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COMPUTING AND COMPARING ANALYSIS OF PLANE FRAMES BY USING SCILAB

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Abstract*— Civil Engineering students have to solve many problems in structural analysis in order to have more in sight in understanding the structural behaviour. An understanding of the structural behaviour is essential in designing the structures and in executing the structures in the field. But to solve the problems manually takes lot of time. With the advent of computers, many soft war es are available like C Programming Language, ANSYS, STAAD, MATLAB, Mathematica, Octave, Scilab etc., for implementing the structural analysis methods. Scilab is open source free software. Scilab's ability to plot 2D and 3D graphs helps in visualizing the data effectively. Scilab's capabilities make it an excellent tool for teaching, especially those subjects that involve matrix operations. Hence the students can use the software for solving the engineering problems and can learn programming skills. Also new modules can be developed on top of the existing modules thereby decreasing the development time. So the present paper entitled "Analysis of Plane Frames by Matrix Method using Scilab" is carried out. The developed program in Scilab is used to solve example problems and results obtained are same as the manual results.

***Keywords*— Matrix Methods, Plane Frames, SCILab, Structure Analysis, Stiffness Method, Flexibility Method**

I. INTRODUCTION

A. Plane Frames

Plane frame is a structure consisting of series of members joined together in one plane to form a frame work (pin joined, rigid, and triangulated). Plane frame structures are composed of structural members which lies in a single plane. When the loads act upon the plane then frame is subjected to both axial action and bending. Of particular interest are the axial thrust, shear and moment distributions for the members due to external loads.

Analysis of plane frames must be done to know the response of the frame to external loads. So, that the design of the frame is done based on the analysis results. In structural analysis the response of a structure to specified loads are determined by mathematical process. The responses are calculated by finding the internal forces and deformations or displacements throughout the frame. Structural analysis is purely based on Mechanics of solids, Engineering Mechanics, laboratory work, model and prototype testing, experience and judgment. The skeletal structure is one whose members can be represented by lines possessing certain rigidity properties. These 1-D members are also called beams or bar members because they have very less cross sectional dimensions i..e, breadth x depth compared to their length. The skeletal structures may be determinate or indeterminate.

B. Methods of Structural Analysis

The following are the some of the methods of Structural analysis.

- Slope-Deflection Method (Θ-δ)
- Moment Distribution Method
- Kani's Method
- Strain Energy Method
- Finite Element Analysis
- Matrix Method

C. Matrix Methods

Mainly there are two basic methods in Matrix methods. One is Flexibility method and the other one is Stiffness method. These two methods are developed in conventional and matrix forms. The conventional methods are discussed below

D. Flexibility Matrix Method

First the given indeterminate structure is made statically determinate by introducing suitable number of releases. The number of releases required is equal to the Degree of Redundancy (D.O.R / Ds) or static indeterminacy. By introducing those releases displacements discontinues at these releases under the externally applied loads. Pairs of unknown bi-actions (forces and moments) are applied at these releases in order to restore the continuity or compatibility of structure. The computation of these unknown bi-actions involves solution of linear simultaneous equations. The number of these equations is equal to static indeterminacy. After the unknown bi-actions are computed all the internal forces can be computed in the entire structure using equations of equilibrium and free bodies of members. By using methods like displacement computation the required displacements can be computed. In flexibility method, unknowns are forces at the releases so, the methods is also named as Force method. Since computation of is placement is also required at releases for imposing conditions of compatibility the method is also called compatibility method. For computing displacements we use flexibility properties , hence, this method also termed as Flexibility method.

E. Stiffness Matrix Method

In this method first constraint nodes are introduced in the indeterminate structure to make it kinematically determinate. The required number of constraints is equal to the Kinematic Indeterminacy / Degrees of Freedom(D_k). Hence, the fixed members in the structure will have zero nodal displacements.

