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Development of Expert System for Tower Cranes

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Abstract

The paper is concerned with application to develop the expert system, which deals with structural analysis and design process for tower cranes. The system is organized into three groups. One is pre-processor for creating input data files, another is 'model former' which combines knowledge-base with inference engine for automatic generating structural analysis models, a third is application group for final analysis checks. In this study, geometric subroutine of 'model former' designates node positions, nodes, elements numbers and element types. Load data subroutine computes weight of tower crane and device, slewing force, cargo load, wind force from rules or equations in knowledge-base. Also, Property and boundary subroutine applies element properties and boundary conditions to suitable elements and nodes. Design and analysis expert system for tower crane integrates these subroutine, 'model former' and pre-processor. RBR(Rule-Base Reasoning) was adopted for a reasoning strategy of this expert system. And this expert system can produce structural analysis model and data, which can be used in ordinary structural analysis program(SAP, ADINA or NASTRAN, etc.). In this paper, this expert system produces format of the analysis model data, which are used in MSC/NASTRAN. The main discussions included in the paper are introduction of the tower crane and structural analysis, composition of the design expert system for tower crane and structural analysis using the expert system.

Keywords : CAD, Expert system, Tower crane, IDS, FEM

1 Introduction

The study of Intelligent Design System(IDS) integrating CAD system, expert system, Data manufacturing system is investigated to embody the concurrent engineering concept in recent years. Development of Design Expert System for tower cranes based on the concept of IDS to produce automatic structural analysis model is carried out.

There are RBR(Rule-Base Reasoning), CRB(Case-Base Reasoning), MBR(Model-Base Reasoning) for a reasoning strategy of the expert. Especially, The Rule-Base Reasoning is the representative method in order to represent the knowledge-base and perform inference. This reasoning strategy is base on the expert's heuristic knowledge.

The process of structural analysis can be subdivide into geometry, property, boundary condition and load data process. Because the rule determine or govern the process of forming the geometric model, designating the element property, boundary condition for analysis of tower crane, RBR was adopted for a reasoning strategy of this expert system.

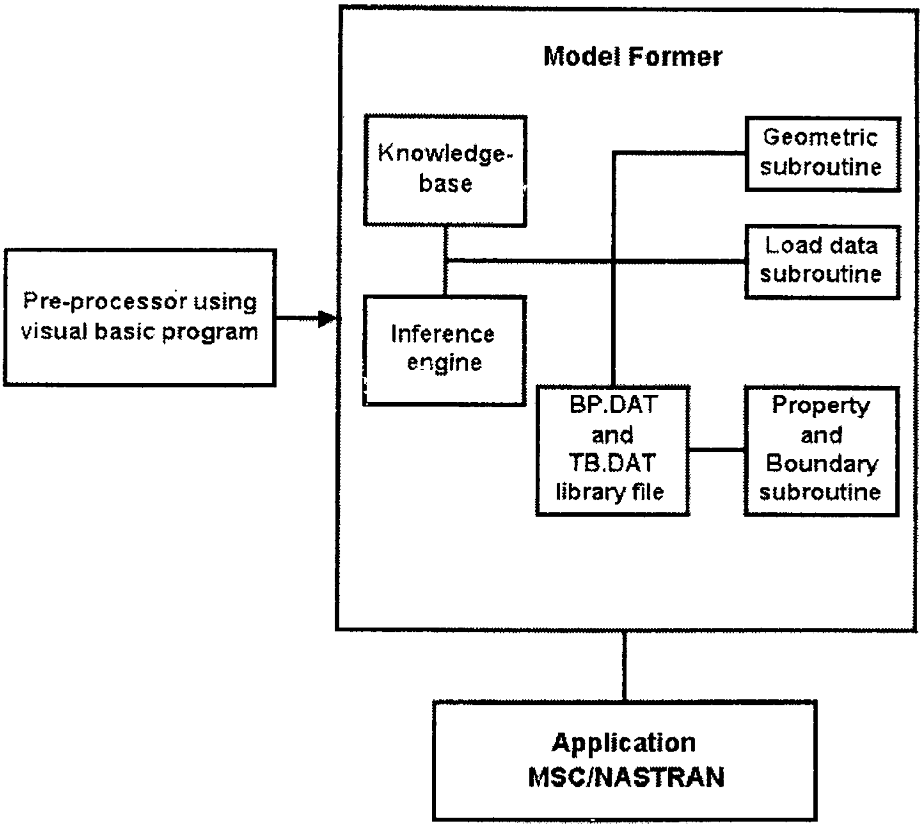


Figure 1. Pre-processor and structure of expert system.

In this paper, the expert system has 'model former' which combines knowledge-base with inference engine. Knowledge-base of 'model former' contains static-dynamic, wind force equations, aerodynamic and reducing coefficients of F.E.M(Federation Europeenne de la Manutention) rule book for structural analysis. Inference engine of 'model former' build up load data, boundary condition, element property, apply these to suitable node and element of analysis model as stored rules.

This system automatically generates analysis model and load data for final analysis of crane structure. Design which is produced by the system is carried out to meet the owner's requirements such as loading, capability, height of mast, jib length etc. Then the system automatically finds out optimum structural arrangements and scantlings of tower crane.

2 Structure of Tower Crane

The general structure of a tower crane consists of mast, jib, trolley, counter jib, cathead, slew pivot, operation box, foundation anchor are shown in Figure 2.

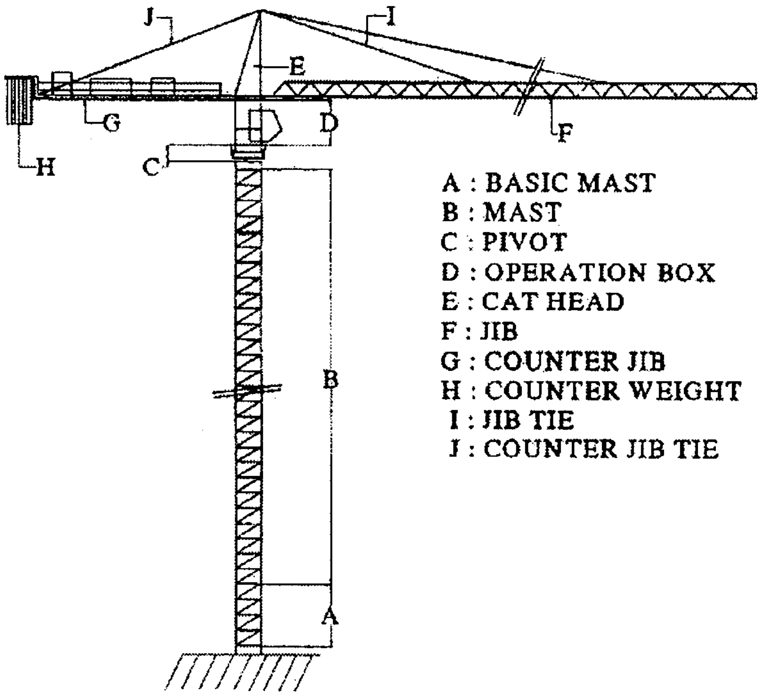


Figure 2. Structure of tower crane.

