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ARAŞTIRMA MAKALESİ/**RESEARCH ARTICLE**

COMPUTER AUTOMATED ACCESS to the "F.E.M. RULES" for CRANE DESIGN

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ABSTRACT

Standardisation of crane design procedures enables designers to develop their own crane automation software for crane design applications. Since main effort and time for implementation of the crane design procedures are generally spent for interpretation and explanation of the available crane design standards, a computer-automated access to the available standards may improve speed, reliability and quality of the design procedures. Starting from the fact that components of cranes are generally composed of similar mechanical and electrical sub-components independent of the crane type, a general component tree of cranes is developed for automation purpose. Design Modules of cranes are defined from the developed component tree of the cranes based on the available design procedures. Independent Design Procedures are defined as atomic design modules of the crane design procedures by considering computational approaches and rules in the "F.E.M. Rules" for each crane component. The "F.E.M. rules" is selected for this purpose because of its widespread use and established popularity among the crane manufacturers. Access to the "F.E.M. Rules" from any design procedure is fully automated by using a systematic approach. The system is implemented fully for Personal Computers. The software package is used for various crane design cases.

Key Words: F.E.M. Rules, Crane Design, Computer Automated Design.

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ÖZ

Kren tasarım işlemlerinin standartlaştırılması ile, tasarım mühendislerinin kendilerine ait kren tasarımları için tasarım otomasyon yazılımlarını geliştirmeleri mümkün olabilmektedir. Kren tasarım işlemlerinde en fazla emek ve zaman varolan kren standartlarının yorumu ve açıklamalarına harcanmakta olduğundan, varolan standartlara bilgisayar destekli otomasyon ile erişim, tasarım işlemlerinin hızını, güvenirliliğini, ve kalitesini arttıracağı düşünülmektedir. Bu çalışmada kren elemanlarının kren tipinden bağımsız olarak genel düzeyde benzer mekanik ve elektrik elemanlardan oluştuğunu düşünerek, tasarım otomasyonu amacına yönelik olarak krenlerin tasarım ağacı geliştirilmiştir. Bu tasarım ağacını ve bilinen tasarım işlemlerini kullanarak Tasarım Birimleri tanımlanmıştır. Her bir kren elemanı için F.E.M. kurallarında belirtilmiş olan hesaplama yöntemleri ve kurallar kullanılarak bölünemez düzeyde tasarım birimleri olarak belirlenen Bağımsız Tasarım İşlemleri tanımlanmıştır. Bu amaca yönelik olarak F.E.M. Kurallarının seçilme nedeni, bu kuralların ülkemizde ve Avrupa ülkelerinde kren tasarımında yaygın ve zorunlu bir kurallar zinciri olarak kullanılmakta olmasıdır. Sistematik herhangibir kren tasarım sürecinden F.E.M. kurallarına erişim tamamen otomasyona bağlanabilmektedir. Yazılım kişisel bilgisayarlara uygulanmıştır. Yazılım paketi değişik kren tasarımı uygulamalarında kullanılmıştır.

Anahtar Kelimeler: F.E.M. Kuralları, Kren Tasarımı, Bilgisayar Destekli Tasarım Otomasyonu.

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1. INTRODUCTION

Cranes are industrial machines that are mainly used for materials movements in construction sites, production halls, assembly lines, storage areas, power stations and similar places. Their design features vary widely according to their major operational specifications such as: type of motion of the crane structure, weight and type of the load, location of the crane, geometric features, operating regimes and environmental conditions. However, an appraisal of the available literature reveals that procedural design of cranes are highly saturated and standardised in various industrial companies and organisations independent of the crane type. Consideration of the available technology that is mainly based on the accumulated previous experience, is important for better performance, higher safety and more reliable designs. It is well known that generic features of crane components are similar for various different types of cranes. Since the crane design procedures are highly standardised with these components, main effort and time spent in crane design projects are mostly for interpretation and implementation of the available design standards. Many international and/or national standards and rules are available to guide the crane designers for that purpose; e.g. BS 357 (Anon, 1965), AISE Standard No.6, (Anon, 1966), CMAA No.70 (Anon, 1971), JIS B8801 (Anon, 1974), DIN-Taschenbuch 44 (Anon, 1979), " F.E.M. Rules" (Anon, 1987). They offer design methods and empirical approaches and formulae that are based on previous design experiences and widely accepted design procedures. It is believed that computer automated access to these standards with pre-loaded interpretation and guidance rules increase speed and reliability of the design procedures and increase efficiency of the crane designers.

2. STANDARDS IN CRANE DESIGN AND "F.E.M. RULES"

Modified static analysis of mechanical and structural components was the only approach for crane design before 1960s (Brainard, 1978). In this approach, the main trend was to use allowable design stresses that are calculated empirically by using safety factors based on some previous experience. Crane components are designed accordingly assuming that they are subjected to heavy operational conditions. This approach led to unnecessarily large and expensive cranes and crane components. As the crane capacities increase and applications are varied, new design methods are developed for the crane design. There are large number of published studies on structural and component stresses, fatigue limits, automatic control, safety under static loading and dynamic behaviour of cranes (Demokritov, 1974; Lemeur, Ritcher and Hesser, 1977; Buffington, 1985; Rowswell and Packer, 1989; Reemsyder and Demo, 1978; Totten, 1985; Federov, 1985; Marchese and Rice, 1974; McCaffrey, 1985; Erofeev, 1975; Zaretskii, 1975; Baker, 1971; Anon, 1978). Some of these studies are later contributed significantly development of design rules and/or standards which are commonly used for crane design in the current state of technology.

Among these standards related to the crane design, AISE Standard No.6 (Anon, 1966) introduced a new approach in crane design with consideration of fatigue failure criteria in the design and analysis of mechanical and structural components. It covers heavy duty, mill type, overhead traveling cranes and all types of cranes with special services such as charging, pit, stripper, ladle, gantry cranes and ore bridges. The standard is revised in 1970 to consider advancements in fatigue design, service classifications varying with usage, and new materials and manufacturing methods.

Structural design of trolley frames, bridge girders, platforms and similar components are considered in the first section. Design of mechanical components is the subject of the second section. The third section includes recommendations for selection of electrical devices. CMAA No.70 (Anon, 1971) is another standard that established a basis for uniform quality and performance, and introduced guidelines for a reliable procedure, information for purchasers and users of cranes. It covers top running bridge and gantry type cranes, multiple girder electric overhead traveling cranes except mill cranes of the type covered by the AISE Standard No.6 specification. The standard has seven sections as; General specifications, Crane service classification, Structural design, Mechanical design, Electrical equipment, Inquiry data sheet and Glossary.

BS 357 (Anon, 1965) is an old British standard (First published in 1930, revised in 1958) related to cranes and excavators with minimum requirements for power driven, rail-wheel mounted cranes. It states the rules and specifications to ensure reliability and safety without replacing restrictions. BS 466 (Anon, 1984) is another British standard that specifies requirements for power driven overhead traveling cranes, semi-Goliath and Goliath cranes for general use. It has six sections including specification for structural, mechanical and electrical components, protection and painting, testing, marking and certification of cranes.

BS 2573 (Anon, 1983) also states rules for the design of cranes for a basis of computing stresses in crane structures (Part I) and mechanisms (Part II), and the way in which permissible stresses in crane structures are determined in order to secure an economical and reliable design. It specifies a classification system that enables the purchasers and the manufacturers to match a particular crane to the required duty and utilization.

