INTRODUCTION

SOLVE LOCAL COLLAPSE (SLC) is a newly implemented feature of AOS/GRAFAX, the pre- and post - processing program for MSC/NASTRAN developed by the Engineering Systems Department of A. O. SMITH. SLC has been implemented within SECTION - a Major Function in AOS/GRAFAX - and provides post-processing capability for calculating eigenvalues and generating graphic displays of the buckled mode shapes for elastic local buckling of thin-wall CBAR and CBEAM elements.

SECTION, when used as a pre-processor, uses a description of the beam cross-section (as shown in Figure 1) which can be digitized from a scale drawing, or simply entered through a graphics terminal keyboard. The user enters MID, the material ID of the MAT1 card, and PID, the property ID of the PBAR or PBEAM card. The geometry is described by NODE and LINE data as shown. The user then requests a section solution which produces a PBAR or PBEAM card containing section data including stress recovery points. An example appears in Figure 2. GRAFAX then places a $ at the beginning of each line of this section data and it is retained in the NASTRAN deck as comments. This data can be used subsequently in SLC when SECTION is used as a post-processor. Thus, when SLC is used, input data include MSC/NASTRAN output of stresses and element forces as well as data describing the thin-wall sections.

THEORY

Local buckling in thin wall beams is considered plate buckling of the plate elements making up the beam. It is a buckling mode characterized by the long edges of the plate remaining straight but restrained rotationally by adjacent plates.

The critical buckling stress for longitudinally stressed plates can be expressed by [1]

$$\sigma_{cr} = k \frac{\pi^2 E}{12(1-\nu^2)} \left(\frac{t}{b}\right)^2$$

where E and ν are Young's modulus and Poison's ratio, t is plate thickness and b is plate width. The buckling coefficient k is a function of plate boundary conditions and aspect ratio as shown in Figure 3. From Figure 3 it is seen that k becomes independent of aspect ratio and loaded edge boundary conditions for long plates, i.e. plates that are

(1) G. Gerard and H. Becker, "Handbook of Structural Stability" NACA Technical Notes 3781-3786, D-162, 1957-59.

at least 4 times greater in length than width. Thus the buckling of long plates, which is a large and technically important class of problems, is simply a two-dimensional problem involving only material constants, longitudinal stresses, cross section geometry and boundary conditions on long edges of the plate.

SLC is itself a finite element program. From a shape function for the buckled plate the stiffness and differential stiffness matrices are obtained using section geometry, material properties and in-plane stresses. Internally, SLC puts additional nodes at mid-sides as indicated by X's in Figure 4. These mid-side nodes are free to translate and rotate. The user must supply nodes only at corners. Since corners remain straight in local buckling, user-supplied nodes are constrained from translation except at free ends of open sections.

SLC solves the resulting eigenvalue problem by an iterative technique. Each solution is for a specific plate length. It is assumed the variation of the eigenvalue with aspect ratio resembles the curves in Figure 3, i.e., a series of cusps and troughs with the bottom of each trough being constant. The program starts with an aspect ratio of 5.0 and successively decreases the length until the bottom of a trough, or minimum eigenvalue is found.

For an open section it is assumed initial buckling causes the section to fail. SLC produces a plot of the deformed shape and draws it superimposed over the undeformed shape. Also output with the plot are the eigenvalue, subcase, the CBAR or CBEAM element ID, the element end solved, the PBAR or PBEAM ID and the material constants from the corresponding MAT1 card.

For closed sections, the analysis continues. It is assumed closed sections do not fail with initial buckling but can carry the additional load necessary to buckle the open section obtained when the initially buckled part is removed. The SLC program finds the plate segment with greatest deformation and removes it giving an open section beam. The section data indicated in Figure 1, with the buckled plate removed, is reanalyzed to obtain section properties for the open section. These properties and NASTRAN force data are used to obtain stresses in the open section and SLC performs a second eigenvalue analysis. The output produced is the same as for the open section except three eigenvalues are output. The first is the eigenvalue for the closed section, the second is the eigenvalue for the open section described above and the third is the total of these two. The buckled shape shown is for the closed section.

EXAMPLES

SOLVE LOCAL COLLAPSE is executed through an interactive mode via a graphics terminal. The user first selects the function in GRAFAX as shown in Figure 5 by entering the word SECTION. GRAFAX responds with the request: ENTER A SECTION COMMAND. Figure 6 shows the various section commands. When the user enters SLC, GRAFAX responds with requests for subcase number, CBAR or CBEAM ID, and beam end. An example of GRAFAX requests and user entries are shown in Figure 7 where the user requests a local buckling analysis of End A of Beam 37 for Subcase 1.

In illustrating results from