3 Basic Concept of Structural Analysis

3.1 Loading Conditions

In general, there are two types of loads for the design of the tower crane. One is static load such as machinery device weight, body force and working load. The other is dynamic load by vertical or horizontal motion of loads. These two types of loads and wind force are considered for the design or analysis of the tower crane.

3.1.1 Case of Loading

Three cases of loading are to be considered for structural analysis of the tower crane.

Case 1 : Appliance working load without wind

$$M(S_G + \varphi S_L + S_H) \tag{1}$$

Case 2 : Appliance working load with wind

$$M(S_G + \varphi S_L + S_H) + S_W \tag{2}$$

$$M(S_G + \varphi S_L + S_H) \tag{3}$$

Case 3 : Appliance subjected to exceptional loading

a) Appliance out-of-service with maximum
b) Appliance undergoing the test
c) Appliance working and subjected to a buffer effect

Where, M : Correction factor coefficient
φ : Vertical dynamic coefficient
S_L : Working load
S_G : Dead weight
S_H : Slewing load
S_W : Wind force

The values of correction factor coefficient suggested by Federation Europeenne de la Manutention(F.E.M.) are used. These values depend upon the types of the crane and group classification. In general, the value of correction factor coefficient is 1.06 for the tower crane.

3.1.2 Static Load

1) Dead weight

a) Frame structure weight
b) Mechanical device weight
c) Equipment

2) Working load

There are limit loads depend on the length of jib and the position of loads. The following Table 1 shows the typical critical loading cases for structural analyses for different jib lengths and cargo positions.

Table 1. Relation of jib length and cargo position.

Jib 51 m model		**Jib 45 m model**		**Jib 39 m model**	
Position	Cargo	Position	Cargo	Position	Cargo
Jib 16 m	10 ton	Jib 16.5 m	10 ton	Jib 16.9 m	10 ton
Jib 24 m	6.17 ton	Jib 24 m	6.56 ton	Jib 24 m	6.8 ton
Jib Tip	2.2 ton	Jib Tip	2.9 ton	Jib Tip	3.75 ton

Jib 36 m model		**Jib 30 m model**	
Position	Cargo	Position	Cargo
Jib 17.1 m	10 ton	Jib 17.2 m	10 ton
Jib 24 m	7.12 ton	Jib 24 m	7.17 ton
Jib Tip	4.35 ton	Jib Tip	5.56 ton

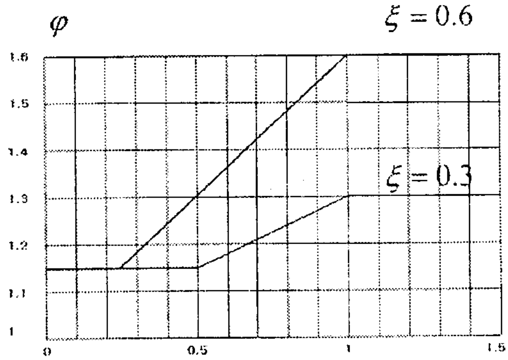


Figure 3. Dynamic coefficient.

3.1.3 Dynamic Load

The vertical or horizontal motions of jib and cargo yield the inertia load in tower crane. In the vertical inertia load, the acceleration of cargo is considered as a function hoisting speed. Also, Horizontal inertia load by the slew motion of jib is applied to the analysis.

1) Vertical dynamic coefficient

The cargo load is amplified by the vertical dynamic coefficient as hoisting speed. The vertical dynamic coefficient is as follows.

$$\varphi = 1 + \xi V_L \tag{4}$$

φ : Vertical dynamic coefficient
ξ : Experimental coefficient
V_L : Hoisting speed (m/s)

The experimental coefficient depends on the types of crane. In the case of the tower crane, the experimental coefficient is 0.6. Figure 3 shows the dynamic coefficient for hoisting speed and the experimental coefficient.

2) Horizontal acceleration

In the case of mobile crane, the horizontal inertia loads which were based on the motion such as traverse, travel, slew must be considered. On the other hand, the fixed type, the tower crane considers only slew motion for structural analysis. The acceleration of horizontal inertia loads by the slew of jib and counter jib are as follows.

$$F = ma, \qquad a = \frac{2\pi rn}{60} \times \frac{1}{t} \;\; (m/s^2) \tag{5}$$

F : Horizontal inertia force

a : Horizontal acceleration
r : Distance of each element from central axis
n : Maximum revolution speed (rpm)
t : Time of acceleration or deceleration

3.1.4 Wind Force

Because the wind force is important external force for design of tower crane, it is important that the precise approximate values by mathematical process are needed.

3.1.4.1 Wind Pressure and Wind Force

1) Aerodynamic pressure

Though wind-velocity pressure varies with the density of air, temperature, height, atmospheric pressure, these variation are negligible. In this study, the expert system adopts the wind pressure and force equation, aerodynamic and reducing coefficients of F.E.M(Federation Europeenne de la Manutention). The proposed equation by F.E.M. is as follows.

$$q = \frac{V_W^2}{16} \tag{6}$$

q : Aerodynamic pressure (kgf/m^2)
V_W : Wind speed (m/sec)

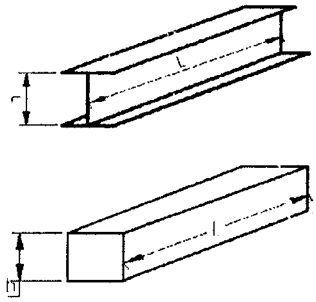
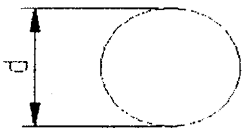
The aerodynamic pressure data indicate in Table 2 are based on F.E.M. These values are adopted to construct the knowledge-base of the expert system.

Table 2. Wind velocity and pressure.