These results in stress resultant discontinuities at these nodes under the action of applied loads are not in equilibrium. So, the equilibrium of stress resultants at the nodes are to be restored. To restore stress resultants, simultaneous equations are to be formed whose number is equal to the degree of kinematic indeterminacy (D_k). Consequently we may be able to find unknown displacements. There by we find the end forces and internal forces of the members by stiffness properties of each member and finally the whole structure is analysed in this procedure. The main unknowns we consider in this procedure are nodal displacements, so this method is known as displacement method. As we used equilibrium equations to find unknowns so this may be termed as Equilibrium method. And after finding unknown displacements we use stiffness properties to decode into unknown forces. Hence it is also called Stiffness method.

Matrix methods are convenient for computer programming, understanding & ease of solving structures with large members.

In the present paper entitled "Computing and Comparing Analysis of Plane Frames Using Scilab" the Stiffness matrix method is used to analyse the Plane Frame structure. Scilab, open source free software is used to implement the Stiffness Matrix Method to analyse the Plane Frame.

II. INTRODUCTION TO SCILAB

A. Scilab:

Scilab is one of the matrix–oriented software just like Matlab. It allows matrix computations, animation, 2D/3D plotting, graphs etc.., Not like Matlab, it is an open programming software that allows users to create their own functions and libraries. Its editor has a built-in, elementary debugger. So, Scilab is a type of Interpreter software.

Main properties of Scilab are:

- It is an Interpreter (Interprets when there is an error in the programming)
- Libraries of functions (procedures, macros)
- Except for Python and/or Ruby, Scilab interfaces all popular softwares like Fortran, C, C++, Java, Modelica etc..,
- Scilab attracts those who use Matlab because of its for free where as Matlab is of high cost.

B. Advantages of Scilab:

- Compared to symbolic computing, Numeric computing is better one for complex tasks.
- Not all mathematical problems have closed form solutions; numeric computing will therefore always be needed.
- Scilab is almost similar to Matlab and keeps on updating even closer. It is quite easy to shift from one to the other.
- Scilab occupies less space than Matlab and GNU Octave.
- It also includes a Matlab-to-Scilab translator which translates/decodes Matlab program to Scilab easily (.m files to .sci files).
- Scilab has easy Data plotting than with GNU Octave (but the trend is toward more complex handle structures).
- In Scilab the Xcos toolbox installs automatically, but, that Xcos is not compatible with Simulink.
- Scilab installation very easy with respect to any type of Operating System.
- Scilab is one of the free software where as licenses to Matlab, Mathematica, etc. is expensive.

C. Disadvantages of Scilab:

- In case of Rounding off, Numeric computing tilt to approximate value where as in symbolic computing it gives accurate value
- The effort for learning required by numeric computing is higher when compared to symbolic computing
- Scilab is lack of a unified user's manual and tutorials. You have less videos on YouTube for learning about Scilab which is a basic drawback
- In some complex problems Scilab takes more time than Matlab and GNU Octave
- Scilab's tools for creating Graphical User Interfaces (GUI) are poor compared with Matlab
- New learners find it difficult with the Help Browser which is very formal and of little use
- Scilab has errors i..e., bugs and may tend to crash

III. CONVERTING FLEXIBILITY MATRIX INTO SCILAB

In programming, algorithm and flow chart are the main souls. If the algorithm and flow chart are correct then our approach towards the solution is accurate and correct. For the analysis of plane frames in Scilab one should follow a step by step procedure. They are

A. Data Organization for Matrix Analysis of Plane Frames
B. Stiffness Matrix of the 1st member
C. Rotation Matrix of a Plane Frame Member
D. Global Stiffness Matrix of a Plane Frame Member
E. Assembling the Load Vector
F. Extracting Member End Forces
G. Data Organization for Matrix Analysis of Plane Frames

A. Data Organization for Matrix Analysis of Plane Frames:
The first step in this process is clearly defining the nodes, connectivity, loads etc.., These data should be collected carefully and written in the matrix form. The input data for a plane frame shall be organized as follows shown in Table

Table 1
Table showing the matrix notations

xy	Coordinates matrix.
Conn	Connectivity matrix.
Bc	Boundary Constraint matrix.
Mprop	Member Property matrix.
Jtloads	Joint Loads matrix.
Memloads	Member Load matrix.

