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17909

DP/ID/SER.A/1279
4 December 1989
ORIGINAL: ENGLISH

COMPUTER AIDED DESIGN AND COMPUTER AIDED MANUFACTURING CENTRE

DP/SRL/86/014

SRI LANKA

Technical report: Mathematical Modelling *

Prepared for the Government of Sri Lanka
by the United Nations Industrial Development Organization
acting as executing agency for the United Nations Development Programme

Based on the work of Maciej Bossak
Expert in CAD/CAM-MME

Backstopping officer: P. Prijapratama, Engineering Industries Branch

United Nations Industrial Development Organization
Vienna

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V.89-61958

TABLE OF CONTENTS

ABSTRACT

The mission has been undertaken under the project "The Establishment of a Computer Aided Design and Computer Aided Manufacturing Centre", DP/SRL/86/014.

The immediate objective of the mission was to assist the University of Moratuwa, Department of Mechanical Engineering in the development of training capabilities in the field of Mathematical Modelling and Design Analysis.

The mission Lasted one month, from 29th August to 28th September 1989.

ACKNOWLEDGEMENT

The author would like to express his thanks and appreciation to the Vice Chancelor of Moratuwa University Professor Patuwathavithane, the Dean of the Faculty of Engineering Professor C.L.K. Tennekoon, The Head of Department of Mechanical Engineering Professor P.A. de Silva and to the staff members for their interest, involvment and kind assistance to fulfilling the mission.

Special thanks are addressed to Professor P.A. de Silva and his staff for their efforts to overcome uneasy circumstances and for making possible the intensive work.

The author would also like to express his warm thanks to the Senior Industrial Development Field Advisor Mr. J.P.Gorski.

FINDINGS AND RECOMMENDATIONS

A. Findings

1. After discussions with the staff members of the Department of Mechanical Engineering, and the industrial engineers from both public and private sectors, involved in the design, production and maintenance of various types of machninery and equipment it is evident that exists real demand for design analyses in several essential fields.

   Some of the fields that were identified are:

   Agricultural machinery and equipment,
   Machinery for plantation industry,
   Equipment for food and beverages industry,
   Equipment for electricity distribution,
   Equipment for water supply and drainage,
   Moulds for plastic industry,
   Moulds for rubber industry,

   All sectors where spare parts are manufactured (transport services, paper industry, oil industry etc).

2. Based on recent discussions and meetings the following institutions are eager to use facilities and services that would be provided by the CAD/CAM Centre as well as to develop their own resources.

   Brown and Co. Ltd.,
   Central Engineering Consultancy Bureau,
   Ceylon Government Railway,
   Ceylon Institute of Scientific and Industrial Research,
   Ceylon Petroleum Corporation,
   Ceylon State Hardware Corporation,
   Ceylon Steel Corporation,
   Colombo Commercial Co. Ltd.,
   Colombo Dockyard Ltd.,
   Engineering Consultants Ltd.,
   Hemas Marketing Ltd.,
   Jinasena and Co. Ltd.,
   National Engineering Research and Development Centre,
   Samuel and Sons Ltd.,
   Sri Lanka Central Transport Board,
   Sri Lanka Ports Authority,
   Sri Lanka Tyre Corporation,
   St. Anthony's Industries,
   State Engineering Corporation of Sri Lanka,
   Walker Sons and Co. Ltd.

3. During the lectures and trainings the attendents (both from the University and Industry) show that their mathematical background is on a high level. Most of them are currently using one or more high level languages such as Fortran, Basic, Pascal or C and are also applying some software packages.
   Therefore, they wouldn't have dificulties in using application software for mathematical modelling and design analysis.

4. A number of books on mathematical modelling and design analysis is currently availble at the library. However, more books, recently published are needed and should be provided as soon possible (see Annex 1 point A).

5. Unfortunately, there is a serious lack of periodicals on mathematical modelling and design analysis. Some essential titles should be subscribed as soon as possible (see Annex 1 point B).

6. For the last few months a lot of new computer equipment has been installed at the Computer Centre of the University. Some of it like 32 bit minicomputer micro VAX3600 and workstation VAX 2000 could be used by CAD/CAM Centre.

7. Despite these deliveries, there is a serious lack of tool - software as well as application software. This can be a serious obstacle in full utilisation of existing computer hardware capabilities.

B. Recommendations.

1. It is advisable to utilize new hardware and software capabilities existing at the University Computer Centre through establishing a link to CAD/CAM Centre. For this purpose it is necessary to purchase some additional equipment (see Annex 2).

2. During this year it is necessary to enhance current hardware capabilities of the CAD/CAM Centre by purchasing new models of micro computers of the IBM-PC line and plotter. (see Annex 3).

3. It is necessary to purchase as soon as possible the application software for mathematical modelling and design analysis. (see Annex 3).

4. Some industry problems concerning design anaylsis (of tools, dies, moulds, etc.) should be selected for solving in the assistance of the Design Analysis Expert, who according to the programme should arrive in January 1990.

I. OBJECTIVE OF THE ACTVITIES AND DUTIES.

A. Objective

The objective to the mission was to assist the University of Moratuwa, Department of Mechanical Engineering in the development of training capabilities in Computer Aided Design (Mathematical Modelling and Design Analysis).

B. Duties

1. To provide lectures on computer assisted mathematical modelling methods and train local staff in application of mathematical modelling to design analysis.

2. To elaborate a proper training programme for local staff and prepare, in cooperation with the counterpart, a detailed training programme for fellowship holders.

3. To assist in elaboration of training methodologies, syllabi and lecture notes for courses for students and industrial engineers.

4. To prepare a report, setting out the findings and recommendations for follow-up actions which should be taken.

II. DESCRIPTION OF ACTIVITIES

A. Lectures

The author has delivered a course with exercises on mathematical modelling and its applications to design analysis. The topics covered in the lectures are given in Annex 4.
The lectures were attended by about twenty mechanical and electronic engineers recruiting from both University and Industry.