Height of menber above ground		**Limiting working wind**				
m	$ft.$	Velocity V_W			Aerodynamic pressure q	
		m/s	km/h	Mph	N/m^2	$lbs/ft.^2$
0 to 20	0 to 65	20	72	45	25	5
20 to 100	65 to 325	22			30	
Over 100	Over 325					

Height of menber above ground		**Maximum wind(appliance out of service)**				
m	$ft.$	Velocity $V_{W\ max}$			Aerodynamic pressure q	
		m/s	km/h	Mph	N/m^2	$lbs/ft.^2$
0 to 20	0 to 65	36	130	80	80	16
20 to 100	65 to 325	42	150	95	110	22
Over 100	Over 325	46	165	105	130	26

Table 3. Values of the aerodynamic coefficient.

	Type of girder			C_f
Solid-web		L/h	20	1.6
			10	1.4
			5	1.3
Box girders			2	1.2
Members of circulars .		$d\sqrt{q}$		1.2
		$d\sqrt{q}$		0.7

2) Wind force

The wind force used in the structural analysis and design is obtained by the following equation.

$$P = AqC \tag{7}$$

P : Wind force (kgf)
A : Project area of the component parts of the girder on a plane perpendicular to the direction of the wind
q : Aerodynamic pressure
C : Aerodynamic coefficient
$= C_f$ for wind acting normal to object
$= C_f\eta$ for consecutive identical equidistant objects
$= C_f sin^2\theta$ for wind at angle to object

Obviously a knife-edged object will cause little disturbance or pressure change in a wind-stream, while a large flat surface will have quite the opposite effect. Through research and tests, data have been gathered relating the shape of objects to the resistance which they induce. The Table 3 shows the example of force coefficient C_f determined by these data.

In the above equation, η is the shielding coefficient. When one object is in front of another identical object, the "shadow" effect must be considered. It is a parameter concerned with both shape and distance. Figure 4 gives values for the shielding coefficient, which represents that part of the wind on the first of two bodies which acts on the second body. Then the coefficient can be

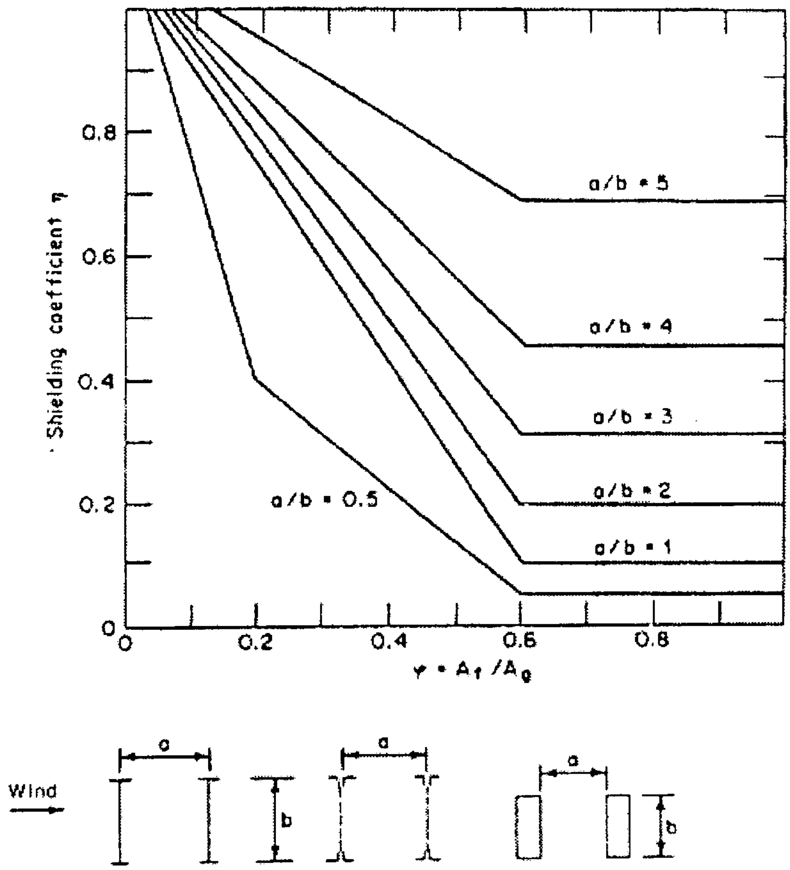


Figure 4. Reducing coefficient.

applied successively to additional bodies.

3) Operation and waiting condition

The structural analyses for the tower crane are separately carried out with operation condition and waiting condition.

a) Operating (In-service) condition

The expert system adopts the direction of wind perpendicular to jib and from the direction of counter jib to jib. Therefore, this system produces two types of wind force data for structural analysis of operating condition.

b) Waiting (Out-of-service) condition

In the case of the direction of wind perpendicular to jib, operating condition is severer than waiting condition. Therefore waiting condition is only considered when the wind blows from counter jib to jib.

3.2 The Boundary Conditions

The expert system applies the end moment release to every joint of hinge. And fixed boundary conditions are applied to the nodes of the basic mast which are fixed to concrete and orientation of the beam element.