JIS B8801 (Anon, 1974) gives recommendations for design of electric overhead traveling cranes with hook, mainly for use indoors of factories and electric power stations. It specifies dimensions, loads, motor characteristics and properties of crane components for high speed, ordinary and low speed crane types.

DIN Norms are internationally accepted standards in industry. DIN-Taschenbuch 44 and 185 (Anon, 1995a, 1995b) are collection of standards related to the crane design. DIN norms generally state standard values of design parameters related to crane components rather than the design procedures.

" F.E.M. Rules" (Anon, 1987) is a collection of internationally accepted guidelines for crane design. Section I of the " F.E.M. Rules", titled as "The Rules for the Design of Hoisting Appliances", has eight booklets. More information about the structure of the " F.E.M. Rules" will be given in the next section.

3. STRUCTURE OF THE "F. E. M. RULES"

" F.E.M. Rules" is mainly a collection of rules (not procedures) to guide the crane designers. Many requirements are implied within the " F.E.M. Rules", but explicit and detailed statements towards established design calculations are not available. This is very convenient for crane designers of different companies and institutions, since each company has its own know-how and experience to be implemented in their own crane design technology. Overwhelming features of the " F.E.M. Rules" are stated below:

- Extensive classification of cranes and crane components for the purpose of design,
- Classification and identification of crane loads for safe and reliable crane design,
- Strength and stability requirements to be satisfied for various load (including test loads) conditions,
- Informative for non-critical crane components.

A schematic representation of structure of the " F.E.M. Rules" is given in Figure 1. The figure summarizes the outline of the text of the F.E.M. Rules from a topical view. The " F.E.M. Rules" starts with a classification of cranes and their mechanisms/components and continues with the discussion of loads and their identification and related stress/deflection analysis. It also includes criteria to decide on the external loads, to select crane components and to test the manufactured cranes.

A comprehensive research is completed at METU to analyse the "F. E. M. Rules" systematically and develop a computer-automated medium to guide the crane designers. Although most of the work has limited access (Ünsal, 1992; Erkan, 1993; Alper, 1994; Kesemen, 1997), some of the main achievements of the project are already published partially (Ünsal and Erden, 1992; Ünsal and Erden, 1993; Erden et al., 1996). Particular emphasize in this project is given to develop a computer automation of the "F. E. M. Rules" to guide the crane designers in industry.

4. COMPUTERS IN CRANE DESIGN

Computers are used mainly for two purposes in a crane design process. The first is procedural programming that enables designers to make lengthy and tedious calculations in a short time. This also includes use of CAD techniques and reduces the design time significantly. Another approach is the use of Artificial Intelligence techniques for expert system applications. Artificial Intelligence techniques are used mainly in selection and decision making stages of the design process.

It is believed that Design Automation by using Artificial Intelligence techniques may result in significant improvements on designers' productivity. Greater consistency of design, ability to explore more alternatives and integration of the design/analysis/documentation processes are most significant advantages of the design automation (Chryssolouris and Wright, 1986). There are many design automation software packages and many more expert systems developed for industrial applications on various fields. (Korane, 1986; Fagan, 1987; Arora and Baenziger, 1986; Basu et al., 1989; Galbraith, AL-Najjar and Babu, 1988; Nau and Chang, 1983; Wysk et al., 1980; Gupta, 1990; Miska, 1989; Preiss, 1986; Chryssolouris and Wright, 1986; Sohlenius and Kjellberg, 1986; Davies, 1986). Most of these software packages are in the field of production engineering (Nau and Chang, 1983; Wysk et al., 1980; Gupta, 1990; Miska, 1989; Preiss, 1986; Chryssolouris and Wright, 1986; Sohlenius and Kjellberg, 1986; Davies, 1986). Number of expert systems which are used in material handling (Gray,1985, Furusaka and Gray, 1984; Gray and Little, 1985; Zhang and Rice, 1989; Malmborg et al., 1987; Gabbert and Brown, 1989; Marsuo et al., 1989) is not very large and their scope is limited. Among the few successful expert systems on this field, an expert system is worth to mention which is used to determine Tower crane locations in a site handling (Furusaka and Gray, 1984; Gray and Little, 1985). This expert system is written in PROLOG language and is aimed to obtain least cranage cost by calculating the combined use of different cranes, such as truck crane, craw-

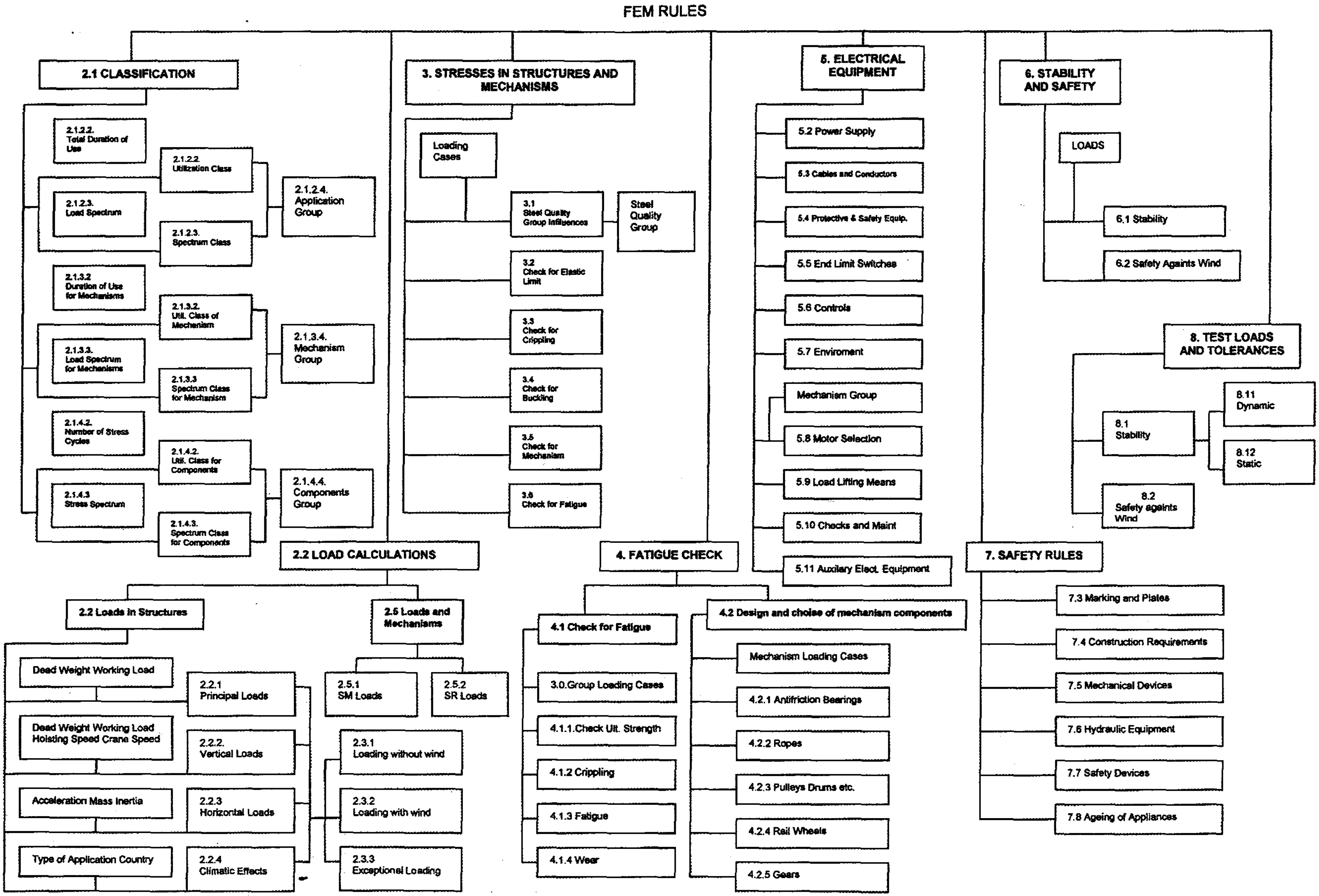


Figure 1. A Schematic Representation of The Structure of The " F.E.M. Rules".

