Strength of Beam-and-Column Subassemblages in Unbraced Multi-Story Frames

COMPUTER PROGRAM FOR ELASTIC-PLASTIC ANALYSIS OF UNBRACED FRAMES

by

Sung-Woo Kim
J. Hartley Daniels

Fritz Engineering Laboratory Report No. 346.6
Strength of Beam-and-Column Subassemblages in Unbraced Multi-Story Frames

COMPUTER PROGRAM FOR ELASTIC-PLASTIC ANALYSIS OF UNBRACED FRAMES

by

S. W. Kim

J. Hartley Daniels

This work has been carried out as part of an investigation sponsored by the American Iron and Steel Institute and the Pennsylvania Science and Engineering Foundation.

Department of Civil Engineering

Fritz Engineering Laboratory

Lehigh University

Bethlehem, Pennsylvania

March 1971

Fritz Engineering Laboratory Report No. 346.6
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABSTRACT</td>
<td>1</td>
</tr>
<tr>
<td>1. INTRODUCTION</td>
<td>2</td>
</tr>
<tr>
<td>2. COMPUTER PROGRAM</td>
<td>4</td>
</tr>
<tr>
<td>2.1 Computational Procedure</td>
<td>4</td>
</tr>
<tr>
<td>2.2 Brief Description of Program</td>
<td>6</td>
</tr>
<tr>
<td>2.3 Limitations</td>
<td>9</td>
</tr>
<tr>
<td>3. DATA CARD SET-UP</td>
<td>12</td>
</tr>
<tr>
<td>4. INTERPRETATION OF OUTPUT</td>
<td>15</td>
</tr>
<tr>
<td>4.1 Sign and Numbering Conventions</td>
<td>15</td>
</tr>
<tr>
<td>4.2 Output</td>
<td>16</td>
</tr>
<tr>
<td>5. APPENDIX I - LISTING OF PROGRAM</td>
<td>18</td>
</tr>
<tr>
<td>6. APPENDIX II - SYMBOLS IN PROGRAM</td>
<td>44</td>
</tr>
<tr>
<td>7. APPENDIX III - FLOW CHARTS</td>
<td>55</td>
</tr>
<tr>
<td>8. APPENDIX IV - SAMPLE OUTPUT</td>
<td>79</td>
</tr>
<tr>
<td>9. FIGURES</td>
<td>83</td>
</tr>
<tr>
<td>10. REFERENCES</td>
<td>88</td>
</tr>
<tr>
<td>11. ACKNOWLEDGMENTS</td>
<td>89</td>
</tr>
</tbody>
</table>
ABSTRACT

This report describes a computer program for the sway increment method for the elastic-plastic analysis of unbraced multi-story frames. The program is designed to determine the lateral load versus drift behavior of an unbraced multi-story frame up to and beyond the stability limit load under nonproportional combined loads. Detailed explanations of the sway increment method can be found in Ref. 1 of the report.

The report gives a brief explanation of the program, instructions on the use of the program and interpretation of the output. Also, a full listing of the program, flow charts and portions of the output from an analysis of an example frame are provided.
1. **INTRODUCTION**

In the analysis and design of an unbraced multi-story frame it is necessary to be able to determine the complete lateral-load versus drift behavior of the frame or individual stories.\(^{(1)}\) The loading conditions should be nonproportional where the gravity loads are held constant while the lateral loads vary. This loading condition is considered more realistic than the proportional loading condition.

Continuing research into the behavior of multi-story frames is presently investigating the redistribution of lateral loads to parallel frames which are dissimilar. This research also requires that the complete loading and unloading behavior of multi-story frames under the nonproportional loading conditions described above can be determined.

This report describes a computer program developed for use in conjunction with the sway increment method of analysis described in Ref. 6. The sway increment method of analysis is based on determining the magnitude of an assumed distribution of lateral loading when the frame is subjected to a known sway or drift, and the gravity loads are held constant. The method uses a second-order elastic-plastic analysis, an incremental procedure and a "next hinge" prediction technique to improve the program speed and efficiency. The method includes column shortening, hinge reversal and the effect
of residual stresses in the columns. A unique aspect of the sway increment method of analysis is the technique of applying the constant gravity loads. Before considering the lateral loads, the gravity loads are applied incrementally to detect plastic hinges under gravity loads alone. In this way a frame with initial plastic hinges or real hinges can be analyzed under combined loads. Further details of the theoretical development of the method are contained in Ref. 1.

The computer program described herein was programmed in Fortran IV for use on a CDC 6400 computer located at Lehigh University.
2. COMPUTER PROGRAM

2.1 Computational Procedure

The computational procedure in the program is that given in Chapter 2 of Ref. 1, which is repeated as follows:

1. Assume that the frame is initially unloaded and unstrained.
2. Apply the working gravity loads first. After that, increments of the gravity load will be applied.
3. Calculate joint rotations and joint vertical deflections at non-swayed position and then all member end forces.
4. Check all moments. If there is any cross-section where the moment exceeds its plastic moment capacity, insert a plastic hinge.
5. Repeat steps 2 and 4 until the factored gravity loads are reached.
6. Set sway increment. Initially, an arbitrary small increment is chosen and from then on, the increment is determined in steps 13 and 18.
7. Determine stability factors and stability functions of incremental slope-deflection equations for all members with the known member end forces.
8. Apply the sway increment which is fixed in step 6, to the bottom story (to the failed story, after the
stability limit load is reached) and calculate the corresponding incremental load intensity.

9. Determine the sway increment which results in same incremental load intensity with that calculated in step 8 at each story except the story used in step 8, by iteration.

10. If the sway increment cannot be obtained at a particular story in step 9, this means that no more lateral load can be resisted by the story and the stability limit load is reached. Now on the sway deflection of the failed story is incremented.

11. Calculate incremental moments, axial forces and axial shortening of columns from the deformations determined in the calculations of steps 8 and 9.

12. Repeat steps 6 to 12 inclusive until the value of the incremental load intensity calculated in the bottom story (in the failed story, after the stability limit load is reached) converges for the given sway increment.

13. Predict the minimum sway increment required in the bottom story (in the failed story, after the stability limit load is reached) for next hinge. Repeat steps 6 to 12 until prediction converges within tolerance.

14. Calculate inelastic hinge angles and test if there are any hinge reversals. If there are any hinge reversals, lock the hinges that have been unloaded. Return
sway increment to the value at the start of the current increment and do again from step 6.

15. Calculate the total lateral load and the total sway deflection at each story by adding the current incremental values to the previous subtotals.

16. Test the ratio of the maximum lateral load (corresponding to the stability limit load) and the present lateral load. If the ratio reached the desired range on unloading part, stop the program and terminate the calculation.

17. Check all moments and insert a new hinge at the location where the moment reaches its plastic moment of the section.

18. Predict the minimum sway increment of the bottom story (of the failed story) required for the next hinge.

19. Repeat steps 6 to 18 until the condition in step 16 is satisfied.

2.2 Brief Description of Program

The whole program was divided into a main program and nine subroutines for ease in compiling. A listing of the computer program is presented in Appendix I. The flow charts of the main program and individual subroutines are given in Appendix III. The symbols used in the program and in the flow charts are explained in Appendix II. The subroutines called by the main program or other subroutine are briefly described below.
Subroutine BEGIN: - Reads the geometry of the frame, member sizes and working gravity loads and lateral load indices. The material properties such as yield stress, modulus of elasticity and residual stress level are read at the same time. All the input quantities are printed out for future reference.

The end moments on beams and columns, joint rotations and lateral deflection are initialized. The plastic hinge combination for beams and columns is initialized as combination which does not have any plastic hinges (the detailed description on various combinations is given in Section 4.1).

This subroutine also calls subroutine GRALD which performs the function described below.

Subroutine GRALD: - The gravity loads are applied to the frame in the non-swayed position. The working gravity loads are applied at first and after that, the gravity loads are incremented until the factored gravity loads are reached. The main function of this subroutine is to check the formation of any plastic hinges under gravity loads only and to take into account of the effect of the plastic hinges, if any.

Subroutine CSCOE: - Determines the incremental fixed-end moments for all beams and the slope-deflection coefficients for beams and columns according to the plastic hinge combination. It also computes the summation of incremental independent moments at the joints and in the stories. These moments do not depend upon the incremental
joint rotations or sway deflections of stories. They are incremental fixed-end moments due to incremental gravity loads or vertical deflections of joints or the moment differences caused by the variation in reduced plastic moments at the column plastic hinge locations or carryover moments.

**Subroutine HORE**: Solves the joint equilibrium equations for the incremental joint rotations utilizing the Gauss-Seidel iteration method. These equations contain known quantities like slope-deflection coefficients, incremental independent moments and sway deflections of stories. From the values of calculated incremental joint rotations, the story shear force is computed. Then, the value of the applied lateral load consistent with the given sway deflection of a story is determined from the story shear force.

**Subroutine ENMT**: Determines the incremental end moments acting on the beams and columns utilizing incremental joint rotations, sway deflections of stories, slope-deflection coefficients and incremental independent moments acting on each member. These incremental end moments acting on each joint will be in balance. Adding the incremental end moments to the previous subtotals, the total end moments acting on the beams and columns at a sway increment are determined.

In this subroutine the axial loads in columns are also computed from statical equilibrium for the given vertical loads and the end moments on the beams. From the calculated axial loads, the incremental axial shortening of the columns and then the incremental joint vertical deflections are computed.
Subroutine PRED: - Predicts the minimum sway increment required in the bottom story (in the failed story, after the stability limit load is reached) for the next plastic hinge. The increments of lateral load intensity at all the potential hinge locations are calculated for plastic hinges from the linear predictions and then the smallest increment is selected for the next hinge. The smallest increment of lateral load intensity is converted to the necessary sway increment of the bottom story (of the failed story, after the stability limit load is reached).

Subroutine HINRE: - Computes the incremental inelastic hinge rotation and examines for any reversal of the direction of the rotation at each plastic hinge. If there are any hinge reversals occurred, the plastic hinges are eliminated and plastic hinge combination numbers are adjusted accordingly.

Subroutine BEAM: - Checks all beams for new hinge formation. If a plastic hinge has formed, a proper plastic hinge combination number is allotted to that beam. The combination number, the end moments and the maximum positive moment of each beam are printed out at each sway deflection increment.

Subroutine COL: - Does the same functions for the columns, which subroutine BEAM does for the beams.

2.4 Limitations

The limitation imposed on the number of bays and the number of stories is that dictated only by the computer time and the storage
capacity of the particular computer employed. The program listed in Appendix 1 can be used for a frame up to 30 stories high and 3 bays wide. For a larger frame, the dimensions for various variables should be adjusted accordingly.

In the program, the deformation history is specified at working gravity loads and at each increment of gravity loads in the non-swayed position and at each successive hinge. The information between hinge formations is not recorded. Also, the deformations are calculated only at the joints; that is, in-span deflections of the beams and columns are not calculated.

In the computer program, the test employed for convergence of a hinge prediction requires that the difference between the prediction in the previous cycle and in the current cycle should be within 5 percent of the predicted sway increment of the previous cycle. As the criteria for the formation of a plastic hinge, the difference between the calculated moment at a section and the plastic moment or the reduced plastic moment of the section should be within 1 percent for beams and 2 percent for columns. In some cases, the above criteria are satisfied simultaneously at more than one point in a frame. In such a case it is considered that more than one plastic hinge form at the same sway increment. Those criteria could be modified, if necessary.

In applying the gravity loads to the frame at non-swayed position, the working gravity loads are applied at first. After that, the gravity loads are increased with the increment of one-
tenth of the working gravity loads until the factored gravity loads are reached. If it is desired to use a different magnitude of the increment of the gravity loads or other initial gravity loads instead of the working gravity loads, those factors can be adjusted.
3. **DATA CARD SET-UP**

The first card of the data card requires the specification of number of stories, number of bays, modulus elasticity, yield stress level, residual stress level, load factor for combined loads and load factor for the initial gravity loads to be applied.

On the second card, bay lengths (center-to-center span lengths) are read from the left. On the third card, story heights and lateral load indices are read from the top. Following this card, moments of inertia and plastic moduli of beams are read from the top left to the bottom right. Next, working gravity loads for beams are read from the top left to the bottom right. Then, moments of inertia, plastic moduli, areas and working gravity loads for columns are read from the top left to the bottom right. Last, depths of columns are read.

The following descriptions show the set-up of the data cards and input formats used in the program.
<table>
<thead>
<tr>
<th>Card No.</th>
<th>Data</th>
<th>Symbol</th>
<th>Format</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Number of stories</td>
<td>MS</td>
<td>2I5</td>
</tr>
<tr>
<td></td>
<td>Number of bays</td>
<td>NB</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Modulus of elasticity (k/in(^2))</td>
<td>E</td>
<td>5F10.3</td>
</tr>
<tr>
<td></td>
<td>Yield stress level (k/in(^2))</td>
<td>FY</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Maximum compressive residual stress non-dimensionalized with yield stress</td>
<td>FRC</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Load factor for combined loads</td>
<td>FAC</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Load factor for initial gravity loads to be applied</td>
<td>GLF</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Bay length (in)</td>
<td>S</td>
<td>4F10.5</td>
</tr>
<tr>
<td>3F*</td>
<td>Story height (in)</td>
<td>H</td>
<td>8F10.5</td>
</tr>
<tr>
<td></td>
<td>Lateral load index</td>
<td>WH</td>
<td></td>
</tr>
<tr>
<td>4F*</td>
<td>Moment of inertia--Beams (in(^4))</td>
<td>BI</td>
<td>6F10.5</td>
</tr>
<tr>
<td></td>
<td>Plastic modulus--Beams (in(^3))</td>
<td>BZ</td>
<td></td>
</tr>
<tr>
<td>5F*</td>
<td>Working gravity load--Beams (k/in)</td>
<td>FL</td>
<td>6F10.5</td>
</tr>
<tr>
<td>6F*</td>
<td>Moment of inertia--Columns (in(^4))</td>
<td>CI</td>
<td>8F10.5</td>
</tr>
<tr>
<td></td>
<td>Plastic modulus--Columns (in(^3))</td>
<td>CZ</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Area--Columns (in(^2))</td>
<td>AR</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Working gravity load--Columns (kip)</td>
<td>PC</td>
<td></td>
</tr>
<tr>
<td>7F*</td>
<td>Depths of Columns (in)</td>
<td>D</td>
<td>8F10.5</td>
</tr>
</tbody>
</table>

Read "and following cards as required" for F*

As an illustration, for a frame with the geometry, member sizes, working gravity loads and lateral loads as shown in Fig. 1, the set-up of the data cards for input is given in Fig. 2. The frame shown in Fig. 1 is used for simplicity in this report. Otherwise, no restrictions on the frame size are implied other than those imposed by the capacity of the computer.
4. **INTERPRETATION OF OUTPUT**

4.1 **Sign and Numbering Conventions**

The sign convention adopted in the program is as follows:

1. Moments and rotations at the ends of members are positive when clockwise.
2. Moments acting at a joint are positive when counterclockwise.
3. Moment in the interior of a beam is positive when it produces tension on the bottom.
4. Moment in the interior of a column is positive when it produces tension on the right.
5. Horizontal shear in a column is positive if it causes a clockwise moment about the end of the column.
6. Axial forces in beams and columns are positive when they produce compression.
7. Vertical deflection of joints are positive when downward.
8. Lateral deflections of joints are positive when towards the right.