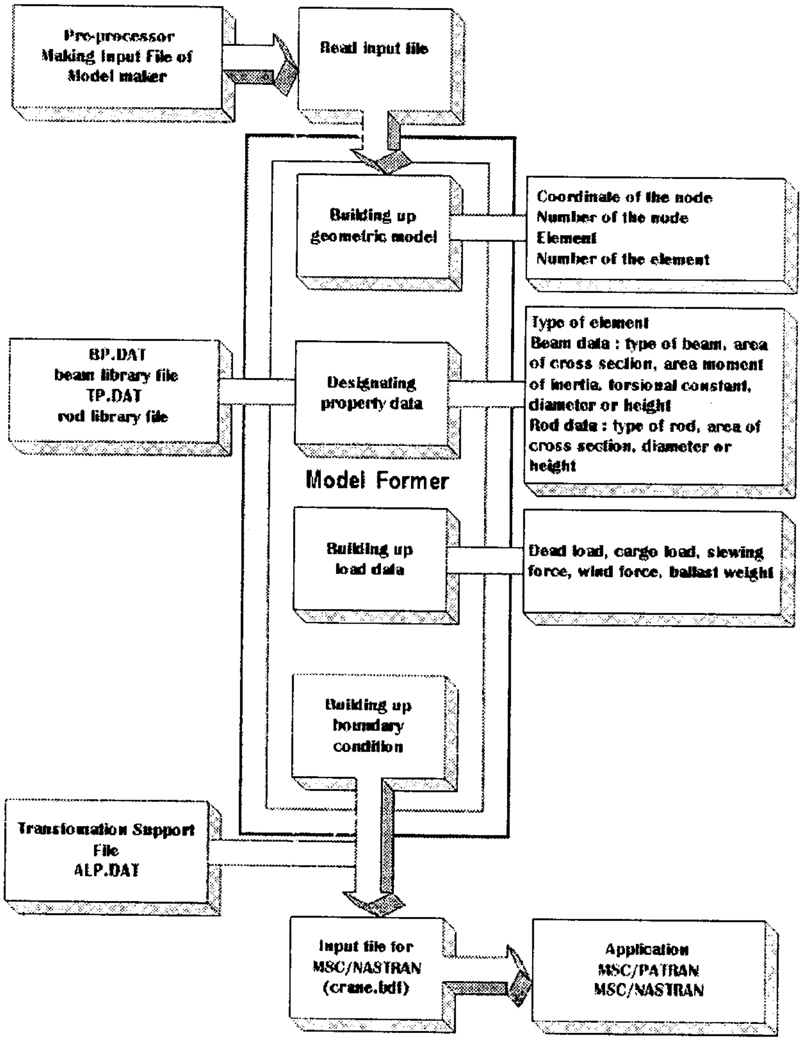


Figure 5. The organization and function of the expert system for tower crane.

4 The Expert System for Tower Crane

4.1 The Organization and Function of the Expert System for Tower Crane

The expert system of structural analysis and design for tower crane is consist of pre-processor, model former, beam library, rod library file and support file. Pre-processor play a role in composing various input data for required model by users. It has various dialogue box. User input variables to the dialogue box in order. Pre-processor using visual basic produces CRANE.DAT file for model former to make the structural analysis model. Model former play a role in inference and knowledge-base. Model former is divided into two parts. One is knowledge-base part including case of loading, static load-dynamic load, wind force equations, various coefficients and rules in order to organize proper load and model for analysis. The other is inference part. This part determine each load, suitable coefficients, boundary conditions and designate property data from the rules of knowledge-base and given input data. Model former reading CRANE.DAT produces structural analysis data such as geometry model, property data, load data and boundary conditions. In forming property data, model former is supported by property library file such as TP.DAT and BP.DAT. When structural analysis model automatically produced is imported to MSC/PATRAN, NASTRAN, transformation support file(ALP.DAT) is used to suit format of MSC/NASTRAN bulk data. The output of the expert system apply to any other ordinary structural analysis program by converting output format of model former. Figure 5 shows the organization of the expert system and flow of data.

4.2 Pre-processor and Model Former

Pre-processor using visual basic produces CRANE.DAT file. CRANE.DAT includes geometry-input data, property-input data and load input data. This file is used as formal input file of the expert system program.

1) Variables of geometry input data

The expert system divides tower crane into several parts. And then the input of each part's dimension is carried out in dialogue box. Without using pre-processor tool of other structural analysis

Table 4. Variables of geometry input data.

BH1,2	BASIC MAST HEIGHT	**JL**	LENGTH OF JIB
MB	BREADTH OF MAST	**JB**	BREADTH OF JIB
MUL 1	A UNIT LENGTH1 OF MAST	**JH**	HEIGHT OF JIB
MUL 2	A UNIT LENGTH2 OF MAST	**JK**	BLOCK LENGTH OF JIB
MN	NUMBER OF MAST BLOCK	**CJL**	LENGTH OF COUNTER JIB
OH	OPERATION BOX HEIGHT	**CJB**	BREADTH OF COUNTER JIB
CH	CATHEAD HEIGHT	**CJK**	BLOCK LENGTH OF COUNTER JIB
CSL	CATHEAD PART 1 LENGTH	**CWBL**	BLOCK LENGTH OF BALLAST
CSM	CATHEAD PART 2 LENGTH	**CWBN**	BLOCK NUMBER OF BALLAST
CSU	CATHEAD PART 3 LENGTH	**JTN**	NUMBER OF JIB TIE

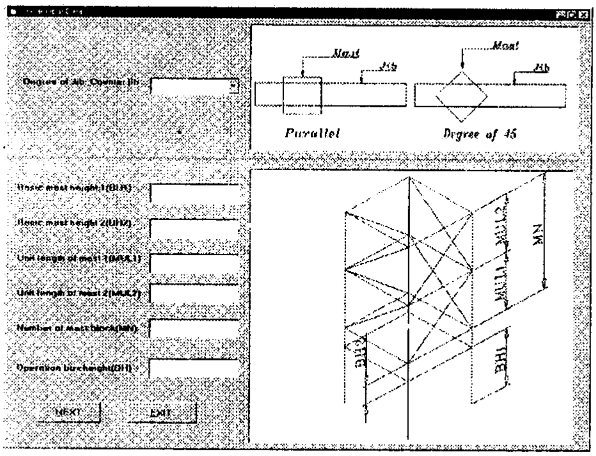


Figure 6. Dialogue box for input data of geometry.

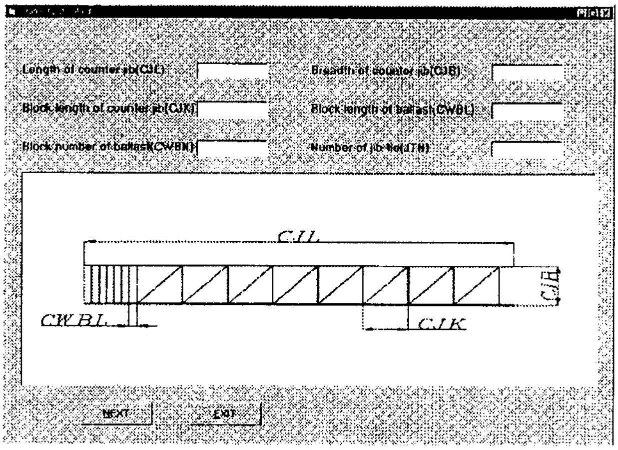


Figure 7. Dialogue box for input data of geometry.

program, structural analysis models are automatically produced by only inputting variables in dialogue box. Table 4 shows the variables of geometry input data.

Figs. 6 and 7 show the dialogue box for input data of geometry. After each variables are input in dialogue box, these variables are transformed into the input file format of expert system. Finally, these transformed variables are stored in CRANE.DAT.

2) Variables of property input data

Automatically produced structural analysis model by the expert system is composed of beam and rod element. Therefore this system has BP.DAT and TP.DAT as the beam library data file.