ler crane, traveling base tower crane or fixed based tower crane. Some conclusions are reported from several construction projects. Another interesting expert system is proposed and developed for overhead traveling cranes as a special case of conceptual design of mechanical systems (Zhang and Rice, 1989). The software is developed in LISP language and detailed information is not available in the literature. Further information is needed for any evaluation. Another simple expert system is developed in PROLOG for the selection of industrial trucks Malmborg et al., 1987). It is mainly used for illustrative purposes and not much suitable for any industrial application. No other expert system is known to be published in the field of material handling.

5. COMPUTER AUTOMATED ACCESS TO THE "F.E.M. RULES"

The first phase of this study is to computerise access to the " F.E.M. Rules" through a crane design code. This is achieved by automated access to the elements of the " F.E.M. Rules" in a computer environment. This software is called DES_CRANES/FEM_RULES and composed of two parallel-developed software packages. One of them (FEM_RULES) is developed to enable crane designers to access the "F.E.M. Rules" in an automated environment (Ünsal, 1992). The developed software is applied with an automated design procedure (DES_CRANES) that is developed for automation of the design procedures. Another intermediate software (INDEPENDENT_DESIGN_PRO) is later developed to cover a crane design procedure completely "Alper (1994)". These software packages are developed and integrated such that related recommendations, computational procedures and data are transferred mutually during the runtime. The primary aim is to guide the user along a design path with full compatibility to a selected standard. Both of these software packages are developed using C++ programming language for personal computers. Following benefits are expected from the development of a computer-automated procedure for crane design:

i. Development of an established design procedure,

ii. Elimination of any misinterpretation of the standards for crane design during limited design period,

iii. Elimination of absolute dependence on human experts, hence inexperienced designers may be employed in a design project,

iv. Accumulation of previous experience in a systematic manner that will lead to an intelligent design database.

Three alternative program structures for design automation are developed, analyzed and tested in detail during this study. These alternatives are explained in the following sections.

5.1. Direct Use of a Data File

Data and knowledge transfers between the two software modules are performed through a common DOS file as it is illustrated in Figure 2. The file is a simple read-write text file and numerical data are associated with some parameter names (Table 1). Structural organization of the file is such that read-write commands are directed to predefined locations depending on the calling modules. Independent modules (child programs) of the FEM_RULES software are called from the parent program that is the design software (DES_CRANES) in this case. In this alternative basic input parameters for a module should be specified and written into the data file whenever a specific module is called. This alternative can be defined as a F.E.M.-aided design. The design software is dominant and it sets the procedure independent of the "F.E.M. Rules". The integrated DES_CRANES/FEM_RULES software guides solely the designer for input data. This alternative is simple and may be considered as conventional approach. However, it has an important disadvantage. The parent program can call

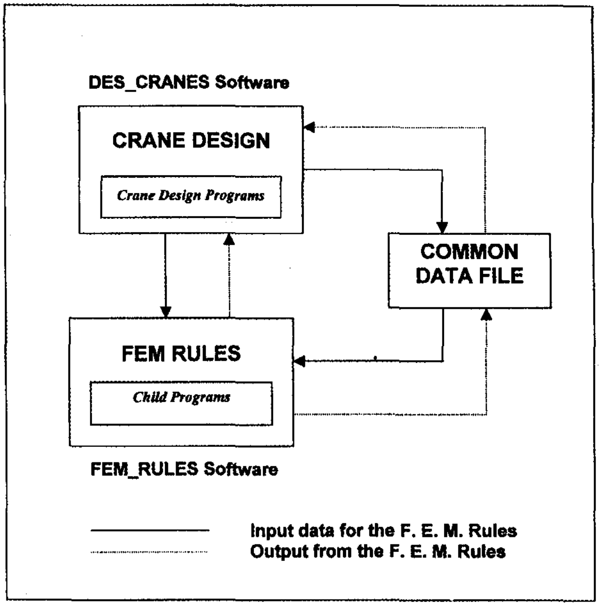


Figure 2. Computer Automated Access to the "F. E. M. Rules" By Direct Use of a Data File.

Table 1. Structure of Data Transfer Files.