The numbering system for a level (boundary between two stories) used in the program starts from the top of a frame with one and proceeds downward. Stories are numbered from the bottom and proceed upward. Bays are numbered from the left.
In order to specify the hinge combinations occurred in members, a numbering system shown in Fig. 3 was used. The same combination number was used for beams and columns. For beams, the end A in Fig. 3 is corresponding to the left end of a beam. For columns, the end A in Fig. 3 is corresponding to the bottom end of a column. Hence, from the combination number of a member, the locations of plastic hinges on the member can be readily located. At each sway increment, the combination number for each member is printed out along with its member moments.

For the designation of the location of the possible next hinge point for which the sway increment is adopted or the locations where hinge reversals occur, the potential plastic hinge locations of a member at the start of analysis were numbered. Those locations are both ends of a member and an interior point where the maximum bending moment occurs. For convenience, in the program the potential hinge locations of a beam and a column are numbered consecutively as shown in Fig. 4. Using this numbering system, a potential hinge location can be identified with the level number, the bay number and the "potential hinge number". As an example, the location marked with A in Fig. 4 is identified with the point with number 2 at the Mth level in the Nth bay of the frame. The quantities pertaining to that location can be conveniently designated with three dimensionally subscripted variables with level number as first subscript, bay number as second subscript and potential hinge number as third subscript. In output, the possible next hinge location for which a sway increment
is adopted is described with the three subscripts. The locations where hinge reversals occur are also indicated with the subscripts.

4.2 Output

All the input quantities discussed in Chapter 3 are printed out at the beginning of output. Then, the total load factor and the incremental load factor for gravity loads, the locations of plastic hinges, member moments (k-in), axial forces in columns (kip) and joint vertical deflections (in) are printed out at each increment of gravity loads in the non-swayed position. Next, the following information is printed out at each sway increment: the required sway increment for next hinge (*E/H) (k/in²) and the location where the increment is adopted, the process of iteration for lateral load intensity by specifying its value at each iteration, the process of hinge prediction by specifying the number of iteration, the total sway increment adopted at the current iteration and the correction for the next iteration, number of hinge reversals occurred, their locations, total inelastic hinge rotations (*E)(k/in²) at the previous increment at the plastic hinges subjected to reversals and increment of rotation (*E)(k/in²) at the locations at the current increment, if there are any hinge reversals, total lateral load intensity (kip), lateral deflections (in) and deflection indices of individual stories, deflection index of frame, locations of plastic hinges, member moments, axial forces in columns and joint vertical deflections.

As an example, portions of the output from the analysis of a two-bay three-story frame shown in Fig. 1 are presented in Appendix IV. Page 80 of Appendix IV includes the results of the analysis with
factored gravity loads in the non-swayed position and the output from the first sway increment. Page 81 contains a portion of the output at a sway increment before the stability limit load is reached. At this increment a number of plastic hinges is seen to have formed. However, there are no hinge reversals at this stage. Page 82 presents a portion of the output at a sway increment after the stability limit load is reached. The negative increment of lateral load intensity indicates that the lateral load decreases and the frame is unloaded. At this increment, eight plastic hinges are subjected to hinge reversals. The stability limit load (the maximum lateral load) is recorded when it occurs. However, in this example the output at the maximum lateral load is omitted.
5. APPENDIX I - LISTING OF PROGRAM
PROGRAM KIMOI3(OUTPUT, TAPE 2=OUTPUT, INPUT, TAPE 1=INPUT)

PROGRAM FOR COMPLETE LOAD-DEFLECTION BEHAVIOR OF UNBRACED FRAME

LA=1 AXIAL SHORTENING IS NOT CONSIDERED
LA=2 AXIAL SHORTENING IS CONSIDERED
LR=1 HINGE REVERSAL IS NOT CONSIDERED
LR=2 HINGE REVERSAL IS CONSIDERED

COMMON/BLOCKA/E,FY,BI(30,3),AZ(30,3),PB(30,3),CI(30,4),CZ(30,4),AR
1(30,4),PC(30,4),ET(31,4),PD(4),KB(30,3),BA(30,3),BB(30,3),BC(30,3)
2,BAP(30,3),BPP(30,3),BGP(30,3),FBA(30,3),FBB(30,3),BAP(30,3),BPP(30
3),BGP(30,3),CA(30,3),SP(30,3),CP(30,3),SC(30,3),KC(30,4),BU(30,
4),AL(30,4),BM(30,4),BUP(30,4),BLP(30,4),BMP(30,4),BUI(30,4),BLO(3
50,4),BMJ(30,4),FBU(30,4),FBP(30,4),BPU(30,4),BPU(30,4),CU(30,4),SU
(650,4),CL(30,4),SL(30,4),CC(30,4),CS(30,4),CX(30,4),SX(30,4),CY(30,
74),SY(30,4),SM(30,4),SH(30),X(30,3),Y(30,3),XC(30,4),YC(30,4),PC(30
84),PP(30,4),PI(30,4),ED(30,4),EDTP(30,4),HF(30),HFP(30),
9,HFT,PHF,MAX,ER(30),ERP(30),ERT(30),IM,KAA,KM,MAXP,MS,MT,MR,NC
14,M,NN,DERL,LD,FRC,NHR,LA,LR,RP(30,3),O(30,4),H(30),WH(30),FL(30
3),2S(3),RY(30,4),HRO(30,4),6,PHRO(30,4,6),KH(30,4,6),KPRD,GLF,TGLF,
3FAC,SM,KB(30,3),KCP(30,4)

DIMENSION HHF(4),HER(4)

LA=2
LR=2
IM=1
KAA=1
NN=1
NDER=1
KM=1
II=1
MAXP=1

CALL BEGIN
IF(IM.LE.0) GO TO 100

100 MK=1
ER(MF)=DER
PD=DER
TDER=0
1 TDER=TDER+DER
NM=1
2 DO 50 M=1,MS
SH(M)=0
50 CONTINUE

WRITE(10,103)M,HF(M),ER(M)
IF(MF.EQ.1) GO TO 14

NS=1
NSL=M-1
IN=1...
GO TO 13
14 NS=MF+1
   NSL=MS
   IN=2
13 DO 15 I=NS,NSL
   IF(IN .EQ. 1) GO TO 11
   M=I
   GO TO 12
11 M=MF-I
12 NN=1
   DO 5 L=1,4
      HHF(L)=0.0
      HER(L)=0.0
      IF(MK-1) .GE. 60,60,61
51 ER(M)=ER(M)*HF(MF)/HF(M)
   GO TO 18
60 IF(KAA .LE. 2) 15,16,17
16 ER(M)=ER(MF)
   GO TO 18
17 ER(M)=ERP(M)*HF(MF)/HFP(M)
18 CALL HRF
   IF(IMP .LE. 0) GO TO 100
   IF(ABS(HF(MF)) .GT. 0.1) GO TO 79
   IF(ABS(HF(MF)/HF(MF)-1.00) .GT. 0.07) GO TO 91
79 IF(HHF .GT. 1.00) GO TO 100
19 IF(NN .GT. 10) GO TO 21
   HHF(4)=HHF(1)
   HHF(3)=HHF(2)
   HHF(2)=HHF(1)
   HHF(1)=HF(M)
   HER(4)=HER(1)
   HER(3)=HER(2)
   HER(2)=HER(1)
   HER(1)=ER(M)
   IF(NN .EQ. 4 .OR. NN .EQ. 8) GO TO 90
92 ER(M)=(HER(1)+(HER(1)-HER(2)) * (HF(MF)-HHF(1))/HHF(1)-HHF(2))
20 NN=NN+1
   GO TO 18
90 IF(HHF .GT. 1.00) GO TO 91
   IF(HHF .LT. 1.00) GO TO 97
91 ER(M)=(HER(2)+HER(1))/2.
   GO TO 20
92 IF(HHF .LT. 1.00) GO TO 93
   IF(HHF .GT. 1.00) GO TO 94
93 ER(M)=(HER(1)+(HER(1)-HER(3)) * (HF(MF)-HHF(1))/HHF(1)-HHF(3))
   GO TO 20
94 IF(HHF .LT. 1.00) GO TO 95
   IF(HHF .GT. 1.00) GO TO 96
95 IF(HHF .GT. 1.00) GO TO 97
   IF(HHF .LT. 1.00) GO TO 98
96 ER(M)=(HER(2)+HER(4)) * (HF(MF)-HHF(2))/HHF(2)-HHF(4))
21 IF(MAXP .GE. 2) GO TO 25
10 IF(NNN .GT. 3) GO TO 25
   DO 121 L=1,MS
      ER(L)=0.0
   DO 121 N=1,NC
ET(L,N) = 0.0
ED(L,N) = 0.0
P(L,N) = PP(L,N)

121 CONTINUE
MPF = MF
MF = M
DERN = ERP(M) * PDERN / ERP(MF)
NNN = NNN + 1
WRITE (2,70) M
IF (DERN .LT. ERT(MF) / 10.) GO TO 120
DERN = ERT / 10.
LD = 2
GO TO 120

9 IF (HF(MF)) 15, 15, 8
8 IF (ER(M)) 10, 10, 15
15 CONTINUE
IF (MF .EQ. 0.0) GO TO 30
IF (IN * EQ. 2) GO TO 30
GO TO 14

30 DO 201 IET = 1, 5
   DO 201 M = 1, MS
   IF (M - 1) 202, 202, 203
203 ET(M, 1) = (-SM(M, 1) - SA(M, 1) * ET(M, 2) - SL(M - 1, 1) * ET(M - 1, 1) - SU(M, 1) * ET(M 1 + 1, 1) + (CU(M, 1) + SU(M, 1)) * ER(M) + (CL(M - 1, 1) + SL(M - 1, 1)) * ER(M - 1)) / (CA(M 3, 1) + CL(M - 1, 1) + CU(M, 1))
   ET(M, N) = (-SM(M, N) * SA(M, N) * ET(M, N + 1) - SB(M, N - 1) * ET(M, N - 1) - SL(M - 1, N) * IET(M - 1, N) - SU(M, N - 1) * ET(M - 1, N - 1) + (CL(M - 1, N) + SL(M - 1, N)) * ER(M - 1) + (CU(M, N) + SU(M, N) * ER(M)) / (CA(M, N) + CB(M, N - 1) + CL(M - 1, N) + CU(M, N))
   GO TO 201
202 ET(1, 1) = (-SM(1, 1) - SA(1, 1) * ET(1, 2) - SU(1, 1) * ET(2, 1) + (CU(1, 1) + SU(1, 1) 1) * ER(1)) / (CA(1, 1) + CU(1, 1) + SU(1, 1) * ER(1))
   ET(1, N) = (-SM(1, N) - SA(1, N) * ET(1, N + 1) - SB(1, N - 1) * ET(1, N - 1) - SU(1, N) 1 N) * ET(1, N) + (CU(1, N) + SU(1, N)) * ER(1)) / (CA(1, N) + CB(1, N) + CU(1, N))
   IF (NB = 1) 201, 201, 204
204 DO 205 N = 2, NO
205 ET(1, N) = (-SM(1, N) - SB(1, N - 1) * ET(1, N - 1) - SA(1, N) * ET(1, N + 1) - SU(1, N) 1(N) * ET(1, N) + (CU(1, N) + SU(1, N)) * ER(1)) / (CA(1, N - 1) + CA(1, N) + CU(1, N))

201 CONTINUE
CALL ENMT
IF (ABS(PHF/HF(MF)) - 1.00) 0.05) 58, 58, 62
62 IF (ABS(HF(MF)) .GT. HFT/200.) GO TO 162
IF (ABS(HF(MF)) .GT. HFT/1000.) GO TO 163
GO TO 58
163 IF (ABS(PHF/HF(MF)) - 1.00) 0.5) 58, 162, 162
162 IF (NM = 1) 69, 25, 25
69 NM = NM + 1
PHF = HF(MF)
'MK = MK + 1
GO TO 2
25 WRITE (2, 26)
WRITE (2, 27) M, HF(M), ER(M)
GO TO 100
58 PHF = 0.0
IF (LO.EQ.2) GO TO 173
IF (ABS(HF(MF)) .LT. HFT/100.) GO TO 173
IF (HF(MF)) 83, 83, 94
83 MAXP=2
84 KPRD=0
CALL PRED
IF (ABS(DERN/TDER) .LE. 0.05) GO TO 173
IF (ABS(DERN/ERT(MF)) .LE. 0.005) GO TO 173
39 IF (NDER-5) 71, 72, 72
71 NDER=NDER+1
IF (LO.EQ.1) GO TO 76
ER(MF)=DERN
TDER=0.0
PDERN=DERN
GO TO 77
76 ER(MF)=ER(MF)+DERN
77 WRITE(2,56) NDER, TDER, DERN
GO TO 1
72 WRITE(2,35) NDER, TDER, DERN
GO TO 80
173 WRITE(2,73) NDER, TDER, DERN
80 NDER=1
IF (LR.EQ.1) GO TO 81
CALL HINRE
IF (NHR) 81, 81, 141
141 WRITE(2,43) II, NHR
IF (KM.GT.1) GO TO 142
MAXP=1
142 II=II+1
TDER=PDERN
ER(MF)=PDERN
NM=1
GO TO 2
81 HFT=HFT+HF(MF)
DELT=0.0
TOH=0.0
DO 82 M=1, MS
TOH=TOH+H(M)
ERT(M)=ERT(M)+ER(M)
DOH=ERT(M)/F
DEL=DOH*H(M)
DELT=DELT+DEL
MI=MT-M
WRITE(2,78) MI, HFT, ERT(M), DOH, DEL
82 CONTINUE
DELT=DELT/TOH
WRITE(2,178) HFT, DELT
IF (KM.GT.1) GO TO 54
IF (HF(MF)) 53, 165, 165
165 MAXP=1
GO TO 54
53 HMAX=HFTP
MAXP=2
KM=2
MI=MT-M
WRITE(2,55) MI, HMAX
54 IF (ABS(HMAX/HFT).GE.1.2) GO TO 100
DO 46 M=1, MS
CALL BEAM
IF(1M)100,100,47
47 CALL COL
IF(1M)100,100,46
46 CONTINUE
IF(LR.EQ.1) GO TO 119
DO 118 M=1,MS
DO 118 N=1,NC
DO 118 L=1,6
118
KHRCM,N,L)=0
IF(L.I.E.1) GO TO 399
DO 400 M=1,MS
DO 401 N=1,NC
L=KBP(M,N)-KR(M,N)
IF(L)401,401,402
402
K=KBP(M,N)
GO TO (401,401,403,403,404,404,405),K
403
PHRO(M,N,1)=0.0
GO TO 401
404
PHRO(M,N,2)=0.0
GO TO 401
405
GO TO (403,403,404,404,406,406),L
406
PHRO(M,N,1)=0.0
PHRO(M,N,2)=0.0
401 CONTINUE
DO 400 N=1,NC
L=KCP(M,N)-KC(M,N)
IF(L)400,400,408
408
K=KCP(M,N)
GO TO (400,400,409,400,410,400,411),K
409
PHRO(M,N,4)=0.0
GO TO 400
410
PHRO(M,N,5)=0.0
GO TO 400
411
GO TO (400,409,400,410,412,412),L
412
PHRO(M,N,4)=0.0
PHRO(M,N,5)=0.0
400 CONTINUE
399 II=1
119
KPRD=1
CALL PRED
DO 45 M=1,MS
ERP(M)=ER(M)
HFP(M)=HF(M)
ER(M)=0.0
DO 57 N=1,NC
BAP(M,N)=BA(M,N)
BBP(M,N)=BB(M,N)
BCP(M,N)=BC(M,N)
KBP(M,N)=KB(M,N)
57 CONTINUE
DO 45 N=1,NC
BUP(M,N)=BU(M,N)
BLP(M,N)=BL(M,N)
BMP(M,N)=BM(M,N)
CPP(M,N)=CP(M,N)
KCP(M,N)=KC(M,N)
ET(M,N)=0.0
PP(M,N)=P(M,N)
IF (LA .EQ. 1) GO TO 49
EDT(M,N)=EDTP(M,N)+ED(M,N)/E
EDTP(M,N)=EDT(M,N)
ED(M,N)=0.0
49 DO 45 L=1,5
PHRO(M,N,L)=PHRO(M,N,L)+HRO(M,N,L)
45 CONTINUE
WRITE(2,37)((P(M,N),N=1,NC),M=1,MS)
ER(MF)=DERN
PDERN=DERN
TDER=0.0
HFTP=HFT
KAA=KAA+1
MK=1
IF (LA .EQ. 1) GO TO 1
WRITE(2,38)((EDT(M,N),N=1,NC),M=1,MS)
GO TO 1
26 FORMAT(* PROBABLE DIVFERENCE OF HF*)
27 FORMAT(* M=*,I4,* HF(M)=*,F12.5,* ER(M)=*,F12.5)
35 FORMAT(* PRED DOES NOT CONVERGE WITHIN 5 CYCLES. NDER,TDER,DERN *
1=*,I4,2F15.5)
37 FORMAT(* AXLD*,8(1X,F8.2))
38 FORMAT(* ENDF*,8(1X,F8.3))
43 FORMAT(* HINGE REVERSAL OCCURRED II=*,I3,* NHR=*,I3)
55 FORMAT(* FAILURE AT STORY *,I3,* HMAX=*,F12.5)
56 FORMAT(* NDER,TDER,DERN=*,I4,2F10.4)
70 FORMAT(* PROBABLE FAILURE AT M=*,I4)
73 FORMAT(* PRED CONV NDER, TDER,DERN=*,I4,2F15.5)
103 FORMAT(* M,HF,ER *,I3,3X,2F11.4)
178 FORMAT(* FOR PLOTTING LATERAL LOAD=*,F12.5,* DEFLECTION INDE *
1X OF FRAME=*,F12.5)
100 CALL EXIT
END
SUBROUTINE BEGIN