- BP.DAT

This file is beam library file. BP.DAT has property data such as type of beam, area of cross section,

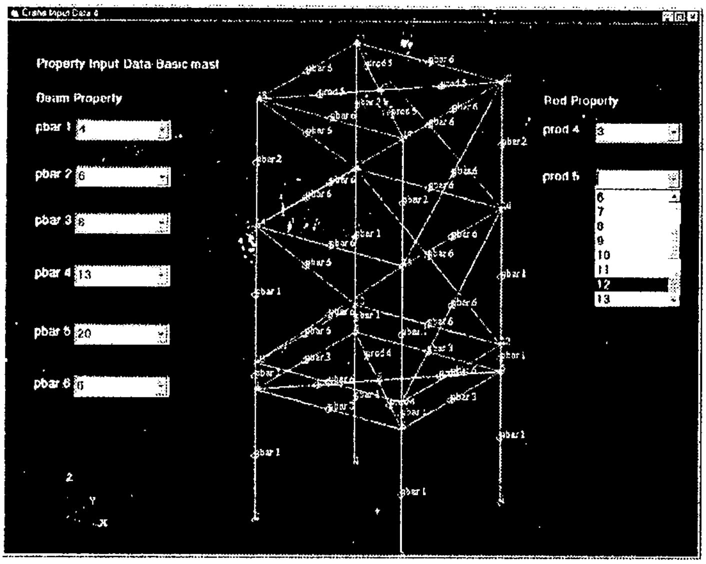


Figure 8. Dialogue box for input property data.

area moment of inertia, torsional constant, diameter or height. BP.DAT includes more than fifty different beam types data and each beam is classified by beam ID. Also, users can edit BP.DAT.

- TP.DAT

This file is rod property library file. TP.DAT has property data such as type of rod, area of cross section, diameter or height. TP.DAT includes more than thirty different rod types data and each rod is classified by rod ID. Also, users can edit TP.DAT.

Figure 8 shows dialogue box of input property. After forming model, model former designates suitable property to each elements of tower crane as input property data of CRANE.DAT. Listbox shows the practicable beam and rod ID in dialogue box. User selects beam or rod ID from listbox. The selected beam or rod ID as element property ID is stored in CRANE.DAT

3) Variables of load input data

The body force, cargo load, slewing force, ballast load and wind force are required in structural analyses of tower crane. To calculate these loads, load data are input from pre-processor. These load data are as follows.

Table 5. Variables of input load data.

CW	Ballast weight	**AL**	Cargo weight
WS	Wind speed	**HS**	Hoisting speed
MWS	Maximum wind speed	**LAL**	Position of cargo
RS	Maximum revolution speed		

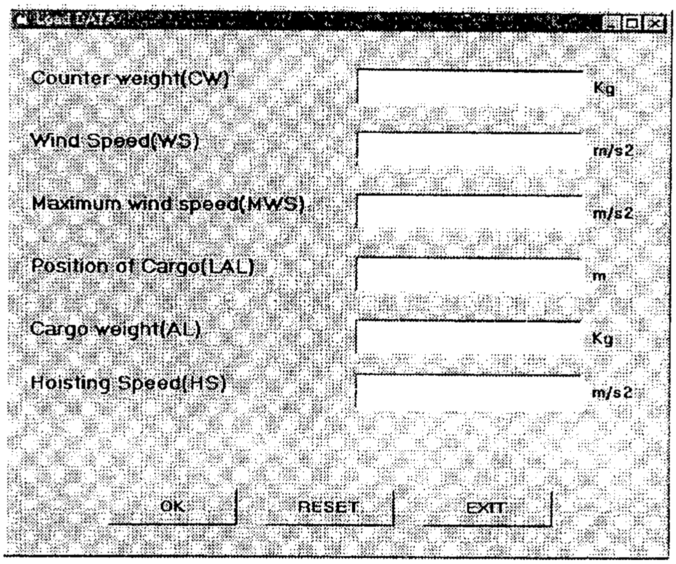


Figure 9. Dialogue box for load data.

Figure 9 shows dialogue box for load data. The load data are input by same way as inputting geometry data.

4.3 Execution of the Expert System for Tower Crane

1) Forming geometric model

After model former reads CRANE.DAT, which is produced by pre-processor, it builds up geometric model. By modifying the variables of geometry, the expert system can easily produce a variety of structural analysis models.

The model former creates the node of basic mast, mast, slewing pivot, operation box, jib, and counter jib in turn. The model former makes the two types of geometric model. One is that jib is parallel to mast. The other is that jib has an angle of 45 degrees to mast.

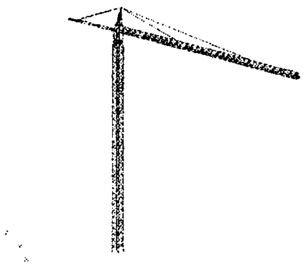
Height of mast, length of jib and counter jib are determined by the number of block. Following Figures shows the examples of analysis models which are made by the expert system.

2) Designating property data

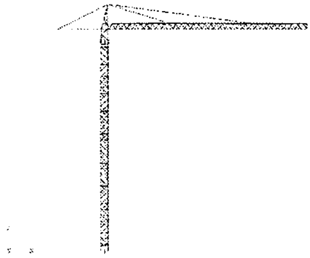
The expert system assigns the property data, which is suitable for input property to the each element from property library file. Various design models are produced through appropriate combination of different properties of tower crane elements.

3) Forming load data

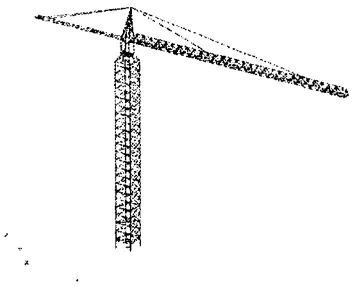
The expert system produces all the load data required for structural analysis by using the equations and coefficients in Chapter 2.