The following institutions were represented:

Department of Mechanical Engineering,
Department of Electrical Engineering,
Department of Computer Science & Engineering,
Department of Chemical Engineering,
Open University of Sri Lanka,
Ceylon Steel Corporation,
Heavy Fab Ltd.,
Nixdorf Computers.

The participants who have direct acces to microcomputer in the work place or privately can use the course material to solve problems that they may come across in their day-to-day activities.

To ensure more successful results the Department of Mechanical Engineering has already made arrangements to make available a printed set of lecture notes for the attendants who wish to have them.

B. Training

To get practise in the topics that were of immediate interest in the lectures the participants were engaged in sloving their own problems, during the afternoon sessions.
To this effect they used software delivered by the author.

The software consists of two parts :

1. Numerical Methods package developed by Professor A. Constantinides from the State University of New Jersey, USA. The programs written in BASIC language are interactive and user-friendly (self explained). The list of programs is given in Annex 5.

2. Finite Element programme FIRFEP (First Finite Element Program) developed by the author. This is a simple educational program written in FORTRAN language which can be utilized for solving plane stress problems using linear triangular element. The listing of the program with instructions on how to use it and test example are given in Annex 6.

Above mentioned software can be used in future for demonstration and education, as well as for solving some engineering problems.

C. Programmes

The author, assisted by the staff of the Department of Mechanical Enginering, University of Moratuwa, has elaborated syllabi and extensive lecture notes for courses on Mathematical Modelling.
The lecture notes will be published by CAD/CAM Centre as educational aids for students and field engineers.

D. Workshop

A workshop on Mathematical Modelling in Design Analysis was prepared for industry engineers and invited participants (see Annex 7). Unfortunately, due to unforseen circumstances the workshop had to be postponed.

ANNEX 1

RECOMMENDED LITERATURE.

A. BOOKS

1. WELLSTEAD P.E.
"INTRODUCTION TO PHYSICAL SYSTEM MODELLING"
ACADEMIC PRESS, 1979

2. BLUNDELL A.
"BOND GRAPHS FOR MODELLING ENGINEERING SYSTEMS"
ELLIS HORWOOD LTD. ,1982

3. REDDY
"APPLIED FUNCTIONAL ANALYSIS AND VARIATIONAL METHODS IN ENGINEERING"
McGRAW HILL

4. PRZEMIENIECKI
"THEORY OF MATRIX STURCTURAL ANALYSIS"
McGRAW HILL

5. RICE J.R.
"NUMERICAL METHODS, SOFTWARE AND ANALYSIS"
McGRAW HILL, 1983

6. CONSTANTINIDES A.
"APPLIED NUMERICAL METHODS WITH PERSONAL COMPUTERS"
McGRAW HILL,1988

7. HAPRA S.C., CANALE R.P.
"NUMERICAL METHODS FOR ENGINEERS WITH PERSONAL COMPUTER APPLICATIONS"
McGRAW HILL, 1985

8. ROBINSON J.
"UNDERSTANDING THE FINITE ELEMENTS"
ROBINSON AND ASSOCIATES

9. REDDY
"AN INTRODUCTION TO THE FINITE ELEMENT METHOD"
McGRAW HILL

10. BATHE K.J.
"FINITE ELEMENT PROCEDURES IN ENGINEERING ANALYSIS"
PRENTICE HALL, 1982

A1 - 2

11. ZIENKIEWICZ O.C.
"THE FINITE ELEMENT METHOD" (4TH EDITION)
McGRAW HILL, 1989

12. KARDESTUNCER
"FINITE ELEMENT HANDBOOK"
McGRAW HILL, 1987

13. SMITH I.M., GRIFFITHS D.V.,
"PROGRAMMING THE FINITE ELEMENT METHOD"
J.WILEY & SONS

14. RAO S.S
"THE FINITE ELEMENT METHOD IN ENGINEERING"
PERGAMON PRESS, 1989

15. "GUIDELINES TO FINITE ELEMENT PRACTICE"
NAFEMS-NEL, GLASGOW

16. MEYER CH. (EDITOR)
"FINITE ELEMENT IDEALIZATION"
ASCE, NEW YORK, 1987

17. COOK W.A.
"CONCEPTS AND APPLICATIONS OF FINITE ELEMENT ANALYSIS"
J. WILEY & SONS, 1981

18. NIKRAVESH P.E.
"COMPUTER AIDED ANALYSIS OF MECHANICAL SYSTEMS"
PRENTICE HALL, 1988

19. DIMAROGONAS A.
"COMPUTER AIDED MACHINE DESIGN"
PRENTICE HALL, 1988

20. WHITE R.E.
"AN INTRODUCTION TO THE FINITE ELEMENT METHOD
WITH APPLICATIONS TO THE NONLINEAR PROBLEMS"
J. WILEY & SONS, 1985

21. BREBBIA C.A.
"THE BOUNDARY ELEMENT METHOD FOR ENGINEERS"
PENTECH PRESS, 1978

22. BANERJEE, BUTTERFIELD.
"BOUNDARY ELEMENT METHODS IN ENGINEERING SCIENCE"
McGRAW HILL

B. PERIODICALS

1. "COMPUTER METHODS IN APPLIED MECHANICS AND ENGINEERING"
   NORTH-HOLLAND, PO BOX 1991,1000 BZ AMSTERDAM,THE NETHERLANDS.

2. "NUMERICAL METHODS IN ENGINEERING"
   J.WILEY, BAFFINS LANE, CHICHESTER, SUSSEX, ENGLAND.

3. "COMPUTERS AND STRUCTURES"
   PERGAMON PRESS, FAIRVIEW PARK, ELMSFORD, NY 10523, USA.

4. "FINITE ELEMENTS IN ANALYSIS AND DESIGN"
   NORTH-HOLLAND, PO BOX 1991,1000 BZ,AMSTERDAM,THE NETHERLANDS.