COMMON/BLOCKA/E,FY,FI(30,3),BP(30,3),FI(30,3),EI(30,4),CZ(30,3),AR
1(30,4),PC(30,4),ET(31,4),PZ(4),KB(30,3),KM(30,3),BB(30,3),BC(30,3)
2,BAP(30,3),BP(30,3),BP(30,3),FB(30,3),FB(30,3),BAP(30,3),BAP(30,3),BAP
3(30,3),DI(30,3),CA(30,3),SA(30,3),CE(30,3),SB(30,3),KC(30,4),RU(30,
4),A(30,4),BU(30,4),BU(30,4),BU(30,4),BU(30,4),BU(30,4),BU(30,4)
50,4),BMI(30,4),FBU(30,4),FL(30,4),CP(30,4),CP(30,4),CP(30,4),CU(30,4)
6(630,4),CL(30,4),SL(30,4),CC(30,4),CS(30,4),CX(30,4),SX(30,4),CY(30,
74),SY(30,4),SM(30,4),SH(30),X(30,3),Y(30,3),X(30,4),Y(30,4),P(30
8,4),PP(30,4),PI(30,4),ED(30,4),EDT(30,4),EDT(30,4),HF(30),HFP(30
9,HFT,PHF,HAMAX,ER(30),ERP(30),ERT(30),IM,KAA,KM,MAXF,MAF,MS,MT,MB,
1,MC,N,DERNM,LO,FRC,NHR,GA,LR,RP(30,3),D(30,4),H(30),WH(30),FL(30,3)
2S(3),R(30,4),HYR(30,4),HYR(30,4),HYR(30,4),HYR(30,4),KPRD,GLF,TGLF,
3FAC,SM,KB(30,3),KCP(30,4)
READ (1,1) MS,NB,E,FY,FR,FA,FL
WRITE(2,2) MS,NB,E,FY,FR,FA,FL
NC=NB+1
MT=MS+1
READ (1,3) (SN,N=1,NB)
WRITE(2,4) (SN,N=1,NB)
READ (1,6) (MM,WMM,M=1,MS)
READ (1,5) ((BM,N),BN=M+1,MB,MM,M=1,MS)
READ (1,5) ((FM,N),FN=M+1,MB,MM,M=1,MS)
READ (1,6) ((CM,N),CN=M+1,MB,MM,M=1,MS)
READ (1,6) ((DM,N),DN=M+1,MB,MM,M=1,MS)
DO 7 M=1,MS
WRITE(2,6) M,H(M),WH(M),FL(M)
WRITE(2,9) (BM,N),BN=M+1,MB,MM,M=1,MS
WRITE(2,9) (WM,N),WN=M+1,MB,MM,M=1,MS
WRITE(2,10) (CM,N),CN=M+1,MB,MM,M=1,MS
WRITE(2,10) (DM,N),DN=M+1,MB,MM,M=1,MS
WRITE(2,10) (CM,N),CN=M+1,MB,MM,M=1,MS
DO 7 CONTINUE
DO 12 N=1,NC
ET(M,N)=0.0
7 CONTINUE
DO 12 N=1,NC
ET(M,N)=0.0
12 PZ(N)=0.0
MF=MS
PHF=0.0
HFT=0.0
HAMAX=0.0
DO 14 M=1,MS
14 CONTINUE
DO 15 N=1,MB
BP(M,N)=FY*BZ(M,N)
BAP(M,N)=0.0
BBP(M,N)=0.0
BCP(M,N)=0.0
X(M,N)=0.0
Y(M,N)=0.0
KBP(M,N)=1
15 KB(M,N)=1
DO 16 N=1,NC
CP(M,N)=FY*CZ(M,N)
BUP(M,N)=0.0
BLP(M,N)=0.0
BMP(M,N)=0.0
16 CONTINUE
BM(M,N) = 0.0
KC(P(M,N) = 1
KC(P(M,N) = 1
XC(P(M,N) = 0.0
YC(P(M,N) = 0.0
PP(P(M,N) = 0.0
ET(E(P(M,N) = 0.0
ED(E(P(M,N) = 0.0
EDT(E(P(M,N) = 0.0
EDTP(E(P(M,N) = 0.0
CPP(C(P(M,N) = 0.0
DO 16 L = 1, 6
KH(R(M,N,L) = 0
HR0(M,N,L) = 0.0
PHR0(M,N,L) = 0.0
16 CONTINUE
ER(P(M) = 0.0
ERP(E(P(M) = 0.0
ERT(E(R(M) = 0.0
HFP(F(P(M) = 0.0
P(P(M,1) = PZ(1) + GLF*PC(M,1) + GLF*FL(M,1)*S(1)/2.0
PZ(1) = P(M,1)
P(P(M,NC) = PZ(NC) + GLF*PC(M,NC) + GLF*FL(M,NB)*S(NB)/2.0
PZ(NC) = P(M,NC)
IF(NB-1)14, 14, 18
18 DO 17 N = 2, NB
P(P(M,N) = PZ(N) + GLF*PC(M,N) + GLF*(FL(M,N)*S(N) + FL(M,N-1)*S(N-1))/2.0
17 PZ(N) = P(M,N)
14 CONTINUE
CALL GRALD
IF(IM.LE.0) GO TO 100
KAA=2
GLF=0.0
TGLF=FAC
1 FORMAT(2I5, 5F10.3)
3 FORMAT(4F10.5)
4 FORMAT(* S(N)=*, 4F10.4)
5 FORMAT((6F10.5))
6 FORMAT((8F10.5))
8 FORMAT(M=*, I3, 3X, 5F10.5)
9 FORMAT(10X, 3(F10.5, 2X))
10 FORMAT(4X, 4(F10.5, 2X))
100 RETURN
END
SUPROUTINE GRALD
COMM/BLOCK/E,F,Y,I,BI(30,3),BZ(30,3),PB(30,3),CI(30,4),CZ(30,4),AR(30,4),
P(30,4),ET(31,4),PB(30,3),K8(30,3),BA(30,3),BB(30,3),BC(30,3),
2.,BB(30,3),BBP(30,3),BGP(30,3),FBA(30,3),E8B(30,3),BAI(30,3),B8I(30,3),BCI(30,3),SA(30,3),GB(30,3),SB(30,3),
KC(30,4),BU(30,4),BL(30,4),BM(30,4),BUP(30,4),BLP(30,4),BMI(30,4),BLC(30,4),
CB(30,4),CA(30,3),SM(30,4),SH(30),X(30,3),Y(30,3),Xc(30,4),Yc(30,4),P(30,4),
PP(30,4),PI(30,4),ED(30,4),EDT(30,4),EDTP(30,4),HF(30),HFP(30),
9,HFT,PHF,HMAX,ER(30),ER(30),ERT(30),IM,KAA,KM,MXP,MF,MS,Mt,NB,NC
1,M,NDN,LD,FR3,NHR,LA,LR,BP(30,3),D(30,4),H(30),WH(30),FL(30,3),
2S(3),RY(30,4),HRO(30,4,6),PHRO(30,4,6),KHR(30,4,6),KPRD,GLF,TGLF,
3FAC,SM,KB(30,3),KCP(30,4)
TGLF=0.0
1 TGLF=TGLF+GLF
WRITE(2,30)TGLF,GLF
DO 103 KSW=1,3
DO 2 M=1,MS
SH(M)=0.0
DO 2 N=1,NC
SM(M,N)=0.0
2 CONTINUE
CALL CSSCE
IF(IM.LE.0) GO TO 101
DO 3 IET=1,5
DO 3 I=1,MS
M=MS-I+1
CALL HOFR
IF(IM.LE.0) GO TO 101
3 CONTINUE
CALL FNM7
103 CONTINUE
CALL HINRE
DO 5 M=1,MS
CALL BEM
IF(IM)100,100,26
26 CALL COL
IF(IM)100,100,5
5 CONTINUE
IF(TGLF.LT.(FAC-0.05)) GO TO 15
DO 39 M=1,MS
DO 40 N=1,NC
L=KB(M,N)-KBP(M,N)
IF(L)40,40,41
41 GO TO (40,42,40,43,40,44),L
42 PHRO(M,N,1)=0.001*BA(M,N)/ABS(BA(M,N))
GO TO 40
43 PHRO(M,N,2)=0.001*BB(M,N)/ABS(BB(M,N))
GO TO 40
44 PHRO(M,N,1)=0.001*BA(M,N)/ABS(BA(M,N))
PHRO(M,N,2)=0.001*BB(M,N)/ABS(BB(M,N))
40 CONTINUE
DO 39 N=1,NC
L=KB(M,N)-KCP(M,N)
IF(L)39,39,45
45 GO TO (39,46,39,47,39,48),L
46 PHRO(M,N,4)=0.001*BL(M,N)/ABS(BL(M,N))  
GO TO 39
47 PHRO(M,N,5)=0.001*BU(M,N)/ABS(BU(M,N))  
GO TO 39
48 PHRO(M,N,4)=0.001*BL(M,N)/ABS(BL(M,N))  
PHRO(M,N,5)=0.001*BU(M,N)/ABS(BU(M,N))
39 CONTINUE
15 DO 17 M=1,MS
    DO 16 N=1,NS
    BAP(M,N)=BA(M,N)
    BBP(M,N)=BR(M,N)
    BCP(M,N)=BC(M,N)
    KBP(M,N)=KB(M,N)
16 CONTINUE
17 DO 17 N=1,NC
    BUP(M,N)=BU(M,N)
    BLP(M,N)=BL(M,N)
    BNP(M,N)=BN(M,N)
    CPP(M,N)=CP(M,N)
    KCP(M,N)=KC(M,N)
    PP(M,N)=P(M,N)
    ET(M,N)=0.0
    ER(M)=0.0
    IF(LA .EQ. 1) GO TO 18
    EDT(M,N)=EDTP(M,N)+ED(M,N)/E
    EDTP(M,N)=EDT(M,N)
    ED(M,N)=0.0
18 DO 17 L=1,6
    PHRO(M,N,L)=PHRO(M,N,L)+HRO(M,N,L)
17 CONTINUE
    WRITE(2,20) ((P(M,N),N=1,NC),M=1,MS)
    IF(LA .EQ. 1) GO TO 19
    WRITE(2,21) ((EDT(M,N),N=1,NC),M=1,MS)
19 IF(TGLF.GT.(FAC-0.05)) GO TO 100
    GLF=0.1
    GO TO 1
100 DERN=0.06*E/H(MF)
    LD=2
101 RETURN
20 FORMAT(*)     AXLD*,12(1X,F8.2))
21 FORMAT(*)     ENDF*,12(1X,F8.3))
30 FORMAT(*)     TOTAL GRAVITY LOAD FACTOR=*,F10.3,*  INCREMNTAL LOAD
               1FACTOR=*,F10.3)
END
SUBROUTINE CSCOE
COMMON/BLCKA/F,FY,BI(30,3),AZ(30,3),PB(30,3),CI(30,4),CZ(30,4),AR
1(30,4),PC(30,4),ET(31,4),PZ(4),KB(30,3),BA(30,3),BB(30,3),BC(30,3)
2,BAP(30,3),BBP(30,3),BCP(30,3),FBA(30,3),FBB(30,3),BAI(30,3),BBI(3
30,3),BCI(30,3),CA(30,3),SA(30,3),CB(30,3),SB(30,3),KC(30,4),BU(30,
4),BL(30,4),BM(30,4),BUP(30,4),BPL(30,4),BMP(30,4),BUI(30,4),BLI(3
50,4),BHI(30,4),FBU(30,4),FL(30,4),CP(30,4),CPP(30,4),CU(30,4),SU(3
630,4),CL(30,4),SL(30,4),CC(30,4),CS(30,4),CX(30,4),SX(30,4),CY(30,
74),SY(30,4),SM(30,4),SH(30),X(30,3),Y(30,3),XC(30,4),YC(30,4),P(30
8,4),PP(30,4),PI(30,4),ED(30,4),ENT(30,4),EDP(30,4),HF(30),HFP(30)
9,HFT,PHF,HMAX,ER(30),ERP(30),ERT(30),IM,KAA,KM,MAXP,IF,MS,MT,NC
1,M,N,DERN,LD,FR,NGR,LA,LR,BP(30,3),D(30,4),H(30),WH(30),FL(30,3),
2S(3),RY(30,4),HR0(30,4,6),PHR0(30,4,6),KHR(30,4,6),KPRD,GLF,TGF,
3FAC,SM,AKD3(30,3),KCP(30,4)
DIMENSION Z(2)
DO 1 M=1,MS
DO 2 N=1,NB
IF(LA.GT.1) GO TO 8
FED=U.0
TOE=0.0
GO TO 9
8 FED=-(ED(M,N+1)-ED(M,N))
TOE=6.*FED*BI(M,N)/S(N)/S(N)
9 CA(M,N)=0.0
SA(M,N)=0.0
CB(M,N)=0.0
SB(M,N)=0.0
FBA(M,N)=0.0
FBB(M,N)=0.0
FM=GLF*FL(M,N)*S(N)*S(N)/12.
K=KB(M,N)
GO TO (3,4,5,10,7,11,2,100),K
3 CA(M,N)=4.0*BI(M,N)/S(N)
SA(M,N)=CA(M,N)/2.
CB(M,N)=CA(M,N)
SB(M,N)=SA(M,N)
FBA(M,N)=TOE-FM
FBB(M,N)=TOE+FM
SM(M,N)=SM(M,N)+FBB(M,N)
SM(M,N+1)=SM(M,N+1)+F88(M,N)
GO TO 2
4 XY=X(M,N)**3+Y(M,N)**3
CA(M,N)=3.0*BI(M,N)*X(M,N)**2/XY
SA(M,N)=3.0*BI(M,N)*X(M,N)/XY
CB(M,N)=3.0*BI(M,N)*Y(M,N)**2/XY
SB(M,N)=SA(M,N)
TO=3.0*SN/SXY
TT=GLF*FL(M,N)*X(M,N)*(Y(M,N)**3+TO+X(M,N))/8.
TTH=GLF*FL(M,N)*Y(M,N)*(X(M,N)**3+TO+Y(M,N))/8.
FBA(M,N)=SA(M,N)*TED/Y(M,N)-TT
FBB(M,N)=SA(M,N)*TED/X(M,N)+TTH
SM(M,N)=SM(M,N)+FBA(M,N)
SM(M,N+1)=SM(M,N+1)+FBB(M,N)
GO TO 2
5 CB(M,N)=3.0*BI(M,N)/S(N)
FBB(M,N)=TOE/2.0+FM*1.5
SM(M,N+1)=SM(M,N+1)+FBB(M,N)
GO TO 2
10 FBB(M,N) = GLF*FL(M)*S(N)*Y(M,N)/2.
   SM(M,N+1) = SM(M,N+1) + FBB(M,N)
   GO TO 2
7 CA(M,N) = 3.0*B1(M,N)/S(N)
   FBA(M,N) = T0E/2.0 - FM*1.5
   SM(M,N) = SM(M,N) + FBA(M,N)
   GO TO 2
11 FBA(M,N) = -GLF*FL(M)*S(N)*X(M,N)/2.
   SM(M,N) = SM(M,N) + FBA(M,N)
2 CONTINUE
   DO N = 1, NC
      POPY = P(M,N)/FY/AR(M,N)
      IF (POPY = 1.0) 14, 14, 15
14 RY(M,N) = 1.0
      GO TO 16
15 IF (1.0 - POPY) 16, 16, 17
16 WRITE (2,116) M,N,POPY
   RY(M,N) = 0.1
      GO TO 16
17 RY(M,N) = SQRT((1.0 - POPY)/FRC)
16 IF (P(M,N)) 32, 32, 30
30 TON = P(M,N)/(E*CI(M,N)*RY(M,N))
   PHI = H(M)/SQRT(TON)
   SMS = (PHI/SIN(PHI) - 1.0)/PHI**2
   SMC = (1.0 - PHI*COS(PHI)/SIN(PHI))/PHI**2
   DSQ = (SMC*SMC - SMS*SMS)/H(M)/CI(M,N)/RY(M,N)
   CC(M,N) = SMC/DSQ
   CS(M,N) = SMS/DSQ
      GO TO 132
32 CC(M,N) = 4.0
   CS(M,N) = 2.0
132 IF (POPY = 0.15) 12, 12, 13
12 CP(M,N) = FY*CZ(M,N)
      GO TO 17
13 IF (POPY = 1.0) 24, 24, 25
24 CP(M,N) = 1.18*(1.0 - POPY)*FY*CZ(M,N)
      GO TO 17
25 WRITE (2,26) M,N,POPY
   CP(M,N) = 0.0
17 RCP = CP(M,N) - CPP(M,N)
   CU(M,N) = 0.0
   SU(M,N) = 0.0
   CL(M,N) = 0.0
   SL(M,N) = 0.0
   FBU(M,N) = 0.0
   FBL(M,N) = 0.0
   RAT = CS(M,N)/CC(M,N)
   K = KC(M,N)
      GO TO (18,22,19,100,20,100,21), K
18 CU(M,N) = CC(M,N)
   CL(M,N) = CC(M,N)
   SU(M,N) = CS(M,N)
   SL(M,N) = CS(M,N)
      GO TO 1
22 Z(1) = XC(M,N)
   Z(2) = YC(M,N)
   DO 23 L = 1, 2
23 IF (P(M,N)) 23, 23, 33
33 PHI=Z(L)*SQRT(P(M,N)/(E*CI(M,N)*RY(M,N)))
SMC=(1.0-PHI*COS(PHI)/SIN(PHI))/PHI**2
SMS=(PHI/SIN(PHI)-1.0)/PHI**2
DSQ=(SMC*SMC-SMS*SMS)*Z(L)/CI(M,N)/RY(M,N)
IF(LE.1)GO TO 27
CY(M,N)=SMC/DSQ
SY(M,N)=SMS/DSQ
GO TO 23
27 CX(M,N)=SMC/DSQ
SX(M,N)=SMS/DSQ
23 CONTINUE
OK=(CX(M,N)*CX(M,N)-SX(M,N)*SX(M,N))/CY(M,N)
TK=(SY(M,N)*SY(M,N)-CX(M,N)*CY(M,N))/CY(M,N)
THK=OK*YC(M,N)/XC(M,N)+TK*XC(M,N)/YC(M,N)-PI(M,N)*H(M)/E
CL(M,N)=OK-OK*OK*YC(M,N)/THK/XC(M,N)
SL(M,N)=OK*TK/THK
CC(M,N)=OK*H(M)*(PI(M,N)/E-TK/YC(M,N))/THK
SK=SY(M,N)*YC(M,N)/CX(M,N)+SY(M,N)*XC(M,N)/CY(M,N)+H(M)
AM=RCP*BM(M,N)/ABS(BM(M,N))
FBL(M,N)=(OK*SK/THK/XC(M,N)-SX(M,N)/CX(M,N))*AM
CU(M,N)=TK-TK*TK*XC(M,N)/THK/YC(M,N)
SU(M,N)=OK*TK/THK
CS(M,N)=TK*H(M)*(XC(M,N)*(TK/YC(M,N)-PI(M,N)/E)/THK-1.)/YC(M,N)
FBU(M,N)=(SY(M,N)/CY(M,N)-TK*TK/XC(M,N)/THK/YC(M,N))*AM
SH(M)=SH(M)+FBL(M,N)+FBU(M,N)
SM(M,N)=SM(M,N)+FBU(M,N)
SM(M+1,N)=SM(M+1,N)+FBL(M,N)
BM(M,N)=CP(M,N)*BM(M,N)/ABS(BM(M,N))
GO TO 1
19 BL(M,N)=CP(M,N)*BL(M,N)/ABS(BL(M,N))
CU(M,N)=(CC(M,N)**2-CS(M,N)**2)/CC(M,N)
AL=RCP*BL(M,N)/ABS(BL(M,N))
SH(M)=SH(M)+(1.0+RAT)*AL
SM(M,N)=SM(M,N)+RAT*AL
SM(M+1,N)=SM(M+1,N)+AL
FBU(M,N)=AL*RAT
GO TO 1
20 BU(M,N)=CP(M,N)*BU(M,N)/ABS(BU(M,N))
CL(M,N)=(CC(M,N)**2-CS(M,N)**2)/CC(M,N)
AT=RCP*BU(M,N)/ABS(BU(M,N))
SH(M)=SH(M)+(1.0+RAT)*AT
SM(M,N)=SM(M,N)+AT
SM(M+1,N)=SM(M+1,N)+RAT*AT
FBL(M,N)=AT*RAT
GO TO 1
21 BU(M,N)=CP(M,N)*BU(M,N)/ABS(BU(M,N))
BL(M,N)=CP(M,N)*BL(M,N)/ABS(BL(M,N))
SH(M)=SH(M)+RCP*BU(M,N)/ABS(BU(M,N))+RCP*BL(M,N)/ABS(BL(M,N))
SM(M,N)=SM(M,N)+RCP*BU(M,N)/ABS(BU(M,N))
SM(M+1,N)=SM(M+1,N)+RCP*BL(M,N)/ABS(BL(M,N))
1 CONTINUE
RETURN
100 IM=0
102 RETURN
26 FORMAT(* M,N,POPY*,2I5,F15.7)
101 FORMAT(* IMP COMB OF KB OR KC M,N,K*,3I4)
118 FORMAT(* POPY GT 1 M=*,I4,* N=*,I4,* P(M,N)=*,F10.4,* POPY
1=*,F10.4)
END
SUBROUTINE HORF