Field	Data Type	Length
Name	Character	30
Value	Character	30

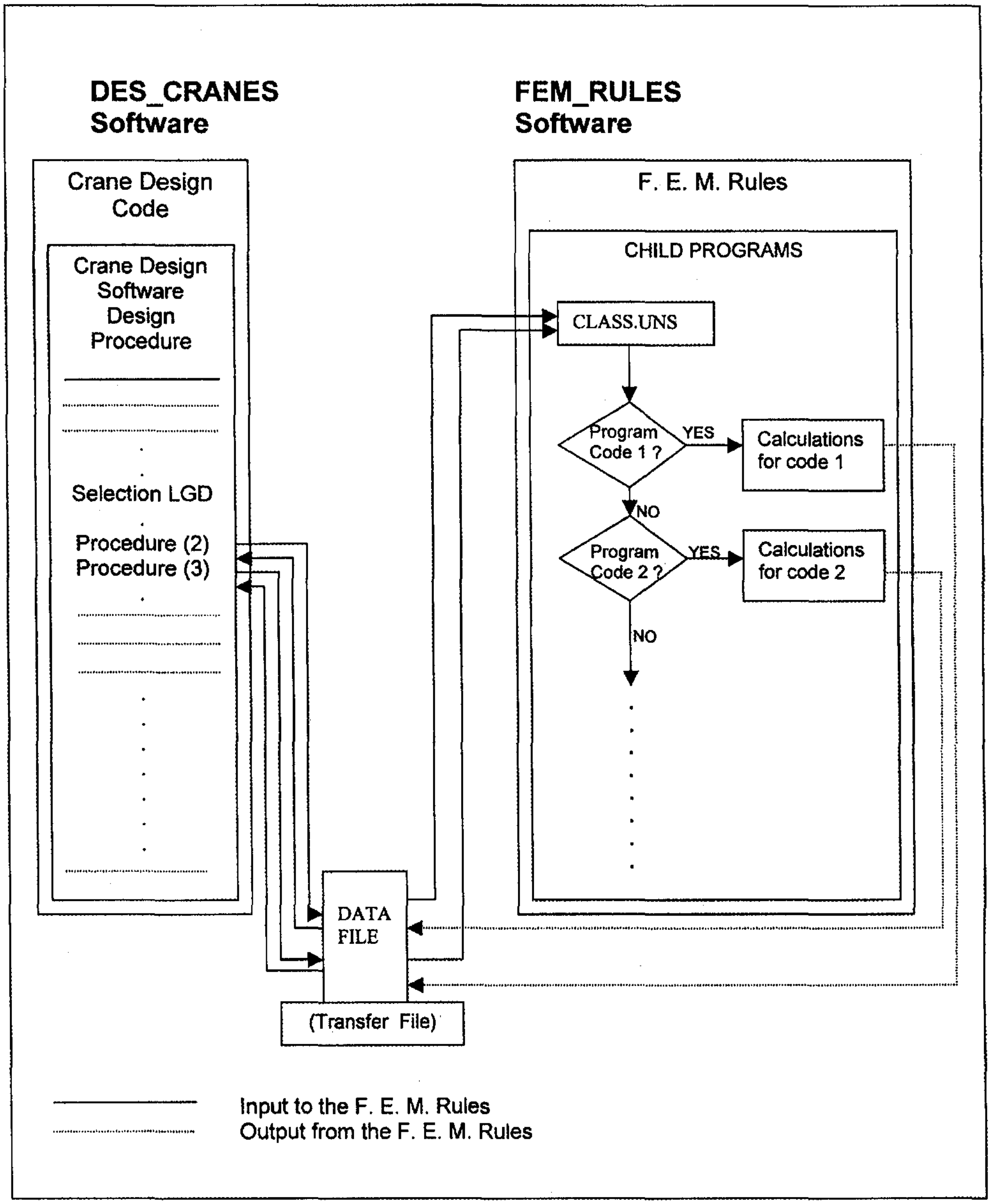


Figure 3. Computer Automated Access to the "F. E. M. Rules" By Using Program Codes.

child programs as a whole. Therefore, if the designer needs to call a small design step solely in a child program, he/she cannot achieve this specific location directly. In this case, all of the steps existing in the child program need to be performed in sequence. This problem can be overcome by a second alternative where the number of accessible locations in the FEM_RULES software is increased.

5.2. Automation with Program Codes

In the second alternative of automation, child programs of the FEM_RULES software are called from the design software by special program codes (simple numbers) as it is illustrated in Figure 3. Each module determines the sequence of procedure according to the program code. That is, either a specific calculation or a series of necessary calculations are performed and results are returned back to the parent program. The sequence of calculations is decided according to whether the required input data are recorded in the data file or not. The data file contains field names and associated numerical data only.

In this alternative, number of steps in the child programs that can be reached from the design software is increased. It is a F.E.M.-aided procedure as it is in the case of previous alternative, but the automation process is improved. This alternative requires an intermediate switch program that controls data and code transfer. By using this alternative, it is possible to reach

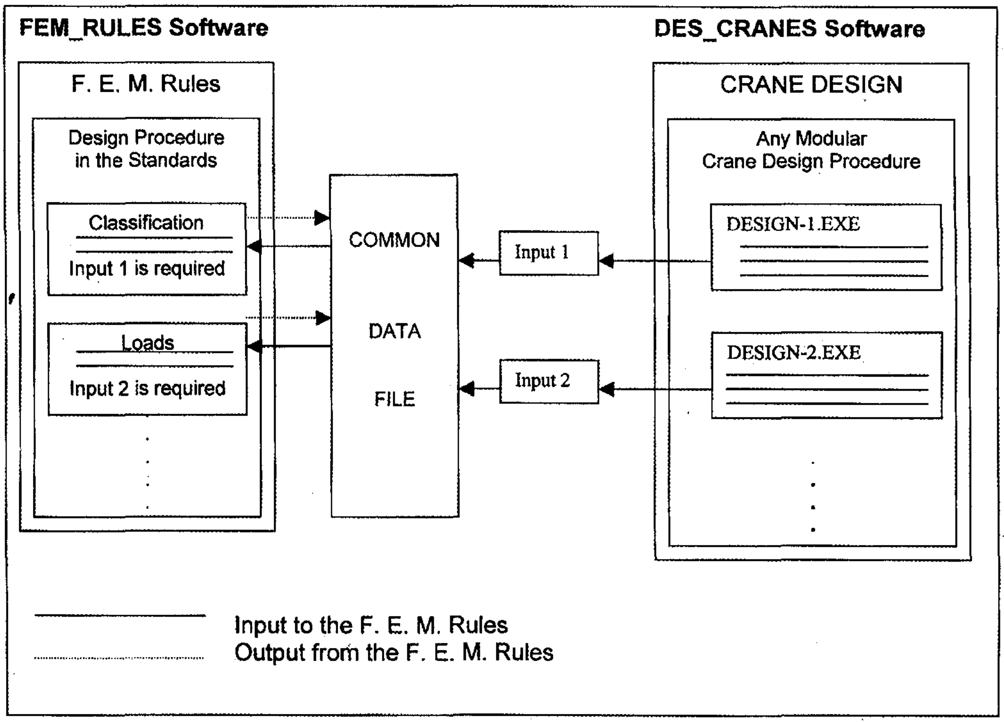


Figure 4. Computer Automated Access to the "F. E. M. Rules" by Using Design Modules.

every function located in different executable modules of the FEM_RULES software.

5.3. Use of Design Modules

Another alternative of design automation is developed and studied for industrial applications. In this alternative FEM_RULES software is used as the core and the design software is established around it as it is illustrated in Figure 4. In this case, independent modules of the FEM_RULES software are executed in sequence. Whenever a parameter is required to be provided manually in the modules, the user/designer can either enter it from the keyboard or run his/her own program to obtain the result. Then he/she imports and uses the data so generated in the calculations of the "F.E.M. Rules". Therefore, the design procedure is developed around the FEM_RULES software. In this case the automation process and use of the "F.E.M. Rules" are integrated in single software. This method is a FEM-based procedure and it may not be suitable for those designers who prefer to use the "F.E.M. Rules" as guidance only.

The above mentioned alternatives are implemented initially for design of hoisting mechanisms for experimentation and their relative performances are studied thoroughly by considering advantages and limitations from designers' point of view. The second alternative is decided for further development of a computer automated design procedure with the "F.E.M. Rules". One of the primary objectives that was considered at this stage was that the developed software should be modular such that any modification in the design methods could be easily implemented. The number of procedures and/or their sequence can be changed easily by means of the automation with program codes. In this alternative, "F.E.M. Rules" is used as an auxiliary design tool for the parent program and this was another significant objective of the study. Program flow for the automation process with program codes in its developed form is shown in Figure 5.

6. AUTOMATION OF THE CRANE DESIGN PROCEDURE

Processes and methods used in crane design are subjected to significant changes after the recent developments in mechanical engineering and computer technology. However it is clear that the crane mechanisms (Hoisting, Locomotion and others) are composed of similar mechanical and electrical components, which are independent of the crane type when crane design procedures in practice and crane mechanisms are examined closely. Starting from this fact, an overall component tree of cranes is developed to illustrate the use of similar mechanical and electrical components in crane mechanisms of different types (Figure 6). Although the mechanical and electrical components of different mechanisms are varying in type, size, and mechanical and electrical properties, all of these components are