B. Generating Local Stiffness Matrix of the member [LSM]:
For generating this matrix first a matrix [LSM] of size 6x6 of zero matrix is considered, then the elements of the upper triangular matrix are defined and lastly the upper triangle is copied into lower triangle. The outcome of the process is shown in the below matrix

$$k = \begin{bmatrix} \frac{EA}{L} & 0 & 0 & \frac{-EA}{L} & 0 & 0 \\ 0 & \frac{12EI}{L^3} & \frac{6EI}{L^2} & 0 & \frac{-12EI}{L^3} & \frac{6EI}{L^2} \\ 0 & \frac{6EI}{L^2} & \frac{4EI}{L} & 0 & \frac{-6EI}{L^2} & \frac{2EI}{L} \\ \frac{-EA}{L} & 0 & 0 & \frac{EA}{L} & 0 & 0 \\ 0 & \frac{-12EI}{L^3} & \frac{-6EI}{L^2} & 0 & \frac{12EI}{L^3} & \frac{-6EI}{L^2} \\ 0 & \frac{6EI}{L^2} & \frac{2EI}{L} & 0 & \frac{-6EI}{L} & \frac{4EI}{L} \end{bmatrix}$$

C. Rotation Matrix of a Plane Frame Member [RM]:
In the last step we computed stiffness matrix which is with respect to local axis of a member. But the local axis reference may give best result for 1-D frames like beams. Unlike as 1-D frames, we can't take local stiffness matrix for solving the problem in 2-D frames. We have to transform the matrix from local stiffness to global stiffness matrix. So for this transformation we need another matrix for conversion which is named as Rotation Matrix. And this rotation matrix can be expressed in terms of cosines of the member. Following matrix is the rotation matrix for 2-D plane frame.

$$[T] = \begin{bmatrix} c_x & c_y & 0 & 0 & 0 & 0 \\ -c_y & c_x & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & c_x & c_y & 0 \\ 0 & 0 & 0 & -c_y & c_x & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

D. Global Stiffness Matrix of a Plane Frame Member [GSM]:
To compute the global stiffness matrix, we consider a equation $k = r' k^e r$ where r is the rotation matrix of the member and k^e is local stiffness matrix. Thus in the above steps we have calculated local stiffness matrix and rotation matrix of plane frame individually. Directly adopting them into the equation will give us global stiffness matrix.

E. Structure Stiffness Matrix Assembling [SSM]:

In this step we obtain structure stiffness matrix of a plane frame. So, to obtain the matrix we superimpose global stiffness matrix with the structure stiffness matrix. To get exact matrix we have to map every row and columns of the global stiffness matrix of the frame with the structural stiffness matrix. This can be solved by taking dof numbers for the rows and columns of the member global stiffness matrix and those can be superimposed with the corresponding elements of the structure stiffness matrix. Hence, there is a need to know about the numbers of start and end nodes of a member and their corresponding degree of freedom from the location matrix 'lm'.

F. Assembling the Load Vector:

In this step the number of rows will be equal to the degree of kinematic indeterminacy or dof of the frame(ndof). So, each element in the load vector indicates the load applied with the corresponding to a dof number. The loads acting on the structure may be of two types. One of them may be Joint loads acting at the nodes where as the other may be on the members.

The Joint loads are already given as input data to the program as components of global coordinate system along three x, y and z axes. By knowing the node numbers and those are to be superimposed with the corresponding load vector.