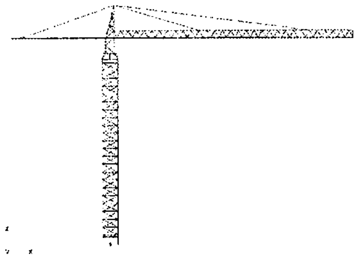
Model A



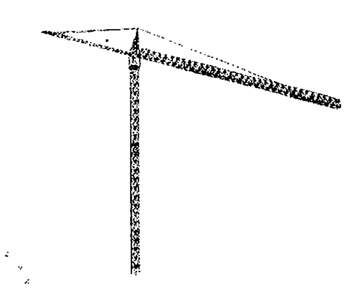
Model A



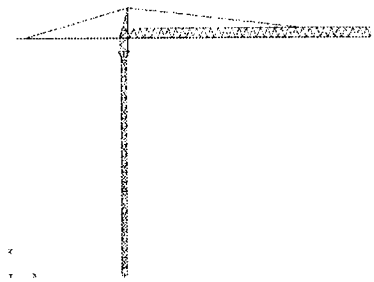
Model B



Model B



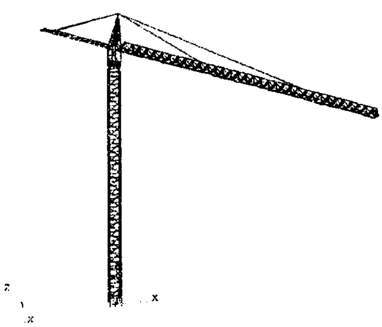
Model C



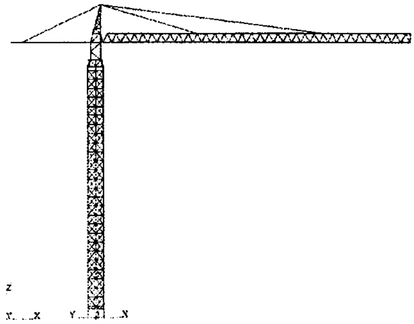
Model C

Table 6. Various models produced by the expert system.

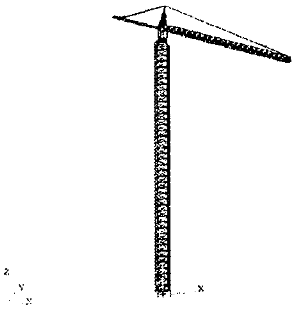
Jib is parallel to mast			
ITEM	**Model A**	**Model B**	**Model C**
MB	188.66 *cm*	300 *cm*	150 *cm*
MUL1	155 *cm*	155 *cm*	200 *cm*
MUL2	145 *cm*	145 *cm*	200 *cm*
MN	16	10	10
JL	5100 *cm*	4600 *cm*	5100 *cm*
JH	150 *cm*	150 *cm*	200 *cm*
CJL	1500 *cm*	1600 *cm*	2000 *cm*
JTN	2	2	1



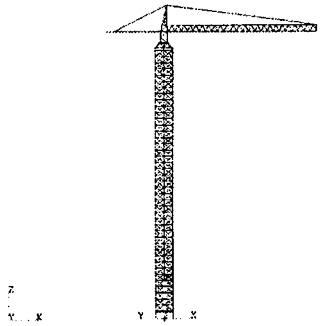
Model D



Model D



Model E



Model E

Table 7. Various models produced by the expert system.

Jib has an angle of 45 degree to mast		
ITEM	**Model D**	**Model E**
MB	188.66 *cm*	300 *cm*
MUL1	155 *cm*	155 *cm*
MUL2	145 *cm*	145 *cm*
MN	12	20
JL	5100 *cm*	3200 *cm*
JH	150 *cm*	150 *cm*
CJL	1100 *cm*	1100 *cm*
JTN	2	1

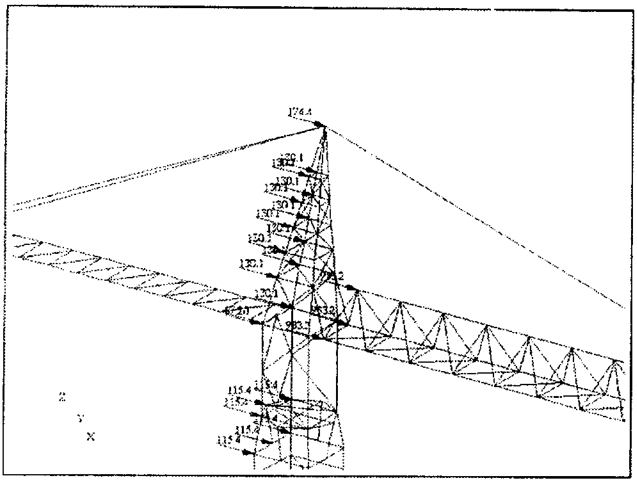


Figure 10. Wind forces are produced by expert system(parallel).

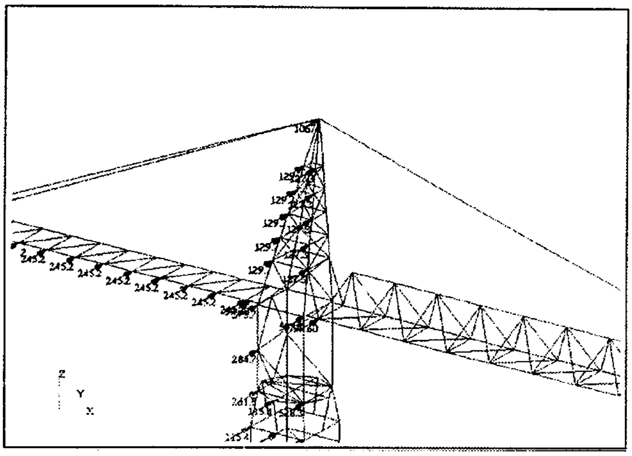


Figure 11. Wind force are produced by the expert system(perpendicular).

Figure 10 and 11 show the two types of wind force. One is parallel to jib and the other is Perpendicular to jib.

4) Designating boundary conditions

The expert system automatically designates suitable boundary conditions such as end moment release and fixed boundaries.

4.4 Output of the Expert System for Structural Analysis of Tower Crane

The output of the expert system program is used as input data file for MSC/NASTRAN. Its format and bulk data file of the MSC/NASTRAN are the same. The expert program adopts small data field format as formats of output to describe geometry, property and load. MSC/NASTRAN bulk data contains ten fields per input data entry. The following are the format and example of MSC/NASTRAN input file.

a) Small field formats

1	2	3	4	5	6	7	8	9	10
A	B	C	D	E	F	G	H	I	J

- A : character name of the bulk data item
- B - I : input data information for bulk data entry
- J : optional continuation information
- A - J : 8 character field

b) Example

1	2	3	4	5	6	7	8	9	10
GRID	ID	CP	X1	X2	X3	CD	PS	SEID	

- ID : grid point identification number
- CP : identification number of coordinate system in which the location of the grid point is defined
- X1, X2, X3 : location of the grid point coordinate system CP
- CD : identification number of coordinate system in which the displacements, degree of freedom, constraint, and solution vector are defined at the grid
- PS : Permanent single-point constraints associated with grid point
- SEID : Superelement identification number