ANNEX 2

SPECIFICATION OF EQUIPMENT NEEDED FOR LINKING UNIVERSITY COMPUTER CENTRE AND CAD/CAM CENTRE.
(EXTENSION OF EXISTING DEC-ETHERNET NETWORK)

1. STANDARD ETHERNET CABLE BNE 2

2. TRANSCEIVER- H 4005 (3 UNITS)

3. LOCAL REPEATER- DEREP-AE (1 UNIT)

4. COMMUNICATION SERVER- DELNI-AE (1 UNIT)

5. TRANSCEIVER CABLE BNE 3H

6. ETHERNET CONTROLLER FOR PC XT/AT- DEPCA-AA

ANNEX 3

SPECIFICATION OF EQUIPMENT FOR CAD/CAM CENTRE (1989)

A. HARDWARE

1. MICROCOMPUTER (2 UNITS)

TYPE:	PC-386
RAM:	MIN 2 MB
HARDDISK:	MIN 40 MB
MATH COPROCESSOR:	

(THESE CAN BE PURCAHSED LOCALLY FROM IBM OR NIXDORF)

2. PLOTTER A1

MODEL HP 7580 B FROM HEWLETT PACKARD
OR GRAPHTEC MP 9101-01 FROM GRAPHTEC

B. SOFTWARE

1. DRAFTING SYSTEM

AUTOCAD VERSION 10.0 (THERE ARE \NY DEALERS ALL OVER THE WORLD)

2. SCIENTIFIC SUBROUTINE LIBRARY

ADVANCED MATH. APPLICATIONS PACK - MATHCAD
DEALER: MATHSOFT, INC., ONE KENDALL 5, CAMBRIDGE, MA 02139, USA.

3. FINITE ELEMENT SYSTEM WITH PRE AND POST PROCESSORS

1. SAP 86 - LEVEL 1 (EDUCATIONAL)
2. SAP 86 - LEVEL 4 (PRO 386-2)
3. MTAB*PRE- PREPROCESSOR
4. MTAB*POST-POSTPROCESSOR

DEALER:
STRUCTURAL ANALYSYIS INC.,
1701 DIRECTORS BLVD.,
SUITE 360, AUSTIN, TEXAS 78744, USA.

CAD/CAM PROJECT

WORK SCHEDULE FOR MATHEMATICAL MODELLING EXPERT

		Morning	Afternoon
SEPTEMBER 1989		9.00 AM - 12.00 noon	1.30 pm - 3.30 pm
Friday	01 st	Discussion with UNDP/UNIDO officials, preparation of the lecture programme	
Saturday	02 nd	WEEKEND	
Sunday	03 rd	Preparation of lecture notes	
Monday	04 th	Arrival at the department Discussion with the University staff members	
Tuesday	05 th	Lecture 1	Discussion/Consultation
Wednesday	06 th	Lecture 2	Discussion/Consultation
Thursday	07 th	Lecture 3	Discussion/Consultation
Friday	08 th	Lecture 4	Discussion/Consultation
Saturday	09 th	WEEKEND	
Sunday	10 th	Preparation of course syllabi and lecture notes for students and Industrial Engineers	
Monday	11 th	Lecture 5	Training
Tuesday	12 th	Lecture 6	Training
Wednesday	13 th	Lecture 7	Training
Thursday	14 th	Lecture 8	Training
Friday	15 th	Lecture 9	Training
Saturday	16 th	WEEKEND	
Sunday	17 th	Preparation of training programme for local staff, Industrial Engineers and Fellowship Holders	
Monday	18 th	Lecture 10	Discussion/Consultation
Tuesday	19 th	Preparation for the workshop	
Wednesday	20 th	Workshop for Industrialists, Day 1	
Thursday	21 st	Workshop for Industrialists, Day 2	
Friday	22 nd	Lecture 11	Discussion/Consultation
Saturday	23 rd	WEEKEND	
Sunday	24 th	Preparation of report to UNDP	
Monday	25 th	Finalisation of report to UNDP and Departure	

PROGRAMME OF LECTURES ON MATHEMATICAL MODELLING

LECTURER: PROFESSOR. M. BOSSAK (UNIDO EXPERT)

VENUE : SEMINAR ROOM, DEPARTMENT OF MECHANICAL ENGINEERING

LECTURE NO.	Topics
1.	The role of Mathematical Modelling in the modern Computer Aided Design.
2.	Phases in Mathematical Modelling. Approximation methods. Weighted residuals method. Variational formulations.
3.	Finite Element Method (FEM). The idea of the method Definition of a finite element-shapes, nodes, nodal values, approximation functions. Examples of different finite elements.
4.	Coordinate systems - global, local boundary, material. Transformations of values from one to another coordinate system.
5.	Linear static analysis. Relations between known and unknown nodal values for the element (stiffness matrix). Relation (in global coordinates) between known and unknown nodal values for the whole system of elements (global stiffness matrix).
6.	Boundary conditions. System of equations and its properties. Solution of the system of equations. Calculation of other desired values. Principle of virtual work. General formula for matrices describing element properties.
7.	Linear dynamic analysis. Frames of reference. Loads, mass forces, elastic forces, damping forces. Equation of motion.
8.	Eigenvalue problems. Initial value problems - direct integration - mode superposition method. Finite element systems. Pre and postprocessors.
9.	Basic information on nonlinear analysis. Classification of nonlinear problems. Equation of equilibrium. Solution of nonlinear equations.
10.	Basic information on Boundary Element Method (BEM).
11.	Basic information on Bond Graph Method (BGM).