G. Extracting Member End Forces:

This is the final step in this method. Once we get the nodal displacements then end forces are to be calculated. We can calculate them as the information required to find end forces by displacements is already available in the location matrix (xy). But the location matrix is related to local axes. So, again we have to transform global axes to local axes. Finally, we get the member end forces which are our required result and noted. The interface to the function that computes the member end forces in local axes for a member with number **imem**.

IV. EXAMPLES AND COMPARISONS

Ex.1: Analyse the rigid frame shown in Fig 5.1 by direct stiffness matrix method. Assume *E*=200GPa, $I_{zz}=1.33*10^{-5}$ m^4 and A=0.01m^2. Consider flexural rigidity *EI* and axial rigidity *AE* are the same for all beams in the whole frame.

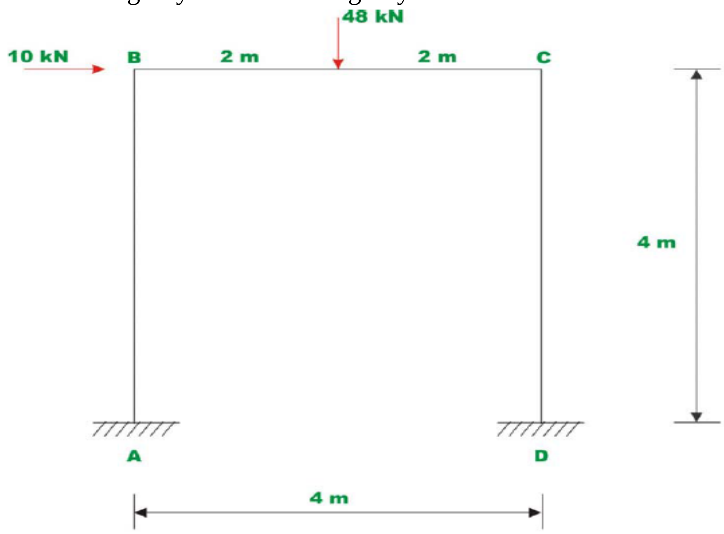

Fig. 1 A Simple Frame with Single bay

Scilab Input

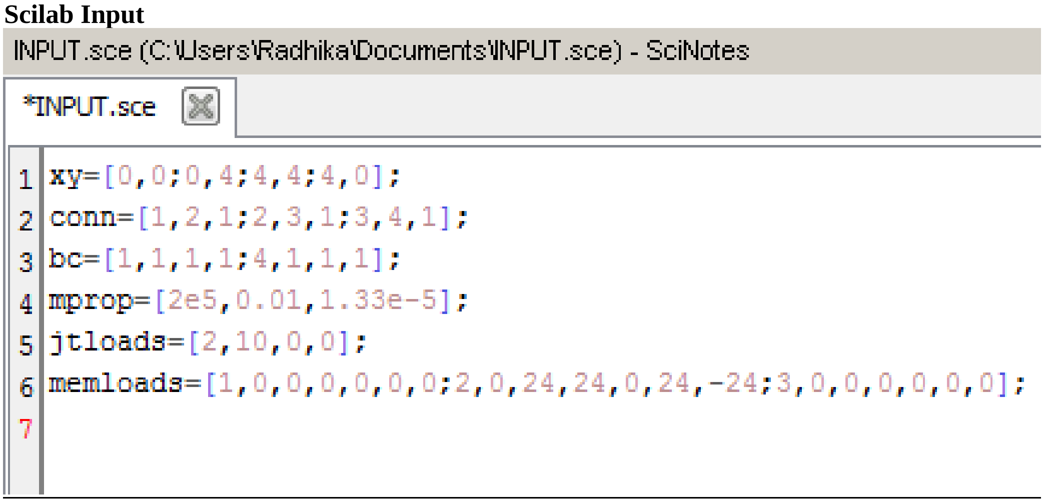

Fig. 2 Screenshot of the Input given in SCILab

Scilab Output

```
-->f1
 f1  =

     0.983711
     21.541836
     3.06628
   - 7.066289
   - 0.068763
   - 27.129258

-->f2
 f2  =

   - 0.068763
     12.066289
     31.129258
   - 12.06628
     29.12925
   - 28.9337
```