COMMON/8LOCKA/FA, FY, BI(30,3), BZ(30,3), PR(30,3), CI(30,4), CZ(30,4), AR
1(30,4), PC(30,4), ET(31,4), PZ(4), KB(30,3), BA(30,3), BR(30,3), BC(30,2)
2, EAP(30,3), EBP(30,4), CPC(30,4), F9A(30,3), FB3(30,3), BAI(30,3), BPI(3
30,3), BCI(30,3), CA(30,4), SA(30,3), CB(30,3), SB(30,3), K C ( 3 0 ) , B U ( 3 0 ,
44), BL(30,4), BM(30,4), D U P ( 3 0 , 4 ) , B L P ( 3 0 , 4 ) , B L M ( 3 0 , 4 ) , B U I ( 3 0 , 4 ) , R L I ( 3
50,4), A M I ( 3 0 , 4 ) , F P U ( 3 0 , 4 ) , F B L ( 3 0 , 4 ) , C P ( 3 0 , 4 ) , C P P ( 3 0 , 4 ) , C U ( 3 0 , 4 ) , S U ( 6 3 0 ,4)
CL(30,4), SL(30,4), CC(30,4), CS(30,4), CX(30,4), SX(30,4), CY(30,4), S Y ( 3 0 ,
74), SY(30,4), SM(30,4), SH(30), X(30,3), Y(30,3), XC(30,4), YC(30,4), P(30
8,4), PP(30,4), PI(30,4), ED(30,4), EDT(30,4), EDTP(30,4), HF(30), HFP(30)
9, HFT, PHF, HMAX, ER(30), ERP(30), ERT(30), IM, KAA, KM, MAXP, MF, MS, MT, NB,
NC 1, M, N, DERN, LD, FRG, NHR, LA, LR, BP(30,3), D(30,4), H(30), M, FL(30,3),
23(S), RY(30,4), HRO(30,4,6), PHRO(30,4,6), KHR(30,4,6), KPRD, GLF, TGLF,
3, FAC, SMA, KGP(30,3), KCP(30,4)

v DO 40 KET=1.5

v 9 DN=CA(M,1)+CL(M-1,1)+CU(M,1)

IF (DN .EQ. 0.00) GO TO 100

ET(M,1)=(-SM(M,1)-SA(M,1)*ET(M,2)-SL(M-1,1)*ET(M-1,1)-SU(M,1)*ET(M
1+1,1)+CU(M,1)+SU(M,1)*ER(M)+CL(M-1,1)+SL(M-1,1))*ET(M-1,1)/DN

11 DN=CB(M,NB)+CL(M-1,NC)+CU(M,NC)

IF (DN .EQ. 0.00) GO TO 100

ET(M,NC)=(-SM(M,NC)-SB(M,NC)*ET(M,NB)-SL(M-1,NC)*ET(M-1,NC)-SU(M,NC
1)+CT(M+1,NC)+(CU(M,NC)+SU(M,NC))*ER(M)+(CL(M-1,NC)+SL(M-1,NC))*ER
2(M-1))/DN

13 IF (NB-1) 40, 40, 16

16 DO 14 N=2, NC

DN=CA(M,N)+CB(M,N-1)+CL(M,N)+CU(M,N)

IF (DN .EQ. 0.00) GO TO 100

ET(M,N)=(-SM(M,N)-SA(M,N)*ET(M,N+1)-SB(M,N-1)*ET(M,N-1)-SL(M-1,N)*
1ET(M-1,N)-SU(M,N)*ET(M,N-1)+(CL(M,N)+SL(M-1,N))*ER(M-1)+(CU(M,N)
2+SU(M,N))*ER(M))/DN

14 CONTINUE

GO TO 40

1 DN=CA(1,1)+CU(1,1)

IF (DN .EQ. 0.00) GO TO 100

ET(1,1)=(-SM(1,1)-SA(1,1)*ET(1,2)-SU(1,1)*ET(2,1)+(CU(1,1)+SU(1,1)
1)*ER(1))/DN

3 DN=CB(1,NB)+CU(1,NC)

IF (DN .EQ. 0.00) GO TO 100

ET(1,NC)=(-SM(1,NC)-SB(1,NC)*ET(1,1)+CB(1,NB)-SU(1,NC)*ET(1,NC)+
1SU(1,NC))*ER(1))/DN

5 IF (NB-1) 40, 40, 8

8 DO 5 N=2, NB

DN=CB(1,N-1)+CA(1,N)+CU(1,NC)

IF (DN .EQ. 0.00) GO TO 100

ET(1,N)=(-SM(1,N)-SB(1,N-1)*ET(1,N-1)-SA(1,N)*ET(1,N-1)+SU(1,N)*ET
1(2,N)+(CU(1,N)+SU(1,N))*ER(1))/DN

6 CONTINUE

40 CONTINUE

IF (KAA .LE. 1) GO TO 21

FN=0.0

DO 20 I=1, M

20 FN=FN+WH(I)

PT=0.0

SSCT=SH(M)

DO 17 N=1, NC
PT = PT + P(M, N)  
SSCT = (CU(M, N) + SL(M, N)) * ET(M, N) + (SU(M, N) + CL(M, N)) * ET(M+1, N) - (CU(M, N) + SU(M, N) + CL(M, N) + SL(M, N)) * ER(M) + SSCT