4.5 Application of MSC/PATRAN and NASTRAN

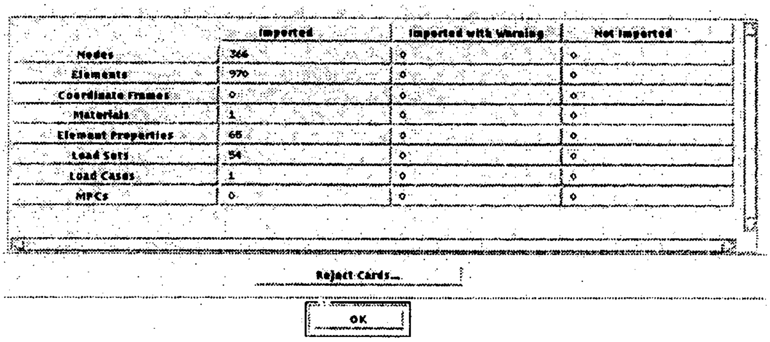
Output file CRANE.BDF produced by the expert system is imported to MSC/NASTRAN for structural analysis. After reading CRANE.BDF at the read input file menu of MSC/PATRAN analysis submenu, then it produces node, element, coordinate frames, materials, element property, load sets and load cases for structural analysis. Figure 12 shows that 366 nodes, 970 elements, 1 material, 65 element properties, and 54 load sets are imported to MSC/PATRAN .

Figure 13 shows the data file and execution-flow of the expert system. After model former of the expert system read the CRANE.DAT produced by pre-processor, it forms CRANE.BDF, import file of MSC/PATRAN and NASTRAN by CRANE.DAT and supporting file.

5 Example of Structural Analysis Using the Expert System

1) Example 1

a) Principle dimensions
- Jib length : 51 m
- Number of mast block : 12 (36 m)



	Imported	Imported with Warning	Not Imported
Nodes	366	0	0
Elements	970	0	0
Coordinate Frames	0	0	0
Materials	1	0	0
Element Properties	65	0	0
Load Sets	54	0	0
Load Cases	1	0	0
MPCs	0	0	0

Reject Cards...

OK

Figure 12. CRANE.BDF is imported to MSC/PATRAN.

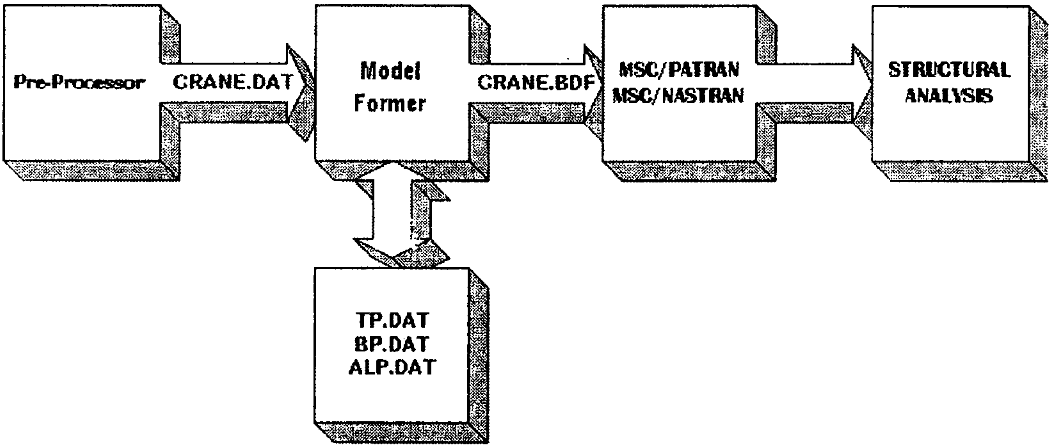


Figure 13. Flow of execution and data file.

- Counter jib length : 11 m

b) Loading conditions
Wind force (perpendicular to jib) + dead weight +cargo weight
Wind speed: 22 m/s, Cargo weight : 2.2 ton, Position of cargo : jib tip

2) Example 2

a) Principle dimensions
- Jib length : 36 m
- Number of mast block : 15 (45 m)
- Counter jib length : 11 m

b) Loading conditions
Wind force (perpendicular to jib) + dead weight +cargo weight
Wind speed: 22 m/s, Cargo weight : 6.56 ton, Position of cargo : 24 m

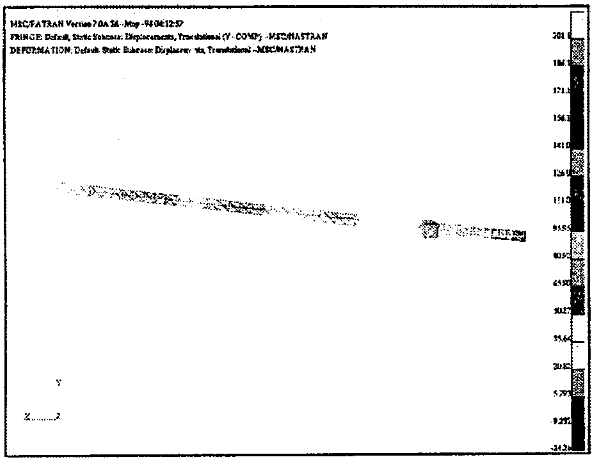


Figure 14. Example 1: Deformation of tower crane(Y-component).

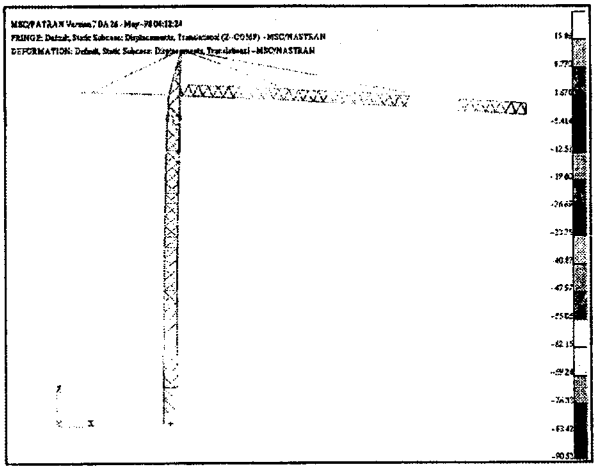


Figure 15. Example 1: Deformation of tower crane(Z-component).