ANNEX 5

LIST OF PROGRAMS IN NUMERICAL METHODS SOFTWARE PACKAGE

1.	AUTOEXEC.BAT	LOADS THE BASICA INTERPRETER AND RUNS THE PROGRAM MENU.BAS
2.	MENU.BAS	DISPLAY THE DIRECTORY OF AVAILABLE PROGRAMS AND GIVES INSTRUCTIONS ON HOW TO LOAD AND RUN THESE PROGRAMS.
3.	ROOT.BAS	SOLUTION OF NONLINEAR FUNCTIONS USING LINEAR INTERPOLATION OR NEWTONS-RAPHSON METHODS.
4.	POLY.BAS	NEWTON-RAPHSON WITH SYNTHETIC DIVISION-APPLIED TO nth - DEGREE POLYNOMIALS.
5.	GRAEFFE.BAS	GRAEFFE'S ROOT-SQUARING METHOD FOR REAL AND COMPLEX ROOTS OF POLYNOMIALS.
6.	NEWTON.BAS	NEWTON'S METHOD FOR REAL AND COMPLEX ROOTS OF POLYNOMIALS AND TRANSFER FUNCTIONS.
7.	GAUSS.BAS	GAUSS ELIMINATION METHOD FOR SIMULTANEOUS LINEAR ALGEBRAIC EQUATIONS.
8.	JORDAN.BAS	GAUSS-JORDAN REDUCTION METHOD FOR SIMULTANEOUS LINEAR ALGEBRAIC EQUATIONS AND MATRIX INVERSION.
9.	SEIDEL.BAS	GAUSS- SEIDEL SUBSTITUTION METHOD FOR DIAGONAL SYSTEMS OF LINEAR ALGEBRAIC EQUATIONS.

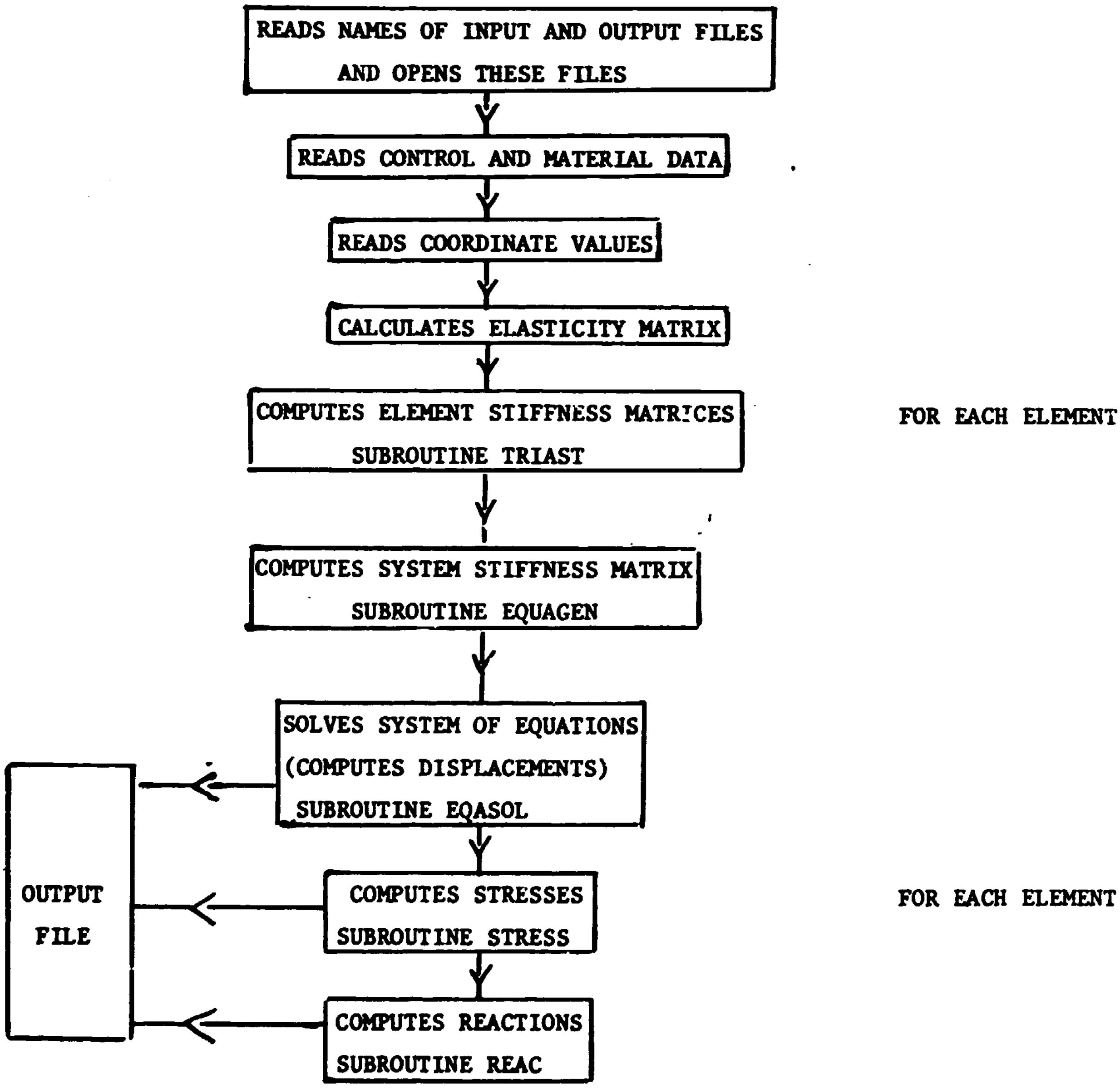
A5 - 2

10. EIGEN.BAS	CALCULATIONS OF EIGEN VALUES AND EIGEN VECTORS USING THE FADDEEV-LEVERRIER/NEWTON-RAPHSON/GAUSS METHODS.
11. QR.BAS	CALCULATION OF EIGEN VALUES AND EIGEN VECTORS USING ELEMENTARY SIMILARITY TRANSFORMATIONS TO CONVERT THE MATRIX TO HESSENBERG FORM, AND THE QR ALGORITHM WITH PLANE ROTATIONS.
12. INTEGR.BAS	INTEGRATION FORMULAS: TRAPEZOIDAL, SIMPSON'S 1/3 AND SIMPSON'S 3/8 RULES.
13. ODE.BAS	FOURTH ORDER RUNGE-KUTTA AND EULER PREDICTOR-CORRECTOR METHODS FOR INTEGRATING SIMULTANEOUS ORDINARY DIFFERENTIAL EQUATIONS.
14. BOUNDARY.BAS	BOUNDARY VALUE PROBLEMS: THE NEWTON METHOD.
15. ELLIPTIC.BAS	ELLIPTIC PARTIAL DIFFERENTIAL EQUATIONS.
16. PARABOL.BAS	PARABOLIC PARTIAL DIFFERENTIAL EQUATIONS.