17 CONTINUE
HF(M) = -(SSCT + PT * H(M) * ER(M) / E) / FN / H(M)
RETURN

100 WRITE(2, 101) M, N
101 FORMAT(* IMPRO HINGE COMB (JOINT MECH)*, 2I3)
IM = 0
21 RETURN
END
SUBROUTINE ENMT
COMM: COMMON/LOCKA/E,FY,BI(30,3),BZ(30,3),PR(30,3),CI(30,4),CZ(30,4),AR
(30,4),PC(30,4),ET(30,4),PZ(4),KB(30,3),BA(30,3),BB(30,3),BC(30,3)
2,BAF(30,3),BAE(30,3),CJP(30,3),FBA(30,3),FBR(30,3),BA(30,3),BAI(30,3)
30,3),BCI(30,3),CA(30,3),SA(30,3),CB(30,3),SB(30,3),KC(30,4),BU(30,
44),RL(30,4),RH(30,4),BUP(30,4),ALP(30,4),BMP(30,4),RUI(30,4),BLI(3
90,4),BMI(30,4),FBU(30,4),FBL(30,4),CP(30,4),CPP(30,4),CU(30,4),SU(6
30,4),CL(30,4),SL(30,4),CC(30,4),CS(30,4),CX(30,4),SX(30,4),CY(30,
74),SY(30,4),SM(30,4),SH(30),X(30,3),Y(30,3),XC(30,4),YC(30,4),P(30
8,4),PP(30,4),PL(30,4),ED(30,4),EDT(30,4),EDTP(30,4),HF(30),HFP(30)
9,HFT,PHF,AMAX,ER(30),ERP(30),ERT(30),IM,KA,AA,AMAX,FH,MS,MT,MB,NC
1,NN,DEN,LD,FRC,NHR,LA,LR,BP(30,3),D(30,4),H(30),WH(30),FL(30,3),S
2(3),RY(30,4),HR(30,4,6),PHR(30,4,6),MRH(30,4,6),KPRD,GLF,TGLF,
3FAC,SMF,KB(30,3),KCP(30,4)
DO 4 M=1,NS
DO 2 N=1,NR
BAI(M,N)=FB(A(M,N)+CA(M,N)*ET(M,N)+SA(M,N)*ET(M,N+1)
BBI(M,N)=FB(A(M,N)+CB(M,N)*ET(M,N+1)+SB(M,N)*ET(M,N)
BCI(M,N)=0.0
BA(M,N)=BAP(M,N)+BAI(M,N)
BB(M,N)=BBP(M,N)+BBI(M,N)
K=KB(M,N)
GO TO (27,2,27,2,27,2,15,100),K
27 SBM=-(BA(M,N)+9Q(M,N)
X(M,N)=S(N)/2.0+SBM*(TGLF*FL(M,N)*S(N)
IF(X(M,N)-O(M,N)/2.)21,21,22
21 X(M,N)=0.0
BC(M,N)=0.0
GO TO 25
22 Y(M,N)=S(N)-X(M,N)
IF(Y(M,N)-O(M,N)/2.)23,23,24
23 X(M,N)=S(N)
BC(M,N)=0.0
GO TO 25
24 BC(M,N)=FL(M,N)*TGLF*Y(M,N)*X(M,N)/2.0+BA(M,N)+SBM*X(M,N)S(N)
25 BCI(M,N)=RC(M,N)-BCP(M,N)
GO TO 2
15 IF(KAA .GT. 1) GO TO 2
GO TO 27
2 CONTINUE
DO 4 M=1,NC
BUI(M,N)=0.0
BLI(M,N)=0.0
BMI(M,N)=0.0
K=KC(M,N)
GO TO (5,4,5,4,5,4),K
5 BUI(M,N)=CU(M,N)*ET(M,N)+SU(M,N)*ET(M+1,N)-(CU(M,N)+SU(M,N))*ER(M)
1+FBU(M,N)
BLI(M,N)=CL(M,N)*ET(M+1,N)+SL(M,N)*ET(M,N)-(CL(M,N)+SL(M,N))*ER(M)
1+FBL(M,N)
BU(M,N)=BUP(M,N)+BUI(M,N)
BL(M,N)=BLP(M,N)+BLI(M,N)
IF (K.GT.1) GO TO 4
IF (KAA .EQ.1) GO TO 4
RAT=ABS(BL(M,N))/ABS(BU(M,N))ABS(BU(M,N))/BL(M,N)
IF(RAT.GE.0.0) GO TO 4
IF(AABS(BL(M,N)-ABS(BU(M,N)))41,41,42
41 AM = ABS(BU(M,N))
BN = ABS(BL(M,N)) * RAT
I = -1
GO TO 43
42 AM = ABS(BL(M,N))
BN = ABS(BU(M,N)) * RAT
I = 1
43 PHI = H(M) * SQRT(P(M,N)/(E*C1(M,N) * RY(M,N)))
ZK = ATAN(-(BN + AM * COS(PHI))/AM / SIN(PHI))
IF (ZK) 44, 44, 45
44 XC(M,N) = 0.0
YC(M,N) = 0.0
BM(M,N) = 0.0
GO TO 49
45 BMX = SQRT((AM*AM + BN*BN + 2*AM*BN*COS(PHI))/SIN(PHI))
XZ = ZK/SQRT(P(M,N)/(E*C1(M,N) * RY(M,N)))
IF (I) 46, 45, 47
46 XC(M,N) = H(M) - XZ
GO TO 48
47 XC(M,N) = XZ
48 BM(M,N) = BMX * BL(M,N) / ABS(BL(M,N))
YC(M,N) = H(M) - XC(M,N)
49 BMX(M,N) = BM(M,N) - BM(M,N)
GO TO 4
40 BU(M,N) = CU(M,N) * ET(M,N) + SU(M,N) * ET(M+1,N) + CS(M,N) * ER(M) + F3U(M,N)
BLI(M,N) = CL(M,N) * ET(M,N) + SL(M,N) * ET(M,N) + CC(M,N) * ER(M) + FBL(M,N)
BU(M,N) = BUP(M,N) + BUI(M,N)
BL(M,N) = BLP(M,N) + BLI(M,N)
CONTINUE
DO 6 N = 1, NC
6 PZ(N) = 0.0
DO 7 M = 1, MS
PM(1) = PZ(1) + TGLF*PC(1,1) + TGLF*FL(1,1)*S(1)/2 - (BA(1,1) + BB(1,1))/S(1)
PM(1) = PZ(1) + TGLF*PC(1,1) + TGLF*FL(M,N)*S(N)/2 + (BA(M,N) + BB(M,N))/S(N)
PZ(NC) = PZ(N) + TGLF*PC(M,N) + TGLF*FL(M,N)*S(N)/2 + (BA(M,N) + BB(M,N))/S(N)
IF (NB-1.J) 7, 7, 8
8 DO 9 N = 2, NR
PM(N) = PZ(N) + TGLF*PC(M,N) + TGLF*FL(M,N)*S(N) + FL(M,N-1)*S(N-1)/2 - 1(BA(M,N) + BB(M,N))/S(N) - (BA(M,N-1) + BB(M,N-1))/S(N-1)
9 PZ(N) = PM(N)
7 CONTINUE
DO 30 M = 1, MS
DO 30 N = 1, NC
30 PI(M,N) = P(M,N) - PP(M,N)
IF (LA.EQ.1) GO TO 100
DO 31 M = 1, MS
DO 31 N = 1, NC
MI = MS
EDI = PI(MI,N)*H(MI)/AR(MI,N)
32 MI = MI-1
IF (MI-M) 33, 34, 34
34 EDI = EDI + PI(MI,N)*H(MI)/AR(MI,N)
GO TO 32
33 ED(M,N) = EDI
31 CONTINUE
100 RETURN
END
SUBROUTINE PRED
COMMON /BLOCKA/F,FY,B(L(30,3),N(30,3),PP(30,3),CI(30,4),CZ(30,4),AR
1(30,4),PC(30,4),ET(31,4),P7(4),KB(30,3),BA(30,3),BB(30,3),BC(30,3)
2,PA(30,3),BPP(30,3),BCP(30,3),FBA(30,3),FBP(30,3),R(30,3),RAI(30,3),ABRI(3
30,3),BCI(30,3),CA(30,3),SA(30,3),CB(30,3),SB(30,3),KC(30,4),BU(30,
44),BL(30,4),BM(30,4),BUP(30,4),BLP(30,4),RMP(30,4),BUI(30,4),BLI(3
50,4),BML(30,4),FBU(30,4),FBL(30,4),CP(30,4),CPP(30,4),CU(30,4),SU(6
30,4),CL(30,4),SL(30,4),CC(30,4),CS(30,4),CX(30,4),SX(30,4),CY(30,
74),SY(30,4),SM(30,4),SH(30),X(30,3),Y(30,3),X(30,4),Y(30,4),P(30
44),PP(30,4),PI(30,4),ED(30,4),EDT(30,4),EDTP(30,4),H(30),HFP(30)
9,HFT,PHF,HMAX,ER(30),ERP(30),ET(30),IM,KAA,KM,MAXP,MF,MS,MT,NB,NC
1,M,ND,DERN,LD,FRC,NHR,LR,RP(30,3),D(30,4),H(30),WH(30),FL(30,3),
2S(3),RY(30,4),HR(30,4),PH(30,4),PHRO(30,4),KH(30,4),KPRD,SLF,TGLF,
3FAC,SMK,KBP(30,3),KCP(30,4)
DIMENSION PRE(30,4,6),SMAL(30),NS(30),LC(30,6)
LD=1
DO 4 M=1,MS
IF (MAXP-2) 6,5,5
5 M=MF
6 DO 1 N=1,NC
DO 1 L=1,6
IF (HF(MF)) 3,2,2
2 TA=HFT*100.
GO TO 57
3 TA=-HFT*100.
57 PRE(N,N,L)=TA
1 CONTINUE
DO 7 N=1,NB
K=KB(M,N)
GO TO (8,8,12,8,12,12,12),K
8 IF (ABS(BAI(M,N)) .LT. BP(M,N)/100.) GO TO 12
9 CBP=-BP(M,N)
GO TO 11
10 CBP=BP(M,N)
11 PRE(N,N,1)=HF(MF)*(CBP-3A(M,N))/BAI(M,N)
12 GO TO (13,13,13,17,17,17,17,17),K
13 IF (ABS(BAI(M,N)) .LT. BP(M,N)/100.) GO TO 17
14 CBP=-BP(M,N)
GO TO 16
15 CBP=BP(M,N)
16 PPF(M,N,2)=HF(MF)*(CBP-3B(M,N))/BBI(M,N)
17 GO TO (18,17,7,7,18,7,7,7),K
18 IF (X(M,N) .GT. D(M,N)/2.) THEN Y(M,N) .GT. D(M,N+1)/2.) GO TO 41
GO TO 7
41 IF (ABS(BCI(M,N)) .LT. BP(M,N)/100.) GO TO 7
IF (BCI(M,N)) 19,7,20
19 CBP=-BP(M,N)
GO TO 21
20 CBP=BP(M,N)
21, PRE(N,N,3)=HF(MF)*(CBP-3C(M,N))/BCI(M,N)
7 CONTINUE
DO 22 N=1,NC
K=KC(M,N)
GO TO (23,27,27,27,23,27,27),K
23 IF (ABS(BLI(M,N)) .LT. CP(M,N)/100.) GO TO 27
IF(BLICM,N>24,27,25
24 CCP=-CP(M,N)
   GO TO 26
25 CCP=CP(M,N)
26 PRE(M,N,4)=HF(MF)*(CCP-BL(M,N))/BLICM,N)
   GO TO (28,50,28,50,50,50,50),K
27 IF(ABS(BUTICM,N)>LT,CP(M,N)/100.) GO TO 50
   IF(BUICM,N))29,50,30
29 CCP=-CP(M,N)
   GO TO 31
30 CCP=CP(M,N)
31 PRE(M,N,5)=HF(MF)*(CCP-BUICM,N)/BUTICM,N)
   GO TO (51,52,52,52,52,52,52),K
50 IF(ABS(BMCM,N)>LT,CP(M,N)/100.) GO TO 22
   IF(BMCM,N))53,54
53 CCP=-CP(M,N)
   GO TO 52
54 CCP=CP(M,N)
52 PRE(M,N,6)=HF(MF)*(CCP-BMCM,N)/BMCM,N)
22 CONTINUE
   DO 80 N=1,NC
   DO 80 L=1,6
   IF(KHRICM,N,L),EQ.0) GO TO 80
   PRE(M,N,L)=TA
80 CONTINUE
   IF(MAXP-2)32,33,33
32 SMAL(M)=PRE(M,1,1)
   DO 34 N=1,NC
   DO 34 L=1,6
   IF(PRE(M,N,L) GT. SMAL(M)) GO TO 34
   SMAL(M)=PRE(M,N,L)
   NS(M)=N
   LC(M,N)=L
34 CONTINUE
4 CONTINUE
   SMA=SMAL(1)
   DO 35 M=1,MS
   IF(SMAL(M) GT. SMA) GO TO 35
   SMA=SMAL(M)
   MC=M
35 CONTINUE
   DERN=ER(MF)*SMA/HF(MF)
   NSS=NS(MC)
   WRITE(2,39)MC,NS(MC),LC(MC,NSS),DERN
42 IF(KPRED,=EQ.0) GO TO 36
   IF(DERN,GT.0.0025*ER(MF)) GO TO 43
   DERN=0.0025*ER(MF)
   GO TO 102
43 IF(ABS(DERN/ERT(MF)) GT.0.02) GO TO 36
   DERN=ERT(MF)*0.02
   GO TO 102
33 DERN=ER(MF)*PRE(MF,1,1)/HF(MF)
   DO 37 N=1,NC
   DO 37 L=1,6
   DD=ER(MF)*PRE(MF,N,L)/HF(MF)
   IF(DD GT. DERN) GO TO 37
   DERN=DD
37 CONTINUE
CED = ER(MF) * TA/HF(MF)
IF (DERN .GT. CED) GO TO 92
IF (ABS(DERN) .GT. ERT(MF)/10.) GO TO 92
GO TO 42
92 DERN = ERT(MF)/10.
102 LD = 2
WRITE (2, 38) MF, DERN
38 FORMAT (* SPECIAL PRED ADOPTED MF=*, I4, * DERN=*, F15.5)
39 FORMAT (* PRED ADOPTED AT MC, NS, LC=*, I4, * DERN=*, F15.5)
36 RETURN
END
SUBROUTINE HINRE

COMMON /BLOCKA/E,FY,BI(30,3),BZ(30,3),PB(30,3),CI(30,4),CZ(30,4),AR
 1(30,4),PC(30,4),ET(31,4),PZ(4),KB(30,3),BA(30,3),BB(30,3),BC(30,3)
 2,BAP(30,3),BAP(30,3),ACI(30,3),FRA(30,3),FRA(30,3),PAI(30,3),PAT(3
 30,3),BCI(30,3),CAI(30,3),SAI(30,3),SB(30,3),SB(30,3),KC(30,4),BUC(30
 4),BIL(30,4),BOM(30,4),BRP(30,4),BU(30,4),BUC(30,4),BUC(30,4),CI(30
 4),CL(30,4),SL(30,4),CC(30,4),CS(30,4),CX(30,4),CY(30,4),SY(30,4)
 5,SM(30,4),SH(30),X(30,3),YS(30,4),CL(30,4),SL(30,4),C(30,4),CY(30,
 74),FZ(30,4),KZ(30,4),J(30),HH(30),BL(30,4),BM(30,4),BVB(30,4),BMP(30
 4),BLC(30,4),BIL(30,4),BUC(30,4),BUC(30,4),CI(30,4),CL(30,4),SL(30,4)
 7,CC(30,4),CS(30,4),CX(30,4),CY(30,4),SY(30,4),SM(30,4),SH(30),X(30,3)
 7,YS(30,4),CL(30,4),SL(30,4),C(30,4),CY(30,4),SY(30,4),SM(30,4),SH(30
 4),X(30,3),YS(30,4),CL(30,4),SL(30,4),C(30,4),CY(30,4),SY(30,4)