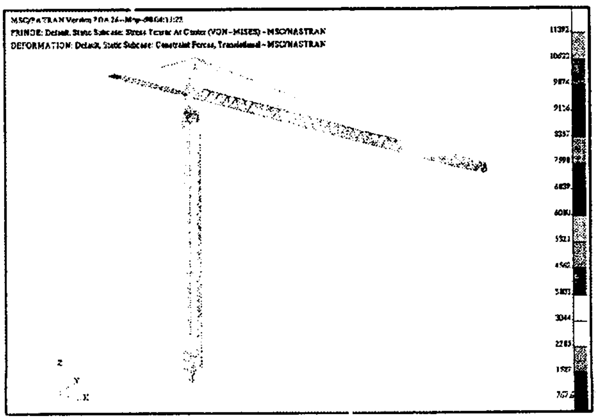


Figure 16. Example 1: Distribution of stress.

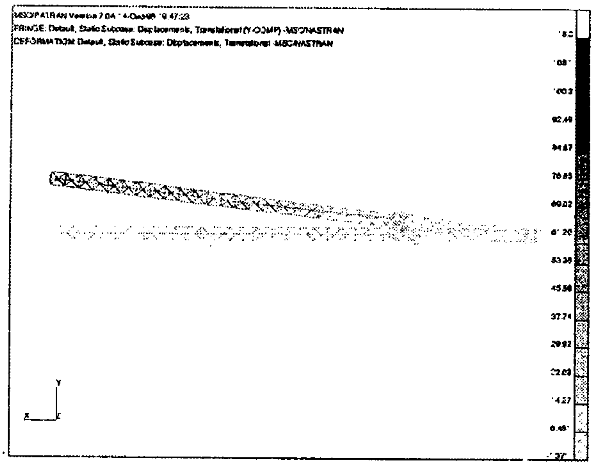


Figure 17. Example 2: Deformation of tower crane(Y-comp.).

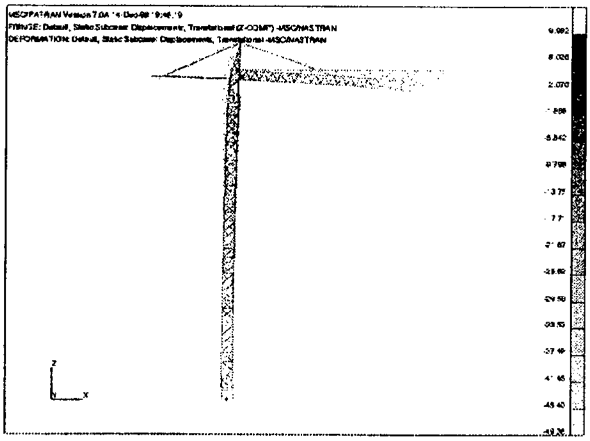


Figure 18. Example 2: Deformation of tower crane(Z-comp.).

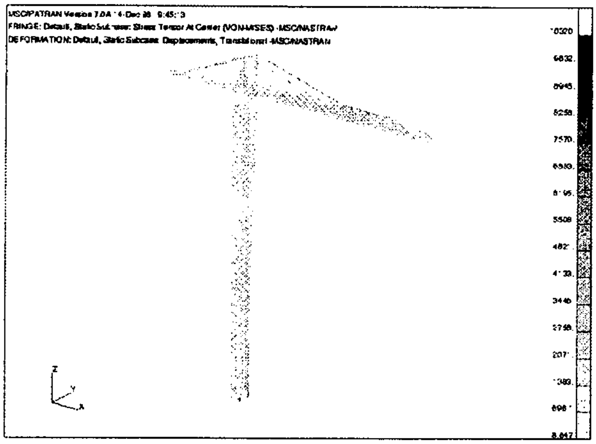


Figure 19. Example 2: Distribution of stress.

6 Conclusions

In this study, the expert system for tower crane is developed to satisfy owner's requirements. The main features of the system are as follows.

1) The effective, reliable and speedy design of tower crane can be carried out by applying expert system.

2) By modifying the variables of geometry and combining the different properties of tower crane elements, the expert system can easily produce a variety of structural analysis models.

3) The final analysis check is carried out by importing the out file of the expert system.

4) Aerodynamic coefficient and wind forces are calculated automatically in the system.

5) The expert system has the various property library files of beam and rod.

Acknowledgements

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References

1. Shapiro, I. Howard, 1986, Crane & Derricks, McGraw-Hill.
2. Federation Europeenne de la Manutention, 1990, Rule for the Design of Hoisting Appliance, F.E.M., 2nd Edition.
3. Hong, Ki-Sup, Kim, Jae-Hyun, 1990, Strength Evaluation of HT160 Tower Crane, Hyundai Maritime Research Institute.
4. Lee, D. K., 1989, A Study on the Prototype Expert System for the Evaluation of Vertical Plane Stability of SWATH Ship, Journal of the Society of Naval Architects of Korea, Vol. 26, No. 4.
5. Reymond, Michael, Miller, Mark, 1996, Quick Reference Guide, MacNeal Schwendler Corporation, ver. 69. 6. Thomas H. Dawson, 1983,Offshore Structural Engineering, Prentice-Hall.
6. Kim, Young-Chul, Lee, Kyu-Yeul, 1990, On a Compartment Layout Computer Model and Associated Data Structure, Journal of the Society of Naval Architects of Korea, Vol. 27 , No. 3.
7. Yakowitz, Sidney, Szidarovszky, Ferenc, 1986, An Introduction to Numerical Computations, Macmillan Publishing Company.
8. Lahey, S. Robert, Miller, P. Mark, Reymond, Michael, 1994, MSC/NASTRAN User's Reference Manual Volumes 1, 2, 3, MacNeal-Schwendler Corporation.
9. Cook, D. Robert, 1994, Finite Element Modeling for Stress Analysis, John Wiley and Sons, Inc.
10. Yoo, Jae-Hyung, 1983, A Study on the Rotating Device of Cargo Derric Booms, Journal of the Society of Naval Architects of Korea, Vol. 20, No. 3.
11. Schakoff, J. Robert, 1990, Artificial Intelligence : An Engineering Approach, McGraw-Hill International Editions.
12. Klaha, Philip, Waterman, A. Donald, 1986, Expert System, Addison-Wesley.

13. Min, Keh-Sik, Hong, Sung-Kyun, Kim Ki-Sup, 1983, A Study on the Ship Hull Form Generation by Interactive Characteristic, Journal of the Society of Naval Architects of Korea, Vol. 20, No. 1.
14. Yang, D. Y. et al., 1992, Study on CAD/CAM and Expert System for Net Shape Manufacturing of Mechanical Parts, Research Report of Korea Science and Engineering Foundation.
15. Kwon, Y. B. et al., 1991, Studies on Korean Expert System Tool, Research Report of Ministry of Science and Technology.