PROGRAM FIRFEP (FIRst Finite Element Program)

FITFEP is simple (educational) finite element program for solving plane stress problems. It uses three nodes triangular element (linear displacements, constant stresses).

STRUCTURE OF THE PROGRAM.



THE FOLLOWING DATA ARE REQUIRED:

1. CONTROL AND MATERIAL DATA

   ONE CARD FORMAT(6I5,E10.2,2F5.2)

   NEN,NDF,NON,NOE,NBC,NLN,E,PR,TH

   NEN - NUMBER OF ELEMENT NODES = 3

   NDF - NUMBER OF DEGREES OF FREEDOM AT EACH NODE = 2

   NON - TOTAL NUMBER OF NODES

   NOE - TOTAL NUMBER OF ELEMENTS

   NBC - TOTAL NUMBER OF NODES WITH BOUNDARY CONDITIONS

   NLN - TOTAL NUMBER OF LOADED NODES

   E - YOUNG`S MODULUS

   PR - POISSON`S RATIO

   TH - ELEMENT THICKNESS

2. NODAL COORDINATES

   NON CARDS FORMAT(I5,2G10.2)

   (N(I),(CORD(I,J),J=1,2),I=1,NON)

   N(I) - NODE NUMBER

   CORD(I,J) - X,Y NODE COORDINATES

3. LOADS

   NLN CARDS FORMAT(I5,2G10.2)

   (NF(I),(RHS(I,J),J=1,2),I=1,NLN)

   NF(I) - NODE NUMBER WHERE LOAD IS ACTING

   RHS(I,J) - X,Y COMPONENTS OF THE LOAD

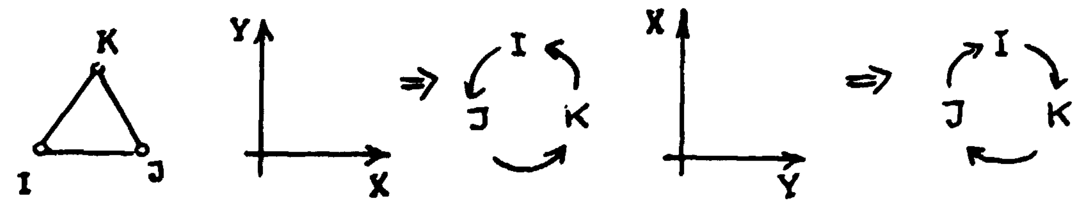
4. TOPOLOGY

   NOE CARDS FORMAT(3I5)

   I,J,K

   I,J,K - ELEMENT NODE NUMBERS

   REMARK: ORDER OF THE NUMBERS MUST BE ADEQUATE TO THE SYSTEM OF COORDINATES



5. TOPOLOGY

NBC CARDS FORMAT(3I5)

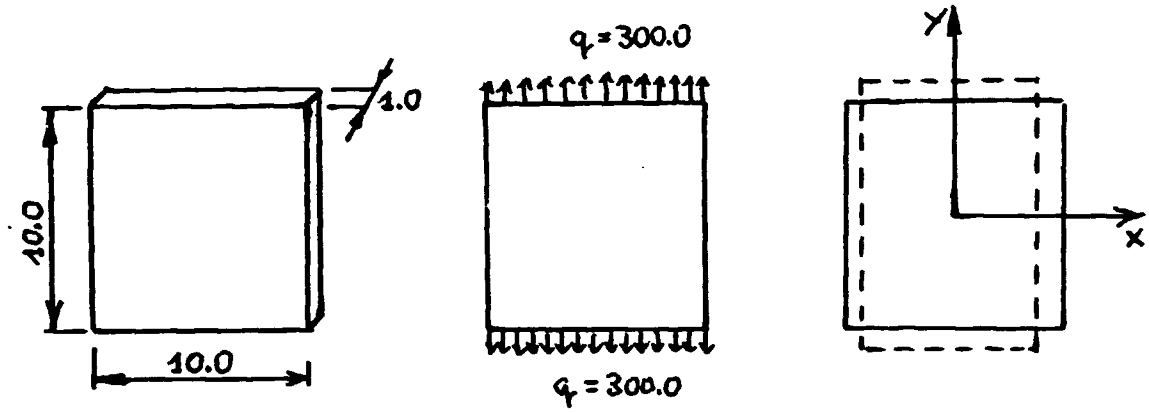
NN,NX,NY

NN - NUMBER OF THE NODE WITH BOUNDARY CONDITIONS

NX - X- DIRECTION (0=FREE, 1=FIXED)

NY - Y- DIRECTION (0=FREE, 1=FIXED)

TEST EXAMPLE :



$E = 2.0*10^6,\ \nu = 0.3$

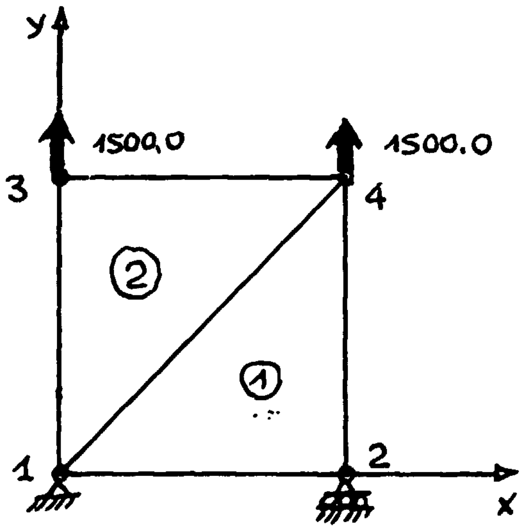
$$\sigma_y = \frac{300.0*10.0*1.0}{10.0*1.0} = 300.0 \Rightarrow \varepsilon_y = \frac{\sigma_y}{E} = \frac{300.0}{2.0*10^6} = 1.5*10^{-4}$$

$$\varepsilon_x = -\nu\varepsilon_y = -0.3*1.5*10^{-4} = 4.5*10^{-5}$$

$$\Delta y = \varepsilon_y * L = 1.5*10^{-4} * 10.0 = 1.5*10^{-3}$$

$$\Delta x = \varepsilon_x * L = 4.5*10^{-5} * 10.0 = 4.5*10^{-4}$$

FINITE ELEMENT MODEL



$$\Leftarrow \frac{300.0*10.0*1.0}{2} = \frac{3000.0}{2} = 1500.0$$

BOUNDARY CONDITIONS:

NODE 1, $U_1=0$, $V_1=0$

NODE 2, $V_2=0$

DATA FOR TEST

NAMES OF INPUT AND OUTPUT FILES

INPUT FILE - FIRE1.DAT

OUTPUT FILE - FIRE1.RES

1. CONTROL AND MATERIAL DATA

   3,2,4,2,2,2,2.0E6,0.3,1.0

2. NODAL COORDINATES

   1, 0.,0.

   2,10.,0.

   3, 0.,10.

   4,10.,10.

3. LOADS

   3,0.,1500.

   4,0.,1500.

4. TOPOLOGY

   1,2,4

   1,4,3

5. BOUNDARY CONDITIONS

   1,1,1

   2,0,1

RESULTS OF CALCULATIONS WILL BE WRITTEN IN OUTPUT FILE FIRTE1.RES

```
c
c     program firfep
c
c     first finite element program
c
c     nen - number of element nodes
c     ndf - number of degrees of freedom at the node
c     noe - total number of elements
c     non - total number of nodes
c     nbc - number of nodes with boundary conditions
c     nln - number of loaded  elements
c     E   - Young's modulus
c     pr  - Poisson's ratio
c     th  - element thickness
c     cord- nodal coordinates
c     d   - elasticity matrix
c
c
c
c
      IMPLICIT REAL*8 (A-H,O-Z)
      COMMON NEN,NDF,NOE,NON,NBC,TH
      COMMON/CORD/ CORD(60,2)
      COMMON/D/ D(3,3)
      COMMON/LOAD/NLN,NF(15),RHS(15,2)
      COMMON/NOEL/ NOEL
      DIMENSION N(60)
      CHARACTER*30 NAME
      CHARACTER*80 NAZWA
C
C
c     reading names of input and output files and opening this files
C
C
      WRITE(0,1)
    1 FORMAT(/' input file name  : '\)
      READ(0,2) NAME
    2 FORMAT(A30)
      OPEN(UNIT=5,FILE=NAME,STATUS='OLD',MODE='READ')
      WRITE(0,3)
    3 FORMAT(/' output file name : '\)
      READ(0,2) NAME
      OPEN(UNIT=6,FILE=NAME,STATUS='NEW',MODE='WRITE')
C
C
C
C
c     openinig temporary files
C
C
C
C
      OPEN(UNIT=1,FORM='UNFORMATTED',STATUS='SCRATCH')
      OPEN(UNIT=2,FORM='UNFORMATTED',STATUS='SCRATCH')
      OPEN(UNIT=3,FORM='UNFORMATTED',STATUS='SCRATCH')
C
C
C
c     problem's name
C
      READ(5,100)NAZWA
      WRITE(6,101)NAZWA
C
c      control and material data
C
      READ(5,102)NEN,NDF,NON,NOE,NBC,NLN,E,PR,TH
```

```
      WRITE(6,103)NEN,NDF,NON,NOE,NBC,NLN,E,PR,TH
C
C       coordinates
C
      READ(5,105)(N(I),(CORD(I,J),J=1,2),I=1,NON)
      WRITE(6,104)
      WRITE(6,106)(N(I),(CORD(I,J),J=1,2),I=1,NON)
C
C       loads
C
      READ(5,105)(NF(I),(RHS(I,J),J=1,2),I=1,NLN)
      WRITE(6,107)
      WRITE(6,106)(NF(I),(RHS(I,J),J=1,2),I=1,NLN)
C
C     elasticity matrix calculation
C
      GASH=E/(1.-PR*PR)
      D(3,3)=0.5*GASH*(1.-PR)
      D(1,1)=GASH
      D(2,2)=D(1,1)
      D(1,2)=PR*GASH
      D(2,1)=D(1,2)
      D(3,1)=0.
      D(1,3)=0.
      D(2,3)=0.
      D(3,2)=0.
C
      REWIND 1
      REWIND 2
      REWIND 3
C
C     computing element's stiffness matrix
C
      WRITE(6,108)
C
      DO 10 I=1,NOE
      NOEL=I
      CALL TRIAST
   10 CONTINUE
C
      REWIND 1
      REWIND 2
C
C     computing system's stiffness matrix
C
      CALL EQAGEN
C
C     solving system of equations
C
      CALL EQASOL
C
C     computing stresses
C
      WRITE(6,109)
      DO 20 K=1,NOE
      NOEL=K
      CALL STRESS
   20 CONTINUE
C
      REWIND 3
C
C     computing reactions
C
      CALL REAC
C
C
```

```
100 FORMAT(A80)
101 FORMAT(1H1///5X,'firfep problem : ',A80)
102 FORMAT(6I5,E10.2,2F5.2)
103 FORMAT(///15X,'control data   '//
   *   20X,'number of element nodes                     =',I3/
   *   20X,'number of degrees of freedom at the node =',I3/
   1   20X,'number of nodes     =',I3/
   2   20X,'number of elements =',I3/
   3   20X,'number of nodes with boundary conditions =',I3/
   4   20X,'number of loaded nodes                      =',I3///
   5   15X,'material data    '//
   6   20X,'Young''s modulus     =',E10.3/
   7   20X,'Poisson ratio        =',F6.3/
   8   20X,'element thickness   =',F6.3)
104 FORMAT(///15X,'coordinates of nodes'//
   1         15X,'node       x - direction     y - direction'/)
105 FORMAT(I5,2G10.2)