Fig. 3 Screenshot of the output reactions after executioon in SCILab

TABLE 2

COMPARISON OF RESULTS BETWEEN MANUAL PROCEDURE AND SCILAB

	R1	R2	R3	R7	R8	R9
Manual	0.99	19.71	3.43	-10.99	28.28	19.42
Scilab	0.98371	21.5418	3.0662	-12.06628	29.1292	-28.9337

Ex 2: Analyse the following beam shown in Fig 5.2 with given values
L=100 in,P=10 kips, *E*=10,000 ksi, A=10 in2, *I*=1000 in^4.

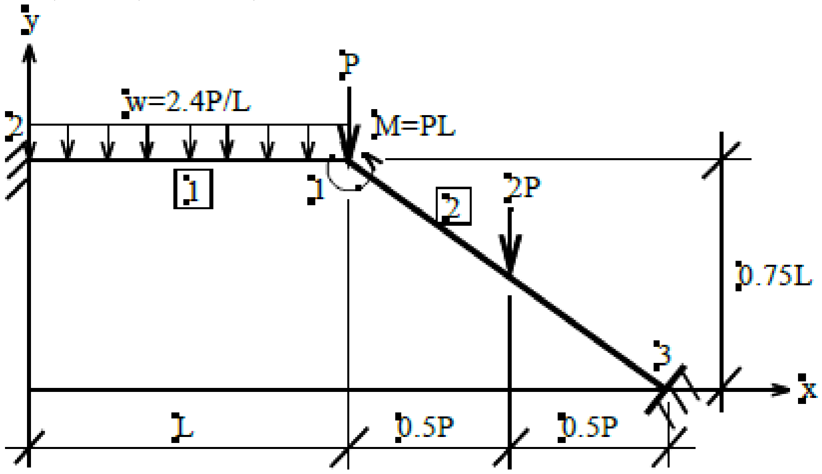

Fig. 4 A frame with Inclined length

Scilab Input:

```
Untitled 1 - SciNotes
*Untitled 1

1 xy=[100,75;0,75;200,0];
2 conn=[2,1,1;1,3,1];
3 bc=[1,1,1,1;3,1,1,1];
4 mprop=[1e4,10,1e3];
5 jtloads=[1,0,-10,-1000];
6 memloads=[1,0,12,200,0,12,-200;2,-6,8,250,-6,8,-250];
```

Fig.5 Screenshot of the Input given in SCILab

Scilab Output:

```
f1  =                          f2  =

   20.260769                      28.72592
   13.137825                    - 4.5332787
   436.64755                    - 677.13496
 - 20.260769                    - 40.72592
   10.862175                      20.533279
 - 322.86504                    - 889.52488
```

Fig. 6 Screenshot of the output reactions after executioon in SCILab

TABLE 3

COMPARISON OF RESULTS BETWEEN MANUAL PROCEDURE AND SCILAB

Reactions	Book values	Scilab Values
R_1	20.26	20.260769
R_2	13.14	13.137825
R_3	436.6	436.64755
R_{10}	-20.26	-20.260769
R_{11}	10.86	10.862176
R_{12}	322.9	322.86504

IV. CONCLUSIONS

- The implemented Scilab program can used to analyse plane frames/portal frames.
- Using the program, the students can solve more problems in less time and can understand the of the plane frame under different loading conditions.
- Can be used to ascertain the results of ANSYS & STADD when in doubt.
- Scilab is easy to understand as it has friendly interface.

V. SCOPE OF FUTURE WORK

- 3 D analysis of frames can be considered.
- R.C.C. Designs using IS Code can be implemented.
- Steel Designs using IS Code can be implemented.
- Design of Shallow Foundations can be considered.

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