2 Hierarchial component abstraction

Methodology

PREDES is intended to offer assistance for the preliminary selection of member sizes for different types of structures. The required member sizes for the proposed framing scheme are determined from the designs of existing structures. The use of previous designs to guide the preliminary member sizing offers the following advantages:

- An approximate analysis is not required.
- Strength is not the only criterion used for member size selection.
- Past experience and knowledge is made available to novice engineers.

The methods employed by PREDES can be classified as a form of analogical reasoning. In general, two main types of analogical reasoning have been identified:

1 Transformational Analogy: Past solutions can be transferred to new problems to satisfy the constraints and criteria of the new problems. This approach is appropriate if the past problem statements, solution solving process, and solutions have strong similarity with the new problems (Carbonell, 1986).

2 Derivational Analogy: The problem-solving process of past solutions can be retrieved and modified in order to construct derivational paths for the new problem (Carbonell, 1986). The past solutions are ignored for this approach. Only the problem statements and solution process are considered.

The methods developed for PREDES would fall into the first category, transformational analogy. The solutions from past engineering experience retrieved from an experience database are transformed by various heuristic procedures into solutions for new structures. To accomplish this goal, two phases are required. The first phase involves identifying and ranking matching structures. During the second phase, the preliminary member sizes are determined. This is done by identifying relevant attributes in the matching structure descriptions and using these attributes to determine the cross-sectional properties for members in the proposed structure.

To simplify the design process, a hierarchical component abstraction is used to break up the process into manageable problems. These abstractions, which are similar to the ones utilized by STRUPLE shown in Fig. 2, include the foundation, jacket system and top side structure.

Figure 3 shows an overview of the different components of the PREDES system. The first step in the process is to provide a description of the proposed structure. From this description a set of criteria is generated that is used to locate matching structures that are contained in the experience database of PREDES. The user is allowed to modify the structure description and criteria at any time during the process. Once the similar structures have been identified, they are ranked in order of best to worst match. Again, the user is allowed to modify the matching structure rankings or remove specific structures from the list. After the list of matching structures and their respective ranks have been determined, the user enters a description of a member in the proposed structure which identifies the member type, length and location. Using this description, the properties of similar members from the matching structures are determined and then used in a heuristic procedure to determine the properties of the member in the proposed structure. The following sections will describe each phase of the system in detail.

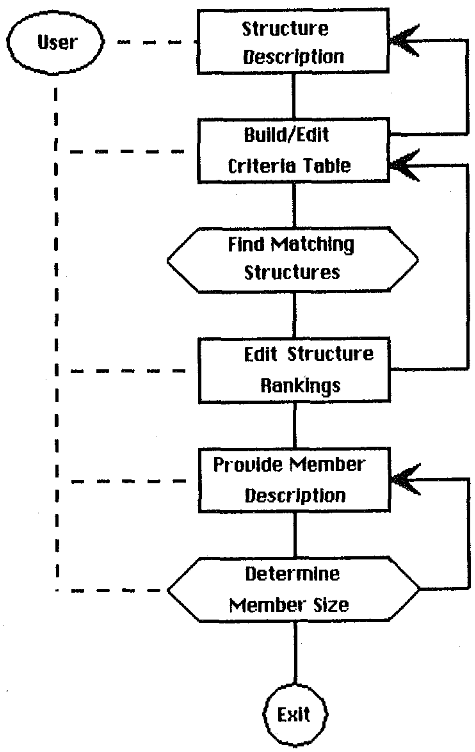

Fig. 3 PREDES organization

Representation of Experience. Experience that is utilized by PREDES is represented by partial descriptions of previously designed structures. This description includes attributes related to the platform location, the environmental conditions at the site, and the engineering requirements. Examples of these attributes include the following:

- Platform use
- Geographic location
- Water depth
- Soil type
- Soil bearing capacity
- Wave loading description
- Live loads
- Wind loads
- Seismic zone
- Design specification
- Structural framing cost
- Foundation cost

The attributes for other types of structures, such as industrial structures, plant facilities or commercial/residential buildings would differ from offshore platforms. Therefore, an important feature of this system is that new attributes can be added to the system, thus allowing different types of structures to be entered into the system.

Finding Matching Structures. Before matching structures can be identified, a description of the proposed structure is required. In general, this description will contain the same information that is used to represent the experience as described in the previous section. However, it is not necessary to specify all of the available attributes. PREDES is designed to work with incomplete information. It a structure attribute is not provided, the system will not consider it when searching for similar structures.

Once the structural description is provided, similar structures are extracted from the experience database. The initial member sizes can then be determined from the matching structures. The matches process requires that structures with the same framing schemes as the proposed structure for the current abstract level be identified. The identification is accomplished through the use of a criteria table. Each criterion in the table consists of: a specific structure description attribute, upper and lower limits for the attribute, and a classification as being either a required or desired criterion.