NHR=0
DO 1 M=1,NS
DO 2 N=1,NS
IF (LA.GT.1) GO TO 48
FED=0.0
GO TO 49
48 FED=ED(M,N+1)-ED(M,N)
49 DO 3 L=1,3
3 HRO(M,N,L)=0.0
FM=GLF*FL(M,N)*S(N)*S(N)/12./BI(M,N)
K=KB(M,N)
GO TO (2,4,5,6,7,8,9,2),K
4 XO=0.5/(X(M,N)**3+Y(M,N)**3)
XT=2.0*Y(M,N)**3+3.0*X(M,N)*Y(M,N)**2-X(M,N)**3
XF=3.0*X(M,N)**3+3.0*Y(M,N)**2-2.0*X(M,N)**3
XS=3.0*X(M,N)**2-3.0*Y(M,N)**2+2.0*X(M,N)**3
XE=6.0*X(M,N)**3+3.0*Y(M,N)**2-1.0/X(M,N)+1.0/XO+6.0
HRO(M,N,3)=XO*(XT*ET(M,N)+XF*ET(M,N+1)+XS+FED)+GLF*FL(M,N)*XE/16./PI
1(M,N)
GO TO 10
5 HRO(M,N,1)=ET(M,N)+ET(M,N+1)/2.-1.5*FED/S(N)-FM/4.0
GO TO 10
6 TO=4.0*X(Y(M,N)+3.*Y(M,N)+3.*X(M,N)+3.*Y(M,N)+3.*X(M,N)+3.*Y(M,N)+3.*X(M,N)
 1/X(M,N)+X(M,N)**3)
TT=Y(M,N)**3*(8.*X(M,N)+3.*Y(M,N)+3.*X(M,N)+3.*Y(M,N)+3.*X(M,N)
 1-Y(M,N)*X(M,N))
HRO(M,N,1)=ET(M,N)+Y(M,N)*ET(M,N+1)/X(M,N)-FED/X(M,N)-GLF*FL(M,N)*
1TO/24./BI(M,N)
HRO(M,N,3)=-(Y(M,N)/X(M,N)+1.0)*ET(M,N+1)+FED/X(M,N)+GLF*FL(M,N)*TT
1/(24.*X(M,N)**3)
GO TO 10
7 HRO(M,N,2)=ET(M,N+1)+ET(M,N)/2.-1.5*FED/S(N)+FM/4.0
GO TO 10
8 TO=3.0*X(Y(M,N)+4.*Y(M,N)+3.*X(M,N)+3.*Y(M,N)+3.*X(M,N)+3.*Y(M,N)+3.*X(M,N)
 1-Y(M,N)*X(M,N))
TT=X(M,N)**3*(8.*Y(M,N)+3.*X(M,N)+3.*Y(M,N)+3.*X(M,N)+3.*Y(M,N)+3.*X(M,N)
 1-Y(M,N)*Y(M,N))
HRO(M,N,2)=ET(M,N+1)+X(M,N)*ET(M,N)/Y(M,N)-FED/Y(M,N)+GLF*FL(M,N)*
1TO/24./BI(M,N)
HRO(M,N,3)=(X(M,N)/Y(M,N)+1.0)*ET(M,N)+FED/Y(M,N)+GLF*FL(M,N)*TT/(124.*Y(M,N)**3)
GO TO 10
9 HRO(M,N,1)=ET(M,N)-FED/S(N)-FM/2.0
HRO(M,N,2)=ET(M,N+1)-FED/S(N)+FM/2.0
10 DO 11 L=1,3
IF (HRO(M,N,L)*PHRO(M,N,L)) 15,11,11
15 NHR=NHR+1
KHR(M,N,L)=1
WRITE(2,40) M,N,L,PHRO(M,N,L),HRO(M,N,L)
40 FORMAT(* HINGF REV M,N,L,PHRO,HRO *,314,2E11.3)
GO TO (16,37,38),L
16 KB(M,N)=K3(M,N)-2
GO TO 11
37 KB(M,N)=K3(M,N)-4
GO TO 11
38 KR(M,N)=K3(M,N)-1
11 CONTINUE
2 CONTINUE
DO 17 N=1,NC
DO 47 L=4,6
47 HRO(M,N,L)=0.0
K=KC(M,N)
GO TO (17,61,18,17,19,17,20),K
61 OK=(CX(M,N)*CX(M,N)-SX(M,N)*SX(M,N))/CX(M,N)
TK=(CY(M,N)*CY(M,N)-SY(M,N)*SY(M,N))/CY(M,N)
THK=OK*YC(M,N)/XC(M,N)+TK*XG(M,N)/YC(M,N)-PI(M,N)*H(M)/E
FK=(CX(M,N)+SX(M,N))/CX(M,N) /XC(M,N)+(CY(M,N)+SY(M,N))/CY(M,N)/YC(M,N)
C1=FK*OK*YC(M,N)/THK-SX(M,N)/CX(M,N)
C2=SY(M,N)/CY(M,N)-FK*TK*XG(M,N)/THK
C3=(SX(M,N)*YC(M,N)/XC(M,N)+SY(M,N)*XC(M,N)/CY(M,N)+H(M))*FK/THK
C4=1./CX(M,N)+1./CY(M,N)
C5=(TK*YC(M,N)-PI(M,N)/E)*FK*XG(M,N)/THK
C6=(CY(M,N)+SY(M,N))/YC(M,N)/CY(M,N)
C7=(CP(M,N)-CPP(M,N))/BM(M,N)/ABS(BM(M,N))
HRO(M,N,S)=C1*ET(M+1,N)+C2*ET(M,N)-(C3+C4)*C5+(C5-C6)*ER(M)*H(M)
GO TO 21
18 OK=CS(M,N)/CC(M,N)
TK=(CP(M,N)-CPP(M,N))/BL(M,N)/ABS(BL(M,N))
THK=TK/CC(M,N)
HRO(M,N,4)=ET(M+1,N)+OK*ET(M,N)-(1.+OK)*ER(M)-THK
GO TO 21
19 OK=CS(M,N)/CC(M,N)
TK=(CP(M,N)-CPP(M,N))/BU(M,N)/ABS(BU(M,N))
THK=TK/CC(M,N)
HRO(M,N,5)=ET(M,N)+OK*ET(M+1,N)-(1.+OK)*ER(M)-THK
GO TO 21
20 OK=(CP(M,N)-CPP(M,N))/BL(M,N)/ABS(BL(M,N))
TK=(CP(M,N)-CPP(M,N))/BU(M,N)/ABS(BU(M,N))
THK=1./(CC(M,N)+CS(M,N))
HRO(M,N,4)=ET(M+1,N)-ER(M)-OK*THK
HRO(M,N,5)=ET(M,N)-ER(M)-TK*THK
21 DO 24 L=4,6
IF( HRO(M,N,L)*PHRO(M,N,L) ) 26,24,24
26 NHR=NHR+1
KHR(M,N,L)=1
WRITE(2,40) M,N,L,PHRO(M,N,L),HRO(M,N,L)
K=L-3
GO TO (27,28,62),K
27 KC(M,N)=KC(M,N)-2
GO TO 24
28 KC(M,N)=KC(M,N)-4
GO TO 24
62 KC(M,N)=KC(M,N)-1
24 CONTINUE
17 CONTINUE
1 CONTINUE
RETURN
END
SUBROUTINE TEAM
DO 40 N=1,NB
2 K=KB(M,N)
GO TO (1,5,1,40,1,40,1,9),K
1 IF(ABS(B(BC(M,N))=BP(M,N)*0.9913,4,4
3 GO TO (5,101,20,101,5,101,40,101),K
4 BC(M,N)=BP(M,N)*BC(M,N)/ABS(BC(M,N))
GO TO (6,101,7,101,8,101,9,101),K
6 IF(ABS(BA(M,N))=BP(M,N)*0.9913,4,4
23 KB(M,N)=2
GO TO 15
7 KB(M,N)=4
GO TO 20
8 IF(ABS(BA(M,N))=BP(M,N)*0.9913,4,4
102 BC(M,N)=0.0
WRITE(2,103)M,N,KB(M,N),X(M,N)
103 FORMAT(* BC MAX OCCURS NEAR CONN.) M,N,KB,X=*,3F5.1,F10.3)
GO TO 12
24 KB(M,N)=6
GO TO 40
9 KB(M,N)=8
WRITE(2,10)M,N
GO TO 100
5 IF(ABS(BA(M,N))=BP(M,N)*0.99515,12,12
15 K=KB(M,N)
GO TO (20,20,101,101,40,40,101,101),K
12 BA(M,N)=BP(M,N)*BA(M,N)/ABS(BA(M,N))
K=KB(M,N)
GO TO (13,13,20,20,14,9,40,9),K
13 KB(M,N)=KB(M,N)+2
GO TO 20
14 KB(M,N)=7
GO TO 40
20 IF(ABS(BB(M,N))=BP(M,N)*0.9940,21,21
21 BB(M,N)=BP(M,N)*BB(M,N)/ABS(BB(M,N))
K=KB(M,N)
GO TO (22,22,9,101,101,101,101),K
22 KB(M,N)=KB(M,N)+4
GO TO 40
101 WRITE(2,11)M,N,KB(M,N)
GO TO 100
40 CONTINUE
30 WRITE(2,31)(M,N,KB(M,N),BA(M,N),BC(M,N),BB(M,N),N=1,NB)
RETURN
100 IM=0
RETURN
10 FORMAT(* BEAM MECHANISM M,N=*,2I4)
11 FORMAT(* IMP COMB OF KB M,N,KR=*,3I4)
END
SUBROUTINE COL
COMMON/BLOCKA/F,FY,RI(30,3),BZ(30,3),PP(30,3),CI(30,4),CZ(30,4),AR
1(30,4),PC(30,4),ET(31,4),PZ(4),KB(30,3),BA(30,3),AB(30,3),BC(30,3),9C(30,3)
2,RAP(30,3),RPP(30,3),RCP(30,3),FRA(30,3),FBB(30,3),BA(30,3),BPI(3
30,3),BCI(30,3),CA(30,3),SA(30,3),CB(30,3),SB(30,3),KC(30,4),BU(30,
44),BL(30,4),BM(30,4),BUP(30,4),ALP(30,4),AMP(30,4),BKI(30,4),9LI(3
50,4),BMI(30,4),F3U(30,4),FBL(30,4),CP(30,4),CPP(30,4),CU(30,4),SU(6
60,4),CL(30,4),SL(30,4),CC(30,4),CS(30,4),CX(30,4),SX(30,4),CY(30,
74),SY(30,4),SH(30,4),SH(30),X(30,3),Y(30,3),X(30,4),Y(30,4),P(30
8,4),PP(30,4),PI(30,4),ED(30,4),EDT(30,4),EDTP(30,4),HF(30),HF
9,HT,PHF,HMAX,ER(30),ERP(30),ERT(30),IM,KAA,KM,MAXP,MF,MS,MT,MP,NC
1,M,N,DERN,LO,FRC,NHR,LA,LR,RP(30,3),D(30,4),H(30),WH(30),FL(30,3),
2S(3),RY(30,4),HR(30,4,6),PHR(30,4,6),KHR(30,4,6),KPRD,GLF,TGLF,
3FAC,SMA,K3P(30,3),KCP(30,4)
DO 1 N=1,NC
K=KC(M,N)
GO TO(2,21,100,4,100,7),K
2 IF(ABS(BM(M,N))>CP(M,N)*0.96) 20,21,21
21 BM(M,N)=CP(M,N)*BM(M,N)/ABS(BM(M,N))
KC(M,N)=2
GO TO 1
20 IF(ABS(BL(M,N))>CP(M,N)*0.96) 14,3,3
3 BL(M,N)=CP(M,N)*BL(M,N)/ABS(BL(M,N))
KC(M,N)=3
14 IF(ABS(BU(M,N))>CP(M,N)*0.96) 1,6,6
6 BU(M,N)=CP(M,N)*BU(M,N)/ABS(BU(M,N))
KC(M,N)=KC(M,N)+4
GO TO 1
4 IF(ABS(BL(M,N))>CP(M,N)*0.96) 9,7,7
7 KC(M,N)=7
8 BL(M,N)=CP(M,N)*BL(M,N)/ABS(BL(M,N))
9 BU(M,N)=CP(M,N)*BU(M,N)/ABS(BU(M,N))
1 CONTINUE
WRITE(2,10) (M,N,KC(M,N),BU(M,N),BL(M,N),N=1,NC)
RETURN
100 WRITE(2,11) M,N,KC(M,N)
IM=0
RETURN
12,1X,3I3,1X,F9.2,F9.2))
11 FORMAT(* IMP COMB OF KC M,N,KC=*,3I4)
END
6. APPENDIX II - SYMBOLS IN PROGRAM
<table>
<thead>
<tr>
<th>AL</th>
<th>Moment change at the bottom of a column due to the change of the reduced plastic moment at the plastic hinge at the top (kip-in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AM</td>
<td>Larger of the two end moments in a column (kip-in)</td>
</tr>
<tr>
<td>AR</td>
<td>Area of a column (in$^2$)</td>
</tr>
<tr>
<td>AT</td>
<td>Moment change at the top of a column due to the change of the reduced plastic moment at the plastic hinge at the bottom (kip-in)</td>
</tr>
<tr>
<td>BA</td>
<td>Moment at the end A in beam (kip-in)</td>
</tr>
<tr>
<td>BAI</td>
<td>Moment increment at the end A in beam (kip-in)</td>
</tr>
<tr>
<td>BAP</td>
<td>Moment at the end A in beam at the previous sway increment (kip-in)</td>
</tr>
<tr>
<td>BB</td>
<td>Moment at the end B in beam (kip-in)</td>
</tr>
<tr>
<td>BBI</td>
<td>Moment increment at the end B in beam (kip-in)</td>
</tr>
<tr>
<td>BBP</td>
<td>Moment at the end B in beam at the previous sway increment (kip-in)</td>
</tr>
<tr>
<td>BC</td>
<td>Maximum moment between ends A and B in beam (kip-in)</td>
</tr>
<tr>
<td>BCI</td>
<td>Moment increment at the location of the maximum moment between ends A and B in beam (kip-in)</td>
</tr>
<tr>
<td>BCP</td>
<td>Maximum moment between ends A and B in beam at the previous sway increment (kip-in)</td>
</tr>
<tr>
<td>BEAM</td>
<td>A subroutine subprogram</td>
</tr>
<tr>
<td>BEGIN</td>
<td>A subroutine subprogram</td>
</tr>
<tr>
<td>BI</td>
<td>Moment of inertia--Beams (in$^4$)</td>
</tr>
<tr>
<td>BL</td>
<td>Moment at the end L in column (kip-in)</td>
</tr>
<tr>
<td>BLI</td>
<td>Moment increment at the end L in column (kip-in)</td>
</tr>
<tr>
<td>BLP</td>
<td>Moment at the end L in column at the previous sway increment (kip-in)</td>
</tr>
</tbody>
</table>
BM  Maximum moment between ends L and U in columns (kip-in)
BMAX  Maximum moment in column (kip-in)
BMI  Moment increment at the location of the maximum moment between ends L and U in column (kip-in)
BMP  Maximum moment between ends L and U in column at the previous sway increment (kip-in)
BN  Smaller of the two end moments in a column (kip-in)
BP  Plastic moment of a beam (kip-in)
BU  Moment at the end U in column (kip-in)
BUI  Moment increment at the end U in column (kip-in)
BUP  Moment at the end U in column at the previous sway increment (kip-in)
BZ  Plastic modulus of a section--Beams (in³)
CA  Slope-deflection coefficient for the moment at A due to rotation at A in the beam AB (kip-in)
CB  Slope-deflection coefficient for the moment at B due to rotation at B in the beam AB (kip-in)
CBP  A variable used in subroutine PRED
CC  Stiffness coefficient for a column
CCP  A variable used in subroutine PRED
CED  A variable used in subroutine PRED
CI  Moment of inertia--Columns (in⁴)
CL  Slope-deflection coefficient for the moment at L due to rotation at L in column LU (kip-in)
COL  A subroutine subprogram
CP  Reduced plastic moment of a column (kip-in)
CPP  Reduced plastic moment of a column at the previous sway increment (kip-in)
CS  Stiffness coefficient for a column
CSCOE A subroutine subprogram