106 FORMAT(17X,I2,6X,F10.4,6X,F10.4)
107 FORMAT(///15X,'loads'//
   1         15X'node        x - direction     y - direction'/)
108 FORMAT(///15X,'topology '//15X,'element  node''s number '/)
109 FORMAT(///15X,'stresses'//
   1   8H ELEMENT,2X,'sigma x',6X,'sigma y',6X,'sigma xy',5X,
   2                  'sigma max',4X,'sigma min',4X,'angle'/)
C
      CLOSE(UNIT=1)
      CLOSE(UNIT=2)
      CLOSE(UNIT=3)
      CLOSE(UNIT=5)
      STOP  '  --- ok ---'
      END
C
C
C
C
      SUBROUTINE TRIAST
C
C
C
C
c     generates stiffness matrix for triangle element
C
      IMPLICIT REAL*8 (A-H,O-Z)
      COMMON NEN,NDF,NOE,NON,NBC,TH
      COMMON/CORD/ CORD(60,2)
      COMMON/D/ D(3,3)
      COMMON/NOEL/ NOEL
      DIMENSION ELST(6,6),LDES(6),BETA(3),GAMA(3),B(3,6),DL(3,3),DF
C
c     topology
C
      READ(5,110) I,J,K
      WRITE(6,111) NOEL,I,J,K
C
c     calculation of beta and gama coefficients
C
      BETA(1)=CORD(J,2)-CORD(K,2)
      GAMA(1)=CORD(K,1)-CORD(J,1)
      BETA(2)=CORD(K,2)-CORD(I,2)
      GAMA(2)=CORD(I,1)-CORD(K,1)
      BETA(3)=CORD(I,2)-CORD(J,2)
      GAMA(3)=CORD(J,1)-CORD(I,1)
      AREA=0.5*DABS(GAMA(3)*BETA(2)-GAMA(2)*BETA(3))
C
c     generation of the strain-displacement matrix B
C
```

```
      DO 100 L=1,3
      M=2*L-1
      N=M+1
      B(1,M)=BETA(L)
      B(1,N)=0.
      B(2,M)=0.
      B(2,N)=GAMA(L)
      B(3,M)=GAMA(L)
      B(3,N)=BETA(L)
  100 CONTINUE
C
c     generation of the matrix DL
C
      WS=0.25*TH/AREA
      DO 200 L=1,3
      DO 200 M=1,3
      DL(L,M)=WS*D(L,M)
  200 CONTINUE
C
c     generation of the matrix product D*B
C
      DO 300 L=1,3
      DO 300 M=1,6
      DB(L,M)=0.
      DO 300 N=1,3
      DB(L,M)=DB(L,M)+DL(L,N)*B(N,M)
  300 CONTINUE
C
c     generation of the stiffness matrix K=BT*DB
C
      DO 400 L=1,6
      DO 400 M=1,6
      ELST(L,M)=0.
      DO 400 N=1,3
      ELST(L,M)=ELST(L,M)+B(N,L)*DB(N,M)
  400 CONTINUE
C
      LDES(1)=2*I-1
      LDES(2)=2*I
      LDES(3)=2*J-1
      LDES(4)=2*J
      LDES(5)=2*K-1
      LDES(6)=2*K
C
c     writing to the storage
C
      WRITE(1)(LDES(I),I=1,6),((ELST(I,J),J=1,6),I=1,6)
      WRITE(2) (LDES(I),I=1,6),((DB(I,J),J=1,6),I=1,3)
C
  110 FORMAT(3I5)
  111 FORMAT(10X,I2,5X,3I3)
      RETURN
      END
C
C
C
C
C
      SUBROUTINE EQAGEN
C
C
C
C
C
C
c     generates the system of equations
```

```
C
      IMPLICIT REAL*8 (A-H,O-Z)
      COMMON NEN,NDF,NOE,NON,NBC,TH
      COMMON/LOAD/NLN,NF(15),RHS(15,2)
      COMMON/UR/ GRAN(120,120),GRANR(120),NBAND,NSSW,NBCC(10)
      DIMENSION LDES(6),ELST(6,6)
C
      DO 100 I=1,120
      DO 200 J=1,120
      GRAN(I,J)=0.
  200 CONTINUE
      GRANR(I)=0.0
  100 CONTINUE
      NSSE=NEN*NDF
      NBAND=0
      DO 300 NE=1,NOE
C
c     reading from the storage
C
      READ(1)(LDES(I),I=1,6),((ELST(I,J),J=1,6),I=1,6)
C
c     generation of the equations coefficients
C
      DO 400 I=1,NSSE
      JD=LDES(I)
      IF(NBAND.LT.JD) NBAND=JD
      DO 500 J=1,NSSE
      KD=LDES(J)
      GRAN(JD,KD)=GRAN(JD,KD)+ELST(I,J)
  500 CONTINUE
  400 CONTINUE
  300 CONTINUE
C
c     writing to the storage
C
      WRITE(3) ((GRAN(I,J),J=1,120),I=1,120)
C
      DO 550 I=1,NLN
      J=NF(I)
      JJ=2*J
      JJ1=JJ-1
      GRANR(JJ1)=RHS(I,1)
      GRANR(JJ)=RHS(I,2)
  550 CONTINUE
C
C     taking into account boundary conditions
C
      WRITE(6,120)
      I=1
      DO 600 J=1,NBC
      READ(5,121) NN,NX,NY
      WRITE(6,122)NN,NX,NY
      NBCC(I)=2*NN*NX-1
      IF(NX.EQ.1)I=I+1
      NBCC(I)=2*NN*NY
      IF(NY.EQ.1)I=I+1
  600 CONTINUE
      NSSW=I-1
      DO 700 J=1,NSSW
      K=NBCC(J)+1-J
      NBAND=NBAND-1
      NBAND1=NBAND+1
      DO 800 L=K,NBAND
      L1=L+1
      GRANR(L)=GRANR(L1)
      DO 802 M=1,NBAND1
```

```
      GRAN(L,M)=GRAN(L1,M)
  800 CONTINUE
      DO 900 M=K,NBAND