Table 1 shows a set of criteria that is used to find matching structures. This table is similar to the one proposed by Zhao

Table 1 Criteria table

Criteria	Comments
Platform use	Required criteria. Similar uses will have to be recognized.
Platform location	Desired criteria.
Water depth	Required criteria. The tolerance for a match will vary with the water depth.
Bottom topology	Desired criteria.
Soil type	Desired criteria.
Soil bearing capacity	Desired criteria.
Live loads	Required criteria.
Wind speed	Required criteria.
Wave loads	Required criteria.
Current loads	Required criteria.
Seismic zone	Required criteria.
Structural framing costs	Required criteria if provided by the user.
Foundation costs	Required criteria if provided by the user.
Design Specification	Desired criteria.

(1988). However, for the selection of member sizes, additional criteria is required. The additional criteria includes the description of the current framing component, such as the lateral framing system. This description must include the framing system type and material. Allowances should be made for similar types of systems and materials when appropriate.

Not all of the criteria available to the system is utilized for any given problem. For example, if the user does not specify a framing cost in the general structure description then this item will not be used during the matching process. This will allow the proposed system to work with incomplete data; however, if a certain level of information is not provided, the results of the system will be suspect. To provide an indication of the accuracy of the system, the number of matching structures, the number of matching numbers and the average structure rank is displayed with the preliminary member sizes.

Once a set of matching platforms is obtained, the individual platforms are ranked in order from the best to worst match. The rankings are determined from the differences in each criteria used during the matching process. There are two types of criteria used by PREDES: numeric and alpha-numeric criteria. To compute the differences for numerical criteria, the following computation is performed:

$$\Delta_i = \frac{|\alpha - \alpha_{prop}|}{U - L} \quad (1)$$

where

Δ = difference for criteria i
α = value of attribute from matching structure for criteria i
α_{prop} = value of attribute for proposed structure for criteria i
U = upper limit for criteria i
L = lower limit for criteria i

The difference for alpha-numeric criteria is determined using the following set of rules:

IF α is equivalent to α_{prop}
THEN $\Delta_i = 0.0$

IF α is not equivalent to α_{prop}
AND α is in a list of alternatives
THEN $\Delta_i = 0.5$

IF α is not equivalent to α_{prop}
AND α is not in a list of alternatives
THEN $\Delta_i = 1.0$

Note that a difference of zero is an exact match while a difference of one or greater is not a match. Furthermore, if the difference is greater than or equal to one and the criteria is required, the structure is not considered a matching structure and no further processing will be done on this structure.

Once the individual differences have been computed for a matching structure, they are combined using the following procedure:

$$\Phi_j = \frac{\Sigma(\Delta_i W_i)}{\Sigma(W_i)} \quad (2)$$

where

Φ_j = ranking of structure j
Δ_i = difference for criteria i
W_i = weighting factor for criteria i

As shown in equation (2), the relative importance of each criteria is incorporated into the process through the use of weighting factors. Table 2 shows the weighting factors currently used by PREDES for ranking offshore platforms. Since the criteria can vary depending on the current structure type or component classification, the weighting factors are also allowed to vary.

Table 2 Weighting factors

Criteria	Required	Desired
Platform use	7.0	3.0
Platform location	6.0	2.0
Water depth	8.0	4.0
Bottom topology	6.0	2.0
Soil type	7.0	3.0
Soil bearing capacity	7.0	3.0
Superimposed dead load	8.0	4.0
Typical live load	8.0	4.0
Wind speed	8.0	4.0
Wave loads	8.0	4.0
Current loads	8.0	4.0
Seismic zone	9.0	5.0
Structural framing cost	8.0	4.0
Foundation cost	7.0	3.0

Table 3 Required properties for members

Member Type	Required Properties
Beam	Strong axis moment of inertia Depth
Column	Area Strong axis moment of inertia Weak axis moment of inertia
Brace	Area

After the matching platforms are evaluated and ranked, the user is allowed to modify the rankings or remove certain platforms from future consideration. This is necessary since the information available to the system is limited. Not every characteristic of a structure is stored in the database, and the set of criteria is not necessarily complete for each type of structure that the system can handle.

Selection of Initial Member Sizes. The final phase of the preliminary design process is to select the initial member sizes. From the matching structures, members that are similar to the member whose size is required are identified. Member attributes such as type, length, location and special loading conditions are used to identify the matching members. Once the matching members are identified, they are ranked in a manner similar to the ranking of the matching structures. To determine the required section properties for desired members, the rankings of the similar members, their sizes as well as the ranking of the structure of which they are a part are used.