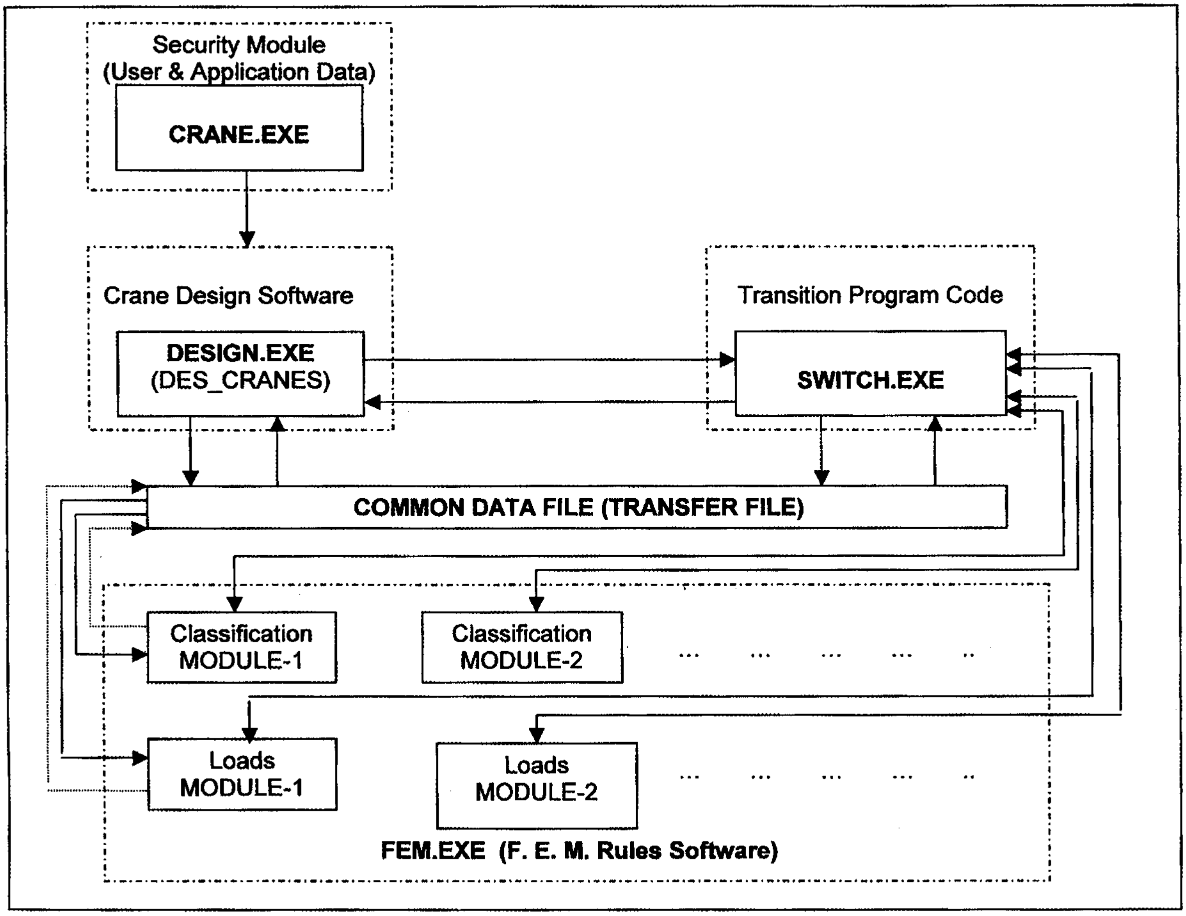


Figure 5. Final Implementation of Computer Automated Access to the “F. E. M. Rules”.

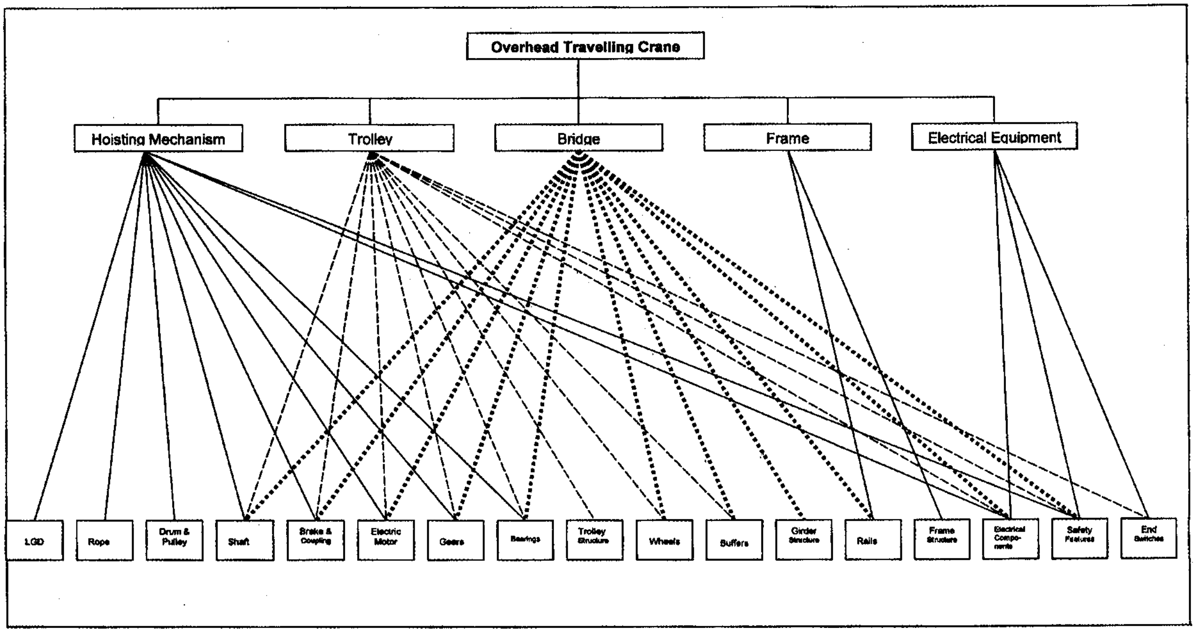


Figure 6. Component Tree of Cranes.

Table 2. List of the Independent Design Procedures.

No	Name of IDP
1	Design/Selection of Load Gripper Device
2	Rope Selection
3	Design/Selection of Drum/Pulley
4	Shaft Design
5	Design/Selection of Brakes/Couplings
6	Electric Motor Selection
7	Gear/Gearbox Design
8	Bearing Selection
9	Design of Trolley Structure
10	Rail Wheel Design
11	Design of Girder Structure
12	Selection of Rails
13	Design of Frame Structure
14	Selection of Electrical Equipment
15	Design for Stability and Safety
16	Implementation of the Safety Rules
17	Test Loads and Tolerances

designed by using similar computational procedures and rules. All subsystems of a crane (as an engineering system) are assemblies of these components; hence design procedures of crane mechanisms show close similarities. These mechanical and electrical components, which have well identified design procedures, are called "Design Modules" of cranes.

Main design modules of cranes are determined from the available design procedures and component tree of cranes as they are listed in the lower row in Figure 6. Design modules are so identified that an "Independent Design Procedure" is defined clearly for each of the design modules. Collection of the developed "Independent Design Procedures" (IDP) covers any crane design procedure completely, for both design calculation and/or selection of the design modules. The IDPs are listed in Table 2. The listed independent design procedures are collected in another software package, which is called INDEPENDENT_DESIGN_PRO. The INDEPENDENT_DESIGN_PRO is an intermediate code that provides access to the FEM_RULES software from a user developed crane design program through DES_CRANES.

The basic engineering design logic of the independent design procedures is summarised in Table 3. The independent design procedures for the design modules of cranes are listed in the first row of Table 3 and modules of FEM_RULES software are listed in the first column of Table 3. Numbers in the columns of the table indicate the order of execution of FEM_RULES software modules with respect to the independent design procedure of each design module of the corresponding column. However order of execution of the FEM_RULES software modules is not completely identical for every application, because order of execution also depends on the recorded data in the transfer data file. Transfer data file is a text file (an open whiteboard) which provides data transfer between the user developed crane design code, the computer automated access software DES_CRANES/FEM_RULES, and INDEPENDENT_DESIGN_PRO. If the output of FEM_RULES software module was recorded previously in the data transfer file, that module is skipped during the execution. The data may be recorded manually or from any of the software package. This feature enables designers to use their own preferred parameter values in their design.