CSMA A variable used in subroutine PRED

CU Slope-deflection coefficient for the moment at U due to rotation at U in column LU (kip-in)

CX Stiffness coefficient for a part of a column in plastic hinge combination (2)

CY Stiffness coefficient for a part of a column in plastic hinge combination (2)

CZ Plastic modulus of section—Columns (in$^3$)

C1, C2, C3, Variables used in subroutines HINRE C4, C5, C6, C7

D Depth of a column (in)

DD A variable used in subroutine PRED

DEL Relative lateral deflection of a story (in)

Delt Lateral deflection at the top of a frame (in)

Dern Predicted increment of lateral deflection ($\times E/H$)(k/in$^2$)

DN A variable used in subroutine HORD

DOH Deflection index of a story

DSQ A variable used in calculating stiffness coefficients for a column in subroutine CSCOE

E Modulus of elasticity (k/in$^2$)

ED Increment of vertical deflection of a joint due to column shortening ($\times E$) (k/in$^2$)

EDT Total vertical deflection of a joint due to column shortening (in)

EDTP Total vertical deflection of a joint due to column shortening at the previous sway increment (in)

ENMT A subroutine subprogram
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ER</td>
<td>Increment of lateral deflection of a story ((k/in^2))</td>
</tr>
<tr>
<td>ERP</td>
<td>Increment of lateral deflection of a story at the previous sway increment ((k/in^2))</td>
</tr>
<tr>
<td>ERT</td>
<td>Total lateral deflection of a story ((k/in^2))</td>
</tr>
<tr>
<td>ET</td>
<td>Increment of rotation of a joint ((k/in^2))</td>
</tr>
<tr>
<td>FAC</td>
<td>Load factor for the combined loads</td>
</tr>
<tr>
<td>FBA</td>
<td>Fixed end moment at the end A in beam ((kip-in))</td>
</tr>
<tr>
<td>FBB</td>
<td>Fixed end moment at the end B in beam ((kip-in))</td>
</tr>
<tr>
<td>FBL</td>
<td>Moment correction at the end L in column due to the change of reduced plastic moment from the previous sway increment ((kip-in))</td>
</tr>
<tr>
<td>FBU</td>
<td>Moment correction at the end U in column due to the change of reduced plastic moment from the previous sway increment ((kip-in))</td>
</tr>
<tr>
<td>FED</td>
<td>A variable used to indicate the difference between the increments of vertical deflection of two adjacent joints in a story ((k/in^2))</td>
</tr>
<tr>
<td>FK</td>
<td>A variable used in subroutine HINRE</td>
</tr>
<tr>
<td>FL</td>
<td>Uniformly distributed beam load ((k/in))</td>
</tr>
<tr>
<td>FM</td>
<td>A variable used in subroutine CSCOE</td>
</tr>
<tr>
<td>FN</td>
<td>A variable used in subroutine HORF</td>
</tr>
<tr>
<td>FRC</td>
<td>Maximum compressive residual stress nondimensionalized with yield stress</td>
</tr>
<tr>
<td>FY</td>
<td>Yield stress ((k/in^2))</td>
</tr>
<tr>
<td>GLF</td>
<td>Load factor for the initial gravity loads to be applied at the start of analysis. Increment of load factor for the gravity loads in the non-swayed position</td>
</tr>
<tr>
<td>GRALD</td>
<td>A subroutine subprogram</td>
</tr>
<tr>
<td>H</td>
<td>Height of a story ((in))</td>
</tr>
<tr>
<td>HER</td>
<td>A variable used in main program</td>
</tr>
</tbody>
</table>
HF  Increment of lateral load (kip)
HFP  Increment of lateral load at the previous sway increment (kip)
HFT  Total lateral load (kip)
HFTP Total lateral load at the previous sway increment (kip)
HHF  A variable used in main program
HINRE A subroutine subprogram
HMAX Maximum lateral load (kip)
HORF A subroutine subprogram
HRO  Inelastic hinge rotation at a plastic hinge (*E) (k/in²)
I    Fixed point variable I keeps track of which end of a column has the larger moment
IET  Number of an iteration to solve simultaneous equations
II   Number used to indicate how many times subroutine HINRE is called in a sway increment
IM   Fixed point variable used to stop the program if undesirable plastic hinge combination is detected
IN   Fixed point variable used to indicate the end of computation performed on individual stories
K    Fixed point variable K is equal to KB or KC when it is used in computed "GO TO"
KAA  Fixed point variable used to indicate the calculation to be performed in the non-swayed position
KB   Plastic hinge combination for a beam
KBP  Plastic hinge combination for a beam at the previous sway increment
KC   Plastic hinge combination for a column
KCP  Plastic hinge combination for a column at the previous sway increment
KET  Number of an iteration to solve simultaneous equations in subroutine HORDF

KHR  Fixed point variable used to indicate the location of hinge reversals occurred in the current sway increment

KM   Fixed point variable used to indicate whether or not the maximum lateral load is passed

KPRD Fixed point variable used to indicate whether subroutine PRED is called for the next sway increment or to check the convergence of the current sway increment

KSW  Number of an iteration to calculate end moments in subroutine GRALD

L    Number used to indicate the potential plastic hinge location or the plastic hinge location. The left end of a beam at a level is numbered 1, the right end of the beam 2 and an interior point of the beam 3. The bottom of the left column of the beam below that level is numbered 4, the top of the column 5 and an interior point of the column 6. Third subscript for the quantities pertaining to that potential plastic hinge location or that plastic hinge location.

LA   Fixed point variable used to indicate whether the effect of axial shortening of columns is considered or not

LC   An index used to indicate the potential plastic hinge location where the prediction is taken

LD   Fixed point variable used to indicate whether the iteration of prediction is required or not

LR   Fixed point variable used to indicate whether the effect of hinge reversals is considered or not

M    Level number, numbered from the top. First subscript for the quantities pertaining to that level and story just below that level

MAXP Fixed point variable used to indicate whether the maximum lateral load is passed or not
MC: An index used to indicate a level. In the story below that level, the prediction is taken.

MF: Level number. At the story below that level, the sway deflection is incremented.

MI: Fixed point variable number for a story.

MK: Fixed point variable used to indicate the start of computation in a story.

MPF: Level number. At the story below that level, the sway deflection was initially incremented.

MS: Total number of stories.

MT: Total number of levels.

N: Bay number, numbered from the left. Second subscript for the quantities pertaining to that bay.

NB: Total number of bays.

NC: Total number of columns in a story.

NDER: Fixed point variable used to limit the number of iterations for the convergence of prediction.

NHR: Number of hinge reversals occurred in a sway increment.

NM: Fixed point variable used to limit the number of iterations at the story whose sway deflection is incremented.

NN: Fixed point variable used to limit the number of iterations at all stories except the story whose sway deflection is incremented.

NNN: Fixed point variable used to stop the program if the solution diverges.

NS: An index used to indicate the lower limit of an iteration in main program.

NSL: An index used to indicate the upper limit of an iteration in main program.

NSS: An index used to indicate the bay where the prediction is taken.
Variables used in subroutine HINRE

P Axial load in a column (kip)

PB Concentrated gravity load applied on a beam (kip)

PC Concentrated gravity load applied at a joint (kip)

PDERN The initial sway increment adopted at the start of the current increment (*E/H) (k/in²)

PHF The lateral load increment at the previous sway increment (kip)

PHI A variable used in calculating stiffness coefficients for a column

PHRO Inelastic hinge rotation of a plastic hinge at the previous sway increment (*E) (k/in²)

PI Increment of axial load in a column (kip)

POPY Axial load (P) nondimensionalized with axial yield load

PP Axial load in a column at the previous sway increment (kip)

PRE Lateral load increment required for a plastic hinge at a potential plastic hinge location (kip)

PRED A subroutine subprogram

PT Total axial load in columns in a story (kip)

PZ A variable used in calculating axial loads

RAT Ratio of stiffness coefficients in a column. Ratio of end moments.

RCP Change of the reduced plastic moment from the value at the previous sway increment (kip-in)

RY Effective moment of inertia factor

S Width of a bay (in)

SA Slope-deflection coefficient for moment at A due to rotation at B in a beam AB

SB Slope-deflection coefficient for moment at B due to rotation at A in a beam AB
SBM  A variable used in calculating the maximum moment in a beam in subroutine ENMT

SH  Sum of the independent moments in all the columns of a story

SK  A variable used in subroutine CSCOE

SL  Slope-deflection coefficient for moment at L due to rotation at U in a column LU

SM  Sum of independent moments at the ends of the members framing into one joint

SMA  The smallest lateral load increment required for the next plastic hinge (kip)

SMAL  A variable used to select the smallest lateral load increment for the next hinge

SMC  A variable used in subroutine CSCOE

SMS  A variable used in subroutine CSCOE

SSCT  A variable used in subroutine HORF

SU  Slope-deflection coefficient for moment at U due to rotation at L in a column LU

SX  Stiffness coefficient for a part of a column in plastic hinge combination (2)

SY  Stiffness coefficient for a part of a column in plastic hinge combination (2)

TA  A variable used in subroutine PRED

TDER  Total lateral deflection taken at each iteration for convergence of prediction (*E/H)(k/in²)

TGLF  Total load factor for the gravity loads at a gravity load increment

THK, TK, TO, TON, TT, TTH  Variables used in subroutines CSCOE and HINRE

TOE  Fixed end moment in a beam due to vertical deflection of joints (k/in²)
XE, XF, XO, Variables used in calculating inelastic hinge rotation in subroutine HINRE

XS, XT

Total height of frame (in)

Lateral load index

Distance from the end A to the maximum positive moment point in a beam (in)

Distance from the end L to the maximum moment point in a column (in)

XA, XF, XO, Variables used in calculating inelastic hinge rotation in subroutine HINRE

XS, XT

Distance from the end L to the maximum moment point in a column

A variable used in calculating slope-deflection coefficient for a beam

A variable used in calculating the distance from the end L to the maximum moment point in a column

Complement of X (in)

Complement of XC (in)

A variable used to indicate whether the maximum moment occurs at an end or an interior point in a column.
7. APPENDIX III - FLOW CHARTS
HFP(M) = 0.0, ER(M) = 0.0
ERP(M) = 0.0, ERT(M) = 0.0

P(M, 1) = PZ(1) + GLF * PC(M, 1) + GLF * FL(M, 1) * S(1)/2
PZ(1) = P(M, 1)
P(M, NC) = PZ(NC) + GLF * PC(M, NC) + GLF * FL(M, NB) * S(NB)/2
PZ(NC) = P(M, NC)

\[ P(M, N) = PZ(N) + GLF * PC(M, N) + GLF * (FL(M, N) * S(N) + FL(M, N - 1) * S(N - 1))/2 \]
\[ PZ(N) = P(M, N) \]

CALL GRALD
IM .LE. 0  Yes \( \text{100} \)
No
KAA = 2
GLF = 0.0
TGLF = FAC

\( \text{100} \)
RETURN
\[
PHRO(M, N, 1) = 0.001 \times \frac{BA(M, N)}{ABS(BA(M, N))}
\]

\[
PHRO(M, N, 2) = 0.001 \times \frac{BB(M, N)}{ABS(BB(M, N))}
\]

\[
PHRO(M, N, 4) = 0.001 \times \frac{BL(M, N)}{ABS(BL(M, N))}
\]

\[
PHRO(M, N, 5) = 0.001 \times \frac{BU(M, N)}{ABS(BU(M, N))}
\]

\[
L = KB(M, N) - KBP(M, N)
\]

\[
L = KC(M, N) - KCP(M, N)
\]

\[
BAP(M, N) = BA(M, N), BBP(M, N) = BB(M, N)
\]

\[
BCP(M, N) = BC(M, N), KBP(M, N) = KB(M, N)
\]

\[
BUF(M, N) = BU(M, N), BLP(M, N) = BL(M, N)
\]

\[
RIP(M, N) = RN(M, N), CPP(M, N) = CP(M, N)
\]

\[
KCP(M, N) = KC(M, N), ET(M, N) = 0.0
\]

\[
PP(M, N) = PO(M, N), ER(M) = 0.0
\]

Yes

No

\[
EDT(M, N) = EDTP(M, N) + ED(M, N)/Z
\]

\[
EDTF(M, N) = EDT(M, N)
\]

\[
ED(M, N) = 0.0
\]
\[
PHRO(M, N, L) = PHRO(M, N, L) + HRO(M, N, L)
\]

\[
((P(M, N), N = 1, NC), M = 1, MS)
\]

\[
LA .EQ. 1 \quad \text{Yes} 
\]

\[
((EDT(M, N), N = 1, NC), M = 1, MS)
\]

\[
TGLF .GT. (FAC - 0.05) \quad \text{Yes}
\]

\[
GLF = 0.1 \quad \text{No}
\]

1

100

\[
\text{DERN} = 0.03 \times \text{E/H(MF)}
\]

101

LD = 2

RETURN
$RCP = CP(M,N) - CPP(M,N) - CU(M,N)$

$CL(M,N) = 0.0, SL(M,N) = 0.0$

$RAT = CS(M,N)/CC(M,N)$

$BU(M,N) = CP(M,N)*BU(M,N)/ABS(BU(M,N))$

$CL(M,N) = (CC(M,N)^2 - CS(M,N)^2)/CC(M,N)$

$AT = RCP*BU(M,N)/ABS(BU(M,N))$

$SH(M) = SH(M) + (1 + RAT)*AT$

$SM(M,N) = SM(M,N) + AT$

$SM(M+1,N) = SM(M+1,N) + RAT*AT$

$FBL(M,N) = AT*RAT$

$BL(M,N) = CP(M,N)*BL(M,N)/ABS(BL(M,N))$

$SH(M) = SH(M) + RCP*BU(M,N)/ABS(BU(M,N)) + RCP*BL(M,N)/ABS(BL(M,N))$

$SM(M,N) = SM(M,N) + RCP*BU(M,N)/ABS(BU(M,N)) + RCP*BL(M,N)/ABS(BL(M,N))$

$SM(M+1,N) = SM(M+1,N) + RCP*BL(M,N)/ABS(BL(M,N))$
BAI(M,N) = FBA(M,N) + GA(M,N)*ET(M,N) + SA(M,N)*ET(M,N+1)
BBI(M,N) = FBB(M,N) + CB(M,N)*ET(M,N+1) + SB(M,N)*ET(M,N)
BCI(M,N) = 0.0
BA(M,N) = BAP(M,N) + BAI(M,N)
BB(M,N) = BBP(M,N) + BBI(M,N)