To select the preliminary member sizes, various cross-sectional properties are first determined from the similar members and then a specific section is selected that satisfies these required properties. The properties that are used for a given member depends upon the member type. For example, if the current member type is a beam then the required strong axis moment of inertia and depth are computed. Table 3 lists the properties that are currently computed for different member types. The following computation is used to determine the required properties:

$$N_{prop} = \frac{\Sigma(\Sigma(\Sigma(\Phi_i \Gamma_j \Omega_k N_k)))}{\Sigma(\Sigma(\Phi_i \Gamma_j))} \quad (3)$$

where

N_{prop} = property value for the proposed member
N_k = property value for the matching member k
Φ_i = rank for ith structure
Γ_j = rank for jth component of ith structure
Ω_k = factor accounting for the difference in length between the proposed member and the matching member
= $(L_{prop}/L_k)^2$
L_{prop} = length of proposed member
L_k = length of matching member k

Equation (3) allows for the possibility of multiple matching members for each component in a matching structure and also allows for multiple components from a matching structure. The factor for the difference in length, Ω_k, is raised to the power of two to account for the following:

- The buckling load for columns varies with the slenderness ratio by a power of two.
- The magnitude of the maximum moments for beams loaded laterally with uniform loads varies with the length by a power of two.
- The torsional buckling load for laterally loaded members varies with the length by power of two.

It must be noted that the factor, Ω_k, is used to increase or decrease the required properties and not as a weighting factor for the computation. This feature provides a means for estimating the required size of a member even if all of the matching members are substantially shorter or longer than the proposed member.

Once these individual property values are known, a specific section is selected by one of two methods depending upon the section type. If the section type is a standard section such as a rolled I shape, the required section will be selected from a database of engineering sections. However, if the section type is not a standard section such as a concrete section, the dimensions that satisfy the required properties are calculated.

Implementation of PREDES

Selection of Development System. To implement PREDES, a software development environment that has the following characteristics was required:

- Fast development of prototypes to test the proposed ideas and methods.
- Separation of knowledge from control strategy. This simplifies the modification of the rules that govern the different phases of the system.
- Simple interface to databases.
- Ability to function with incomplete data.

In addition to these characteristics, the development system must be inexpensive and preferably available on MS-DOS or UNIX computer systems. Various development systems that are used for implementing expert systems were considered. These systems include Borland's Turbo Prolog, Computer Thought's OPS5+, Texas Instruments' PC+ and Inference Corporation's Automated Reasoning Tool (ART). OPS5+, PC+ and ART were compared in detail by Dennis Moy (1989) and his observations were used to help evaluate these systems. Turbo Prolog was selected for the development of PREDES for the following reasons:

- Availability: Turbo Prolog runs on MS-DOS systems.
- Interface to Databases Applications: Turbo Prolog offered easy access to databases. Built in functions are provided that allow for easy creation and utilization of databases. Furthermore, the Turbo Prolog Toolbox offers interfaces to many popular MS-DOS based databases. None of the other systems considered offered the same capabilities.
- Interface to Other Languages: Turbo-Prolog allows C and Pascal functions to be called from Prolog predicates. One weakness of expert systems in general and Turbo Prolog in specific is that complicated mathematical operations are not easily performed with these systems. However, this weakness is overcome by Turbo Prolog by its ability to call functions written in other languages. The external functions can be used to perform the required calculations. ART and OPS-5+ also allowed functions written in C or Fortran to be called from within their own environments.
- Cost: The cost of Turbo Prolog is much less than any other system considered in the evaluation.

Prolog is considered a declarative language as opposed to more traditional languages like C or Fortran that are considered procedural. In the procedural language the computer is instructed how to perform a certain operation. In a declarative language the computer is told what to do but not how the operation is to be done. In using Prolog, the programmer provides a description and governing rules of the problem. Turbo Prolog will then use its unification system to attempt to solve the problem. In addition to the backward chaining capabilities of Prolog and the tools that are available for working with databases, Turbo Prolog also provides a basic expert system shell that can be modified for a particular project's requirements with relative ease.

One drawback in using Turbo Prolog to develop PREDES was the limitation on memory size of MS-DOS systems. There is a limit to the number of rules that the system can work with before running out of memory. Nevertheless, Turbo Prolog does allow for the use of extended memory which in turn allows larger systems to be developed. Another shortcoming to using Turbo Prolog was the fact that rules could not be dynamically defined. All rules must be defined when the system is compiled. This limitation can also be overcome by developing a rule interpreter within an application using Turbo Prolog utilities. These factors did not have a major effect on the development of PREDES, since this system was intended to be only a prototype; however, they may become important if PREDES is expanded into a fully functional design tool.