6.1. Integration of the Software Modules: The INDEPENDENT_DESIGN_PRO software that is operating with the DES_CRANES/FEM_RULES software by using the concept of independent design procedures is connected to a user developed crane design software. The INDEPENDENT_DESIGN_PRO software has a menu of independent design procedures. During the crane design code execution, INDEPENDENT_DESIGN_PRO software is called by pressing a key, whenever it is required to access the "F.E.M. Rules". From the menu of INDEPENDENT_DESIGN_PRO related independent design procedure is selected. The selected independent design procedure reads data in the board and then determines priority of execution of FEM_RULES software modules. If there is more input data required for the execution of DES_CRANES/FEM_RULES software modules, they are asked to input from the keyboard and all of the input values are recorded into the transfer data file for further calculations. Results are also recorded into the transfer data file. These input values and results can be used in the crane design code with the same variable names. A schematic representation of integration of software packages is illustrated in Figure 7 and a general structural view of all of the software packages is given in Figure 8.

7. APPLICATION CASE STUDIES

The presented work is applied on several crane types, but more emphasize is given on the design of overhead travelling cranes (OTC). Since description of

Table 3. Engineering Design Logic of the Independent Design Procedures.

FEM	Independent Design Procedures (From Table 2)	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17
Classification (Determination of-)	Application group		1	1	1		1			1	1		1	1	1	8		
	Mechanism group		2	2	2		2			2	2		2	2	2	9		
	Component group				12					12			12	12	12			
Load calculations	Loads in structures		3	3	3		3			3	3		3	3	3			
	Loading cases				4		4			4	4		4	4	4			
Stresses in structures and mechanisms	Steel quality group				5					5			5	5	5			
	Check for elastic limit				6					6			6	6	6			
	Check for crippling				7					7			7	7	7			
	Check for buckling				8					8			8	8	8			
	Check for deformation				9					9			9	9	9			
Check for fatigue	Check for ultimate strength				10					10			10	10	10			
	Check for fatigue				11					11			11	11	11			
	Check for wear				13					13			13	13	13			
Design and selection of mechanism components	Baerings								1									
	Ropes		4	4														
	Pulleys/Drums			5														
	Rail wheels										5							
	Gears							1										
Electrical equipment	Power supply														1			
	Cables and conductors														2			
	Protective and safety equipment														3			
	End limit switches														4			
	Controls														5			
	Environment														6			
	Motor selection						5								7			
	Load lifting means	1													10			
	Checks and maintanence														11			
	Auxiliary electrical equipment														12			
Stability and safety	Stability															1		
	Safety against wind															2		
Safety rules	Marking and plates																1	
	Construction requirements																2	
	Mechanical devices	2	5	6		1											3	
	Hydraulic equipment																4	
	Safety devices																5	
	Ageing appliance																6	
Test loads and tolerances	Tests																	1
	Tolerances of cranes																	2

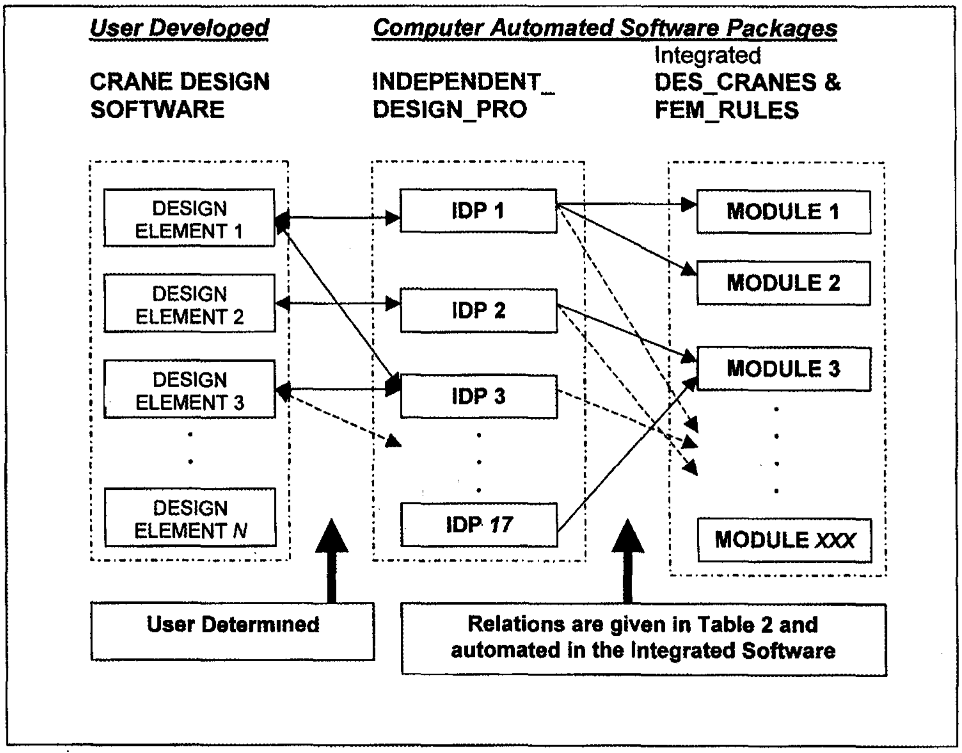


Figure 7. Integration of the Software Packages.