BUI(M,N) = CU(M,N)*ET(M,N) + SU(M,N)*ET(M,N+1) - (CU(M,N) + SU(M,N))*ER(M) + FBU(M,N)
BLI(M,N) = CL(M,N)*ET(M,N+1) + SL(M,N)*ET(M,N) - (CL(M,N) + SL(M,N))*ER(M) + FBL(M,N)
BU(M,N) = BUP(M,N) + BUI(M,N)
BL(M,N) = BLP(M,N) + BLI(M,N)

XM = KB(M,N)

SBM = -(BA(M,N) + BB(M,N))
X(N,N) = S(N)/2 + SBM/(TQLF*PL(M,N)*S(N))

X(N,N) = D(M,N)/2
Y(N,N) = S(N) - X(N,N)

Y(N,N) = -D(M,N+1)/2
X(N,N) = S(N)

BCI(M,N) = BC(M,N) - BCP(M,N)

K = KC(M,N)

BU(M,N) = BUP(M,N) + BUI(M,N)
BL(M,N) = BLP(M,N) + BLI(M,N)

RAT = ABS(BL(M,N)) * ABS(BU(M,N))
SAT = ABS(BL(M,N)) * ABS(BU(M,N))

ABS(BL(M,N)) - ABS(BU(M,N)) > 0

AH = ABS(BU(M,N))
BH = ABS(BL(M,N))
I = -1
XO = \(0.5 / (X(M,N)^3 + Y(M,N)^3)\)

\(XT = 2 \cdot Y(M,N)^3 + 3 \cdot X(M,N) \cdot Y(M,N)^2 - X(M,N)^3\)

\(XF = Y(M,N)^3 - 3 \cdot Y(M,N) \cdot X(M,N)^2 - 2 \cdot X(M,N)^3\)

\(XS = 3 \cdot (X(M,N)^2 - Y(M,N)^2)\)

\(XE = 6 \cdot X(M,N)^3 \cdot Y(M,N)^2 \cdot S(N)^2 \cdot XO - 1 / XO / 6\)

\(HRO(M,N,3) = XO \cdot [XT \cdot ET(M,N) + XF \cdot ET(M,N+1) + XS \cdot FED] + GLF \cdot FL(M,N) \cdot XE / 16 / BI(M,N)\)

\(K = KB(M,N)\)

\(HRO(M,N,1) = ET(M,N) + ET(M,N+1) / 2 - 1.5 \cdot FED / S(N) - FM / 4\)

\(HRO(M,N,2) = ET(M,N+1) + ET(M,N) / 2 - 1.5 \cdot FED / S(N) + FM / 4\)

\(HRO(M,N,3) = (X(M,N) / Y(M,N) + 1) \cdot ET(M,N+1) + FED / X(M,N) + GLF \cdot FL(M,N) \cdot TT / (24 \cdot X(M,N) \cdot BI(M,N))\)
HINGE REVERSAL OCCURRED
M, N, L, PHRO(M,N,L), HRO(M,N,L)

K = KC(M,N)

OK = (CX(M,N)^2 - SX(M,N)^2)/CX(M,N)
TK = (CY(M,N)^2 - SY(M,N)^2)/CY(M,N)
THK = OK*YC(M,N)/XC(M,N) + TK*YC(M,N)/XC(M,N)
FK = (CX(M,N) + SX(M,N))/CX(M,N) - SY(M,N)/CY(M,N)
C1 = FK*OK/YC(M,N)/XC(M,N) - SX(M,N)/CX(M,N)
C2 = SY(M,N)/CY(M,N) - FK*TK/YC(M,N)/XC(M,N)
C3 = SX(M,N)/CX(M,N) - SY(M,N)/CY(M,N)/XC(M,N)
C4 = 1/CX(M,N) + 1/CY(M,N)
C5 = (CY(M,N) - PX(M,N))/XC(M,N) - SY(M,N)/CY(M,N)/XC(M,N)
C6 = CX(M,N) - SY(M,N)/CY(M,N)/XC(M,N)
C7 = CX(M,N) - SY(M,N)/CY(M,N)/XC(M,N)/XC(M,N)

OK = CS(M,N)/CC(M,N)
TK = (CP(M,N) - CPP(M,N))/BL(M,N)/ABS(BL(M,N))
THK = TK/CC(M,N)
HRO(M,N,L) = ET(M,N) + OK*ET(M,N) - (1 + OK)*ER(M) - TK

OK = (CP(M,N) - CPP(M,N))/BL(M,N)/ABS(BL(M,N))
TK = (CP(M,N) - CPP(M,N))/BU(M,N)/ABS(BU(M,N))
THK = TK/CC(M,N)
HRO(M,N,L) = ET(M,N) - OK*ET(M,N) - TK*THK

HINGE REVERSAL OCCURRED
M, N, L, PHRO(M,N,L), HRO(M,N,L)

K = L - 3

KC(M,N) = KC(M,N) - 2
KC(M,N) = KC(M,N) - 4
KC(M,N) = KC(M,N) - 1

RETURN
\[
\begin{align*}
N &= 1, \text{ KC} \\
K &= \text{KC}(M,N) \\
\text{ABS}(BM(M,N)) - CP(M,N) \times 0.99 &\geq 0 \quad \text{21} \\
\text{BM}(M,N) &= CP(M,N) \times \frac{BM(M,N)}{ABS(BM(M,N))} \\
\text{KC}(M,N) &= 2 \\
\text{ABS}(BL(M,N)) - CP(M,N) \times 0.99 &\geq 0 \quad \text{3} \\
\text{BL}(M,N) &= CP(M,N) \times \frac{BL(M,N)}{ABS(BL(M,N))} \\
\text{ABS}(BU(M,N)) - CP(M,N) \times 0.99 &< 0 \quad \text{4} \\
\text{BU}(M,N) &= CP(M,N) \times \frac{BU(M,N)}{ABS(BU(M,N))} \\
\text{KC}(M,N) &= \text{KC}(M,N) + 4 \\
\text{ABS}(BL(M,N)) - CP(M,N) \times 0.99 &< 0 \quad \text{9} \\
\text{KC}(M,N) &= 7 \\
\text{BL}(M,N) &= CP(M,N) \times \frac{BL(M,N)}{ABS(BL(M,N))} \\
\text{BU}(M,N) &= CP(M,N) \times \frac{BU(M,N)}{ABS(BU(M,N))} \\
N, N, \text{ KC}(M,N), \text{ BU}(M,N), \text{ BL}(M,N) &\quad \text{RETURN}
\end{align*}
\]
8. APPENDIX IV - SAMPLE OUTPUT
TOTAL GRAVITY LOAD FACTOR= 1.300 INCREMENTAL LOAD FACTOR= .100

1 1 1 -290.23 284.11 531.52 1 2 1 -531.52 284.11 -290.23
1 1 1 290.23 239.28 1 2 1 0.00 0.00 1 3 1 -290.23 -239.28
2 1 1 -444.99 331.27 624.02 2 2 1 -624.02 331.27 -444.99
2 1 1 205.71 223.68 2 2 1 0.00 0.00 2 3 1 -205.71 -223.68
3 1 1 -383.57 345.60 661.31 3 2 1 -661.31 345.60 383.57
3 1 1 159.88 81.66 3 2 1 0.00 0.00 3 3 1 -159.88 81.66

AXLD 13.99 33.34 13.99 32.18 73.70 32.18 49.82 115.16 49.82
ENDF .053 .122 .053 .045 .104 .045 .027 .063 .027
M, HF, ER 3 .5048 14.8000
M, HF, ER 3 .4233 14.8000
M, HF, ER 3 .4127 14.8000

PRED CONV NDER, TDER, DERN= 1 14.8000 14.8000
STORY 3 HFT= .4127 ERT= 7.8681 DOH= .0003 DEL= .0319
STORY 2 HFT= .4127 ERT= 14.4646 DOH= .0005 DEL= .0586
STORY 1 HFT= .4127 ERT= 14.8000 DOH= .0005 DEL= .0600
FOR PLOTTING LATERAL LOAD= .41265 DEFLECTION INDEX OF FRAME= .00042
1 1 1 -282.55 285.37 537.95 1 2 1 -525.10 282.89 297.90
1 1 1 282.55 234.27 1 2 1 -12.85 -11.07 1 3 1 -297.90 -244.29
2 1 1 -423.76 333.93 542.21 2 2 1 -605.83 328.84 466.23
2 1 1 189.49 210.99 2 2 1 -25.31 -24.08 2 3 1 -221.94 -236.37
3 1 1 -351.02 352.27 687.77 3 2 1 -634.86 341.44 416.11
3 1 1 140.03 52.31 3 2 1 -28.82 -33.58 3 3 1 -179.74 -111.01
PRED ADOPTED AT MC, NS, LC= 3 1 2 DERN= 30.12096
AXLD 13.91 33.34 14.06 31.88 73.70 32.48 49.20 115.16
AXLD 50.45
ENDF .052 .122 .053 .045 .104 .046 .027 .063
ENDF .028
| M, HF, ER | 3 | 1.2524 | 94.5231 |
| M, HF, ER | 3 | 0.8910 | 94.5231 |
| M, HF, ER | 3 | 0.7729 | 94.5231 |
| M, HF, ER | 3 | 0.7365 | 94.5231 |

**PRED ADOPTED AT MC, NS, LC= 3 1 4 DERN= -2.64777**

**PRED CONV NDER, TDER, DERN= 1 94.52312 -2.64777**

**STORY 3 HFT= 6.9294 ERT= 226.4160 DOH= 0.0076 DFL= 1.7206**

**STORY 2 HFT= 6.9294 ERT= 424.4240 DOH= 0.0143 DEL= 1.6893**

**STORY 1 HFT= 6.9294 ERT= 416.7036 DOH= 0.0141 DEL= 1.5893**

**FOR PLOTTING LATERAL LOAD= 6.92935 DEFLECTION INDEX OF FRAME= 0.01202**

<table>
<thead>
<tr>
<th>STORY</th>
<th>HFT=</th>
<th>ERT=</th>
<th>DOH=</th>
<th>DFL=</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>6.9294</td>
<td>226.4160</td>
<td>0.0076</td>
<td>1.7206</td>
</tr>
<tr>
<td>2</td>
<td>6.9294</td>
<td>424.4240</td>
<td>0.0143</td>
<td>1.6893</td>
</tr>
<tr>
<td>1</td>
<td>6.9294</td>
<td>416.7036</td>
<td>0.0141</td>
<td>1.5893</td>
</tr>
</tbody>
</table>

**PREO ADOPTED AT MC, NS, LC= 3 1 3 DERN= 12.80 32.26 16.25 27.76 71.36 38.94 41.07 111.23**

**AXLD 12.80 32.26 16.25 27.76 71.36 38.94 41.07 111.23**

**ENOF .045 .118 .065 .038 .100 .056 .023 .061**

**ENDF .034 .118 .065 .038 .100 .056 .023 .061**
M, HF, ER 3 -.3604 148.9810 148.9810
M, HF, ER 3 -.3604 148.9810

PREO CONV NDER, TDER, DERN= 1 148.98103 148.98103
HINGE REV M, N, L, PHRO, HR0 1 1 2 1.806E+02 -1.103E+01
HINGE REV M, N, L, PHRO, HR0 2 1 2 3.918E+02 -1.355E+01
HINGE REV M, N, L, PHRO, HR0 2 2 2 4.748E+02 -2.431E+01
HINGE REV M, N, L, PHRO, HR0 2 2 4 -1.427E+02 2.505E+01
HINGE REV M, N, L, PHRO, HR0 3 1 2 1.013E+03 -1.699E+01
HINGE REV M, N, L, PHRO, HR0 3 1 3 1.155E+03 -4.888E+01
HINGE REV M, N, L, PHRO, HR0 3 2 2 1.119E+03 -2.737E+01
HINGE REVERSAL OCCURRED II= 1 NHR= 8
M, HF, ER 3 -.3604 148.9810
M, HF, ER 3 -.3604 148.9810

PREO CONV NDER, TDER, DERN= 1 148.98103 148.98103
STORY 3 HFT= 5.9113 ERT= 285.6605 DOH= .0097 DEL= 1.1581
STORY 2 HFT= 5.9113 ERT= 806.9664 DOH= .0273 DEL= 3.2715
STORY 1 HFT= 5.9113 ERT= 1638.7913 DOH= .0554 DEL= 6.6437
FOR PLOTTING LATERAL LOAD= 5.91126 DEFLECTION INDEX OF FRAME= .03076
1 1 1 -92.65 379.02 570.04 1 2 1 -286.93 -301.98 501.84
1 1 1 92.65 187.27 1 2 1 -286.93 -158.31 1 3 1 -501.85 -115.84
2 1 1 169.30 643.25 725.67 2 2 1 -5.75 536.53 722.47
2 1 1 -356.57 374.40 2 2 1 -566.98 -566.98 2 3 1 -606.46 -119.26
3 1 1 309.60 731.58 729.76 3 2 1 303.45 728.39 727.42
3 1 7 -684.25 -684.25 3 2 7 -472.85 -472.85 3 3 7 -610.79 -610.79
SPECIAL PREO ADOPTED MF= 3 DERN= 163.87913
AXLD 12.67 32.09 16.55 26.89 71.45 39.72 40.30 109.88
AXLD 64.63
ENDF .044 .117 .067 .037 .100 .057 .022 .060
ENDF .036
Fig. 1 EXAMPLE FRAME
Note: The data cards are read correctly from the top of the page downward but the cards themselves are stacked in the reverse order.

Fig. 2 SET-UP OF DATA CARDS FOR EXAMPLE FRAME
Combination No. | Hinge Locations
--- | ---
1 | A ----------- B
2 | A ----------- C ----------- B
3 | A ----------- C ----------- B
4 | A ----------- C ----------- B
5 | A ----------- C ----------- B
6 | A ----------- C ----------- B
7 | A ----------- C ----------- B
8 | A ----------- C ----------- B

Fig. 3 HINGE COMBINATION NUMBER USED IN PROGRAM
Fig. 4 NUMBERING FOR POTENTIAL HINGE LOCATIONS
10. REFERENCES

1. Kim, S. W. and Daniels, J. H.
11. ACKNOWLEDGMENTS

The work described in this report was conducted as part of a general investigation into the strength of beam-and-column subassemblages in unbraced multi-story frames at Fritz Engineering Laboratory, Department of Civil Engineering, Lehigh University. Professor David A. VanHorn is Chairman of the Civil Engineering Department and Professor Lynn S. Beedle is Director of Fritz Engineering Laboratory. The investigation was sponsored by the American Iron and Steel Institute, and the Pennsylvania Science and Engineering Foundation (P-SEF) under P-SEF Agreement No. 98. The authors acknowledge the support received from the sponsors.

Technical guidance for the investigation was provided by a Task Force of the American Iron and Steel Institute Project 150 of which Dr. I. M. Viest is Chairman. Other members on the Task Force are: Messrs. R. G. Dean, W. C. Hansell, I. M. Hooper, F. R. Khan and E. O. Pfrang. To the members of this guiding committee, the authors wish to express their gratitude.

The manuscript was typed with great care by Miss Karen Philbin and the drawings were prepared by Mr. John M. Gera.