      M1=M+1
      DO 900 N=1,NBAND
      GRAN(N,M)=GRAN(N,M1)
  900 CONTINUE
  700 CONTINUE
C
  120 FORMAT(///,15X,'boundary conditions',//,5X,'node''s number ',
     1'x - direction  y - direction'/)
  121 FORMAT(3I5)
  122 FORMAT(6X,I3,17X,I1,14X,I1)
      RETURN
      END
C
C
C
C
C
C
      SUBROUTINE EQASOL
C
C
C
C
C
C     solves the system of equation using Gauss method
C
      IMPLICIT REAL*8 (A-H,O-Z)
      COMMON/UR/ GRAN(120,120),GRANR(120),NBAND,NSSW,NBCC(10)
      COMMON/SOLV/ DISP(120)
C
      NBAND1=NBAND-1
      DO 100 I=1,NBAND1
      I1=I+1
      DO 200 J=I1,NBAND
      WS=GRAN(J,I)/GRAN(I,I)
      DO 300 K=I1,NBAND
      GRAN(J,K)=GRAN(J,K)-WS*GRAN(I,K)
  300 CONTINUE
      GRANR(J)=GRANR(J)-WS*GRANR(I)
  200 CONTINUE
  100 CONTINUE
C
      DO 600 JM=1,NBAND
      J=NBAND+1-JM
      GASH=GRANR(J)
      IF(J.EQ.NBAND) GO TO 600
      J1=J+1
      DO 500 K=J1,NBAND
      GASH=GASH-DISP(K)*GRAN(J,K)
  500 CONTINUE
  600 DISP(J)=GASH/GRAN(J,J)
      DO 700 I=1,NSSW
      K=NBCC(I)
      DO 800 L=K,NBAND
      L1=NBAND+K-L+1
      L2=L1-1
      DISP(L1)=DISP(L2)
  800 CONTINUE
      DISP(K)=0.0
      NBAND=NBAND+1
  700 CONTINUE
      WRITE(6,130)
      NBAND=NBAND/2
```

```
      DO 900 I=1,NBAND
      J=2*I-1
      K=2*I
      WRITE(6,131) I,DISP(J),DISP(K)
  900 CONTINUE
C
  130 FORMAT(///,15X,'displacment of nodes    ',//,6X,'node
     1x - direction      y - direction'/)
  131 FORMAT(8X,I2,14X,G12.5,5X,G12.5)
      RETURN
      END
C
C
C
C
      SUBROUTINE STRESS
C
C
C
C
C
c     calculates stresses
C
C
C
C
      IMPLICIT REAL*8 (A-H,O-Z)
      COMMON NEN,NDF,NOE,NON,NBC,TH
      COMMON/NOEL/ NOEL
      COMMON/SOLV/ DISP(120)
      DIMENSION Q(6),SIG(3),LDES(6),DB(3,6)
C
c     reading from the storage
C
      READ(2) (LDES(I),I=1,6),((DB(I,J),J=1,6),I=1,3)
      DO 100 I=1,6
      K=LDES(I)
  100 Q(I)=DISP(K)
      DO 200 I=1,3
      DO 200 J=1,6
  200 DB(I,J)=DB(I,J)*2./TH
      DO 300 I=1,3
      SIG(I)=0.
      DO 300 J=1,6
  300 SIG(I)=SIG(I)+DB(I,J)*Q(J)
C
c     computing of main stresses
C
      C=(SIG(1)+SIG(2))/2.
      BB=(SIG(1)-SIG(2))/2.
      A=DSQRT(BB*BB+SIG(3)*SIG(3))
      SMAX=C+A
      SMIN=C-A
      IF(SIG(2).EQ.SMIN) GO TO 700
      ANG=57.29578*ATAN(SIG(3)/(SIG(2)-SMIN))
      GO TO 210
  700 ANG=90.
  210 CONTINUE
C
c     printing  stresses
C
      WRITE(6,140) NOEL,(SIG(I),I=1,3),SMAX,SMIN,ANG
C
  140 FORMAT(2X,I3,2X,5G13.5,F8.3)
      RETURN
      END
```

```
C
C
C
C
C
C
      SUBROUTINE REAC
C
C
C
C
C     computing reactions
C
      IMPLICIT REAL*8 (A-H,O-Z)
      COMMON NEN,NDF,NOE,NON,NBC,TH
      COMMON/SOLV/ DISP(120)
      COMMON/UR/ GRAN(120,120),GRANR(120),NBAND,NSSW,NBCC(10)
C
C      reading from the storage
C
      READ(3) ((GRAN(I,J),J=1,120),I=1,120)
      NP=NDF*NON
      DO 100 I=1,120
      GRANR(I)=0.
      DO 100 J=1,120
  100 GRANR(I)=GRANR(I)+GRAN(I,J)*DISP(J)
      NP1=NP/2
      DO 200 I=1,NP1
      J=2*I-1
      K=2*I
  200 CONTINUE
      IW = 0
      WRITE(6,150)
      DO 300 I = 1, NSSW
      II = I + IW
      L = NBCC(II)
      IF(L/2.EQ.L/2.) GOTO 10
      RX = GRANR(L)
      L1=NBCC(II+1)
      NR = L1/2
      IF (L1.NE.L+1) GOTO 20
      RY = GRANR(L1)
      WRITE(6,12) NR, RX, RY
      GOTO 40
   10 RY=GRANR(L)
      NR=L/2
      WRITE(6,11) NR, RY
      GOTO 50
   20 NR=(L+1)/2
      WRITE(6,13) NR, RX
      GOTO 50
   40 IW=IW+1
   50 IF(I+IW.EQ.NSSW) GO TO 60
  300 CONTINUE
   60 CONTINUE
      WRITE(6,14)
C
  150 FORMAT(///,15X,'support reactions ',//,10X,' node',10X,
     * 'x - direction',8X,'y - direction',/)
   11 FORMAT(10X, I3, 11X,' no support',10X,F11.4)
   12 FORMAT(10X,I3,11X,F11.4,10X,F11.4)
   13 FORMAT(10X, I3, 11X, F11.4,10X,' no support')
   14 FORMAT(1X,//)
      RETURN
      END
```