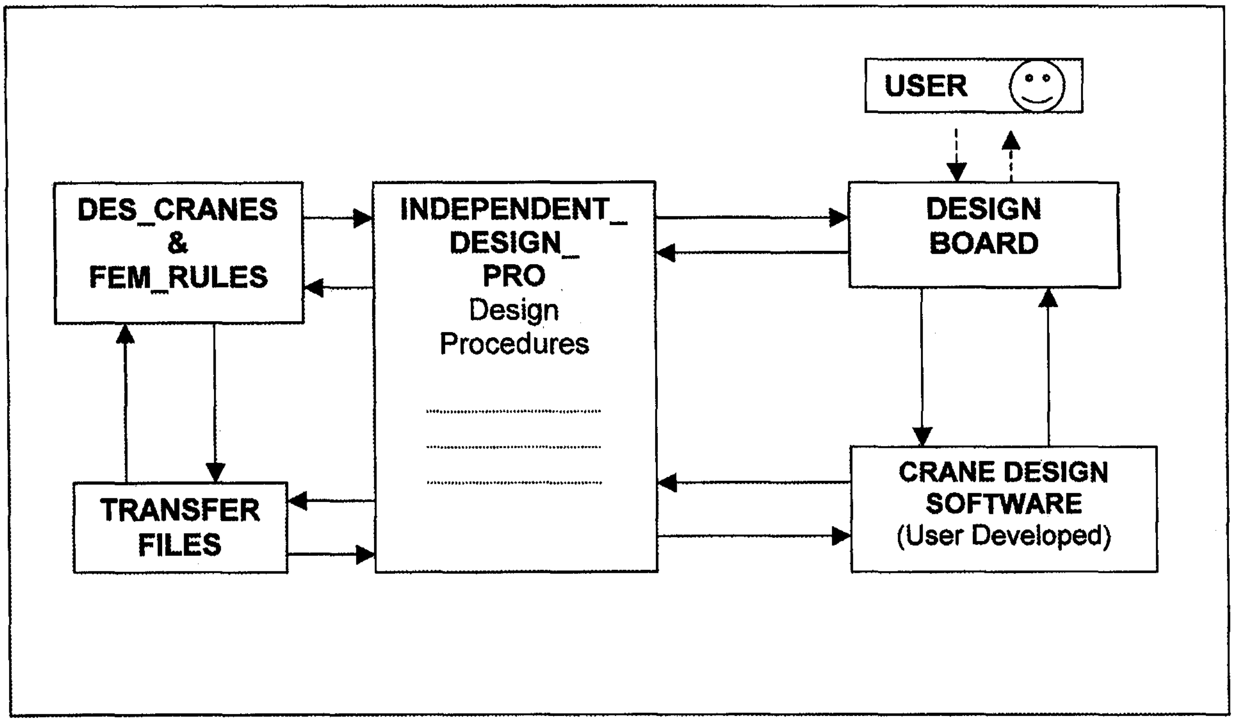


Figure 8. General Structure of the Software Packages.

the OTC design procedure is much longer then this paper, only the main steps will be given here. Steps of the automated design procedure are simply illustrated in Figure 9. The automated software (DES_CRANES/OTC_DESIGN) follows this procedure (Kesemen, 1997). The structure of the software is similar to the traditional sequential programming approaches. The relationship of the OTC_DESIGN and the FEM_RULES software packages, and the user interfaces are given in Figure 10. The software module as it is

Hoisting Mechanism :

* Determination of the load gripping device
* Determination of the rope-pulley configuration
* Selection of the rope type
* Determination of the rope diameter
* Determination of the pulley and drum dimensions
* Design of the power transmission unit
* Selection of the motor

Trolley:

* Design of the trolley structure
* Selection of the wheel and rail
* Design of the power transmission unit
* Selection of the motor
* Design of buffers

Bridge:

* Design of the girder structure
* Selection of the wheel and rail
* Design of the power transmission unit
* Selection of the motor
* Design of buffers

Frame:

* Design of structural components

Electrical Equipment:

* Selection and design of electrical equipment

Safety:

* Checks
* Tests

Figure 9. Sample Design Procedure of an Overhead Travelling Crane.

shown as " "..." *software*" is any user selected auxiliary software for particular application. The design board is the user interface where all the input and output data are displayed. Transfer files are simple text files similar to the file as it was previously illustrated in the Table 1. A sample input screen view is given in Figure 11. Sample input data for an OTC design are given in Table 4. Few more intermediate data need to be input during the design. Output of the automated software is given in Figure 12. The design is completed in a few minutes without any error or missing component.

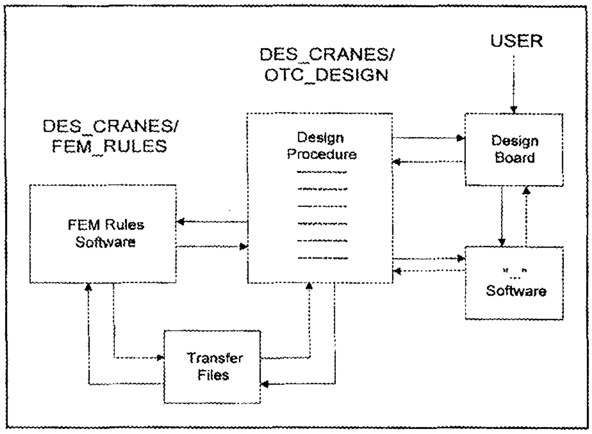


Figure 10. General Structure of the Automated Design Software.

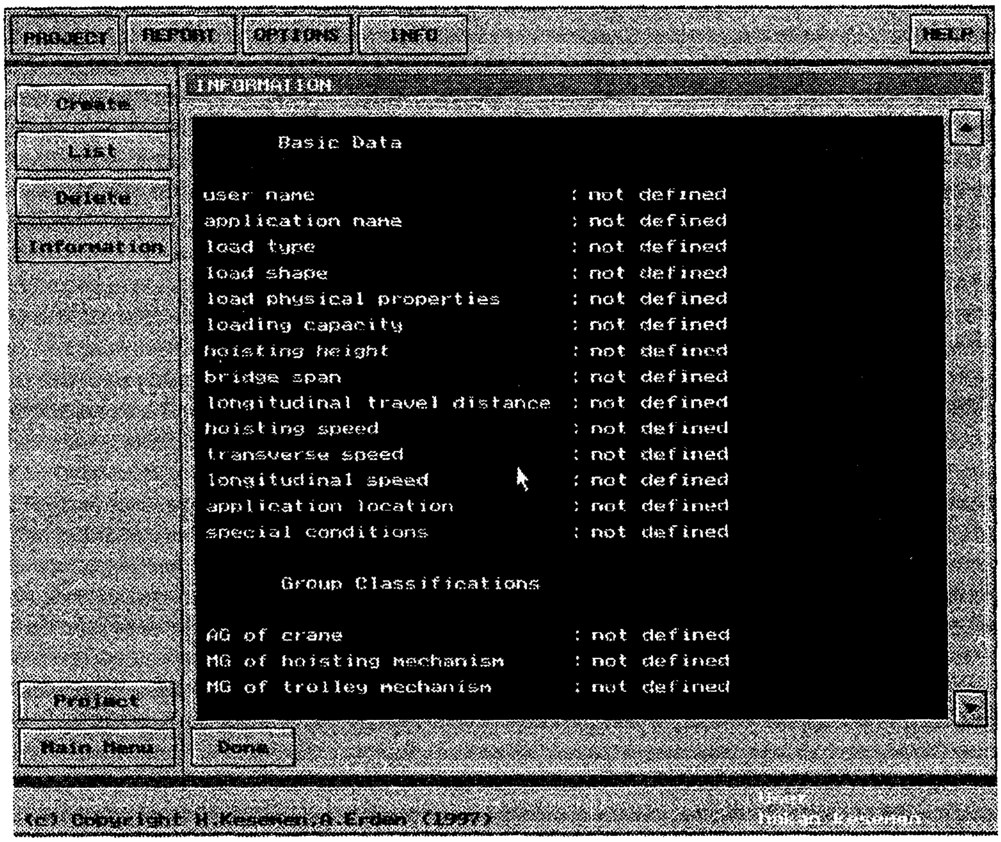
Table 4. Input Data of the Application.

Input name	Data
Capacity	16 000 kg
Hoisting height	16 m
Bridge span	20 m
Longitudinal travel distance	25 m
Hoisting speed	0.08 m/s
Transverse speed	0.7 m/s
Longitudinal speed	1.2 m/s
Number of expected years	25 years
Working days in a year	300
Average hoisting cycles per day	54
Avearge duration of a hoisting cycle	800 s

8. DISCUSSIONS AND CONCLUSION

Cranes vary widely in configuration, capacity, mode of operation, intensity of use, working environment and cost. The variety of forms, operating conditions, environmental factors make the design of cranes challenging. Usually a new design need arises when existing cranes do not meet the requirements for a new application. However, in most of the cases the required knowledge on configuration and structure of a crane can be obtained from previously accumulated technical information. The technical information is generally standardized. Besides that, the available crane components are also well standardized all over the world and suitable for computer automated design procedures. Since crane design procedures are highly standardized, main effort and time spent in crane design procedures are for the interpretation and use of the design standards. As a result of these facts, a computer-automated access to the available standards is required for the completeness and efficiency of any design automation for crane design.