System Hierarchy. The different components of PREDES previously described can be depicted by the Dataflow Diagram (DFD) shown in Fig. 4. The DFD shows the flow of data from one phase of the process to another. There are six major components in the system and these components correspond to the tasks that are performed. The first four components in the figure have previously been discussed. The knowledge base, component number five (KB) in the figure, controls all of the activities in the other components. In addition to rules that control the system, the knowledge base also contains the following information:

- Facts that define the attributes available to the system and how to access these attributes.
- Rules that are used to create the criteria table and compute the weighting factors.
- Heuristics that govern the evaluation of the matching structures.
- Knowledge defining the framing schemes that are known to the system.
- Heuristics used in selecting member sizes.

As mentioned earlier, the knowledge base controls all access to the experience database. This database contains the case histories of the previously designed structures that are known by the system. The information stored includes not only the general description of each structure and the primary framing schemes used, but also the properties of the members used in the framing schemes. It is not practical or even desirable to store the properties of every member in a building. To reduce the number of members that are contained in the database, only the properties of the boundary members in a frame are saved. The properties of the intermediate members are then derived by interpolating among these members. For example, only the top and bottom members in a column stack are stored in the database. The properties for members at different levels are determined by using a linear interpolation with the top and bottom columns as the boundary members.

PREDES Database Relations. The database that contains

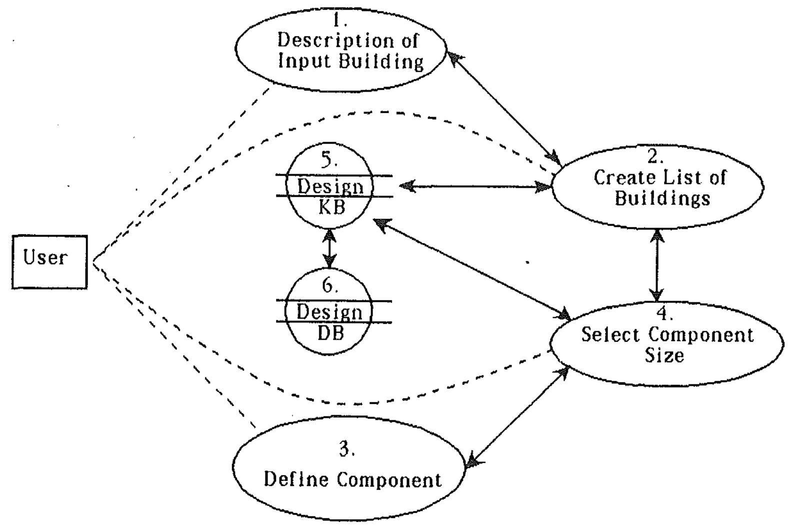

Fig. 4 PREDES DFD

the previous experience is based upon the relational model (Martin, 1976). Tools provided with Turbo Prolog were instrumental in its implementation. The relations currently defined for the system include: general data, geometry data, architectural data, engineering data, lateral 3D system, lateral 2D system, frame data, truss data, floor grid data and member data. Two typical relations, the general data and the engineering data, are shown as examples in the following:

Relation: General Data

Attribute name	Type	Description
Structure case number	Integer	Key number 1
Structure name	String	
Owner	String	
Location	String	
Structural framing cost	Real	
Foundation cost	Real	
Total structure cost	Real	
Date of completion	String	

Relation: Engineering Data

Attribute name	Type	Description
Structure case number	Integer	Key number 1
Superimposed dead load	Real	Units of ksf
Live load	Real	Typical load, units of ksf
Wave loading	Real	Loading on members
Current loads	Real	In mph
Design wind speed	Real	In mph
Seismic zone	Integer	Range from (0-5)
Lateral 3D system Id	Integer	Lateral frame system id
Floor system	Integer	Floor framing system id
Foundation system	String	Foundation system id

When a specific attribute such as the typical live load of an existing structure is required, rules in the knowledge base are used to extract the information from the database. Although the database is currently contained entirely within the Turbo Prolog system, tools are available that allow PREDES to access information stored in external databases, including commercial relational databases. By adding additional rules to the system, attributes could be retrieved from any database containing the required information.

Conclusion

A computer-based procedure that aids an engineer in selecting preliminary member sizes has been described. The benefits of such a system include providing novice engineers with knowledge that normally only experienced engineers possess. Also, the procedure can enhance the design process by speeding up the preliminary design phase, and thus allow more framing schemes to be evaluated. The procedure is based upon the transformational form of analogical reasoning. In implementing the system, "expert system" techniques were used. These techniques allow the system to be modified relatively easily, thus providing a means for increasing the range of structure types that the system can handle.

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