A new computer automated access approach to the "F. E. M. Rules" by considering the design modules of a crane is developed in this work. For that purpose, mechanism and component tree of the cranes and design procedures of each design module are developed. DES_CRANES/FEM_RULES software which includes the rules and calculation procedures of the "F. E. M. Rules" in a modular structure and the INDEPENDENT_DESIGN_PRO software which consists of in-



```
        Basic Data

user name                        : not defined
application name                 : not defined
load type                        : not defined
load shape                       : not defined
load physical properties         : not defined
loading capacity                 : not defined
hoisting height                  : not defined
bridge span                      : not defined
longitudinal travel distance     : not defined
hoisting speed                   : not defined
transverse speed                 : not defined
longitudinal speed               : not defined
application location             : not defined
special conditions               : not defined

        Group Classifications

AG of crane                      : not defined
MG of hoisting mechanism         : not defined
MG of trolley mechanism          : not defined
```

Figure 11. Screen Shot of the Input Menu.

dependent design procedures prepared for each design module of a crane, are designed and developed to integrate with any crane design procedure for rapid, accurate and flexible computer automated access to the "F. E. M. Rules". The developed system provides a structured and compact tool, which combines any user developed crane design procedure with the "F.E.M. Rules".

In this study the software does not only perform the computations but it also guides the user/designer in a predefined design pattern. Moreover, decisions are made by the software and seldom left to the user/designer. The calculated data and related recommendations given in the "F.E.M. Rules" are imported automatically to the design software. Therefore, the user/designer does not need to spend much time to implement the "F.E.M. Rules". Experiments with the developed software package showed that the guidance function of the software is one of the most significant features. The developed software has another important advantage that probable misinterpretations, which may occur in the design procedure during limited design period, are eliminated or reduced significantly.

Modular structure of the software provides addition of any design procedure to the available crane design software. In addition, automation of the "F.E.M. Rules" can be replaced by the automation of other standards. It is also possible to extend the software to cover several design standards in the same program. By this way, alternative solutions for a design problem can be compared and the best one can be selected by interacting with the user/designer.

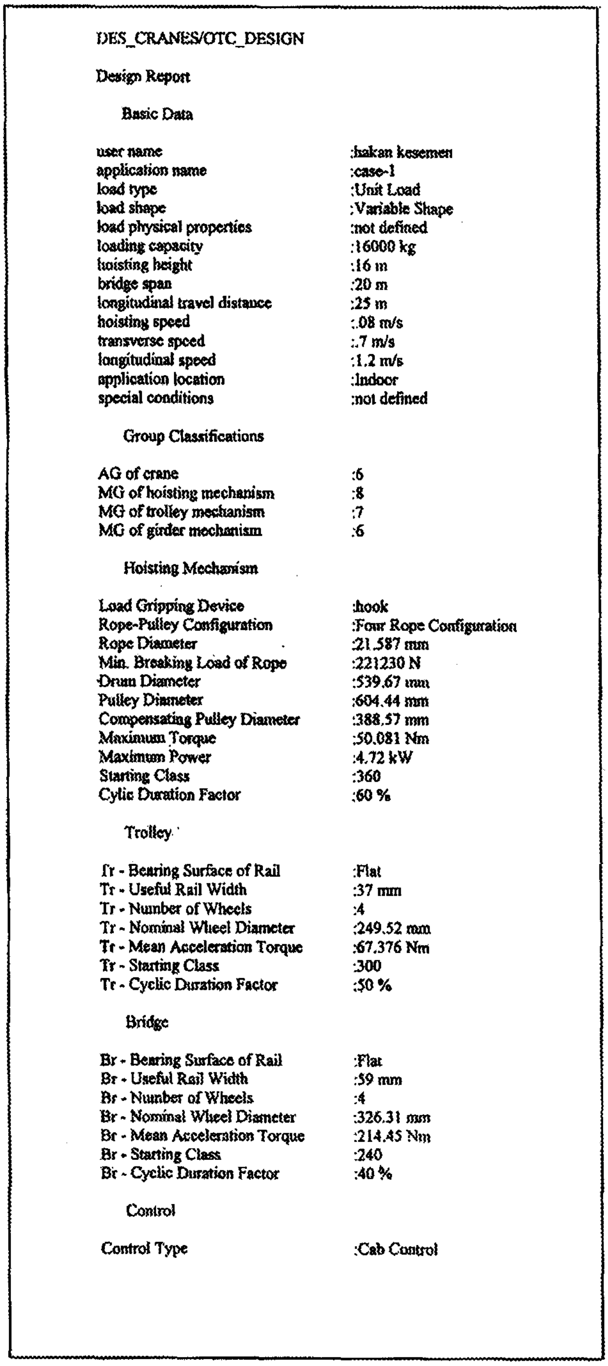
The developed software can also be used by user-oriented data, which may be added into the related data files manually by means of open-ended data structure of the data files, and hence previous knowledge accumulation or some company oriented preferences will offer more alternatives to the user/designer.

In general, some of the main benefits of the automated design include the following:

i. Greater consistency of design; this makes manufacturing and field service easier.

ii. Ability to explore more alternatives; because design can be created in a shorter time, it allows designers to study more alternatives.

iii. Retention of design expertise; Movements of engineering personnel can cause difficulties for engineering organizations. Automating the design process can capture and document this design expertise.



```
DES_CRANES/OTC_DESIGN

Design Report

    Basic Data

user name                          :hakan kesemen
application name                   :case-1
load type                          :Unit Load
load shape                         :Variable Shape
load physical properties           :not defined
loading capacity                   :16000 kg
hoisting height                    :16 m
bridge span                        :20 m
longitudinal travel distance       :25 m
hoisting speed                     :.08 m/s
transverse speed                   :.7 m/s
longitudinal speed                 :1.2 m/s
application location               :Indoor
special conditions                 :not defined

    Group Classifications

AG of crane                        :6
MG of hoisting mechanism           :8
MG of trolley mechanism            :7
MG of girder mechanism             :6

    Hoisting Mechanism

Load Gripping Device               :hook
Rope-Pulley Configuration          :Four Rope Configuration
Rope Diameter                      :21.587 mm
Min. Breaking Load of Rope         :221230 N
Drum Diameter                      :539.67 mm
Pulley Diameter                    :604.44 mm
Compensating Pulley Diameter       :388.57 mm
Maximum Torque                     :50.081 Nm
Maximum Power                      :4.72 kW
Starting Class                     :360
Cylic Duration Factor              :60 %

    Trolley

Tr - Bearing Surface of Rail       :Flat
Tr - Useful Rail Width             :37 mm
Tr - Number of Wheels              :4
Tr - Nominal Wheel Diameter        :249.52 mm
Tr - Mean Acceleration Torque      :67.376 Nm
Tr - Starting Class                :300
Tr - Cyclic Duration Factor        :50 %

    Bridge

Br - Bearing Surface of Rail       :Flat
Br - Useful Rail Width             :59 mm
Br - Number of Wheels              :4
Br - Nominal Wheel Diameter        :326.31 mm
Br - Mean Acceleration Torque      :214.45 Nm
Br - Starting Class                :240
Br - Cyclic Duration Factor        :40 %

    Control

Control Type                       :Cab Control
```

Figure 12. Design Report of the Case Study as the Output of the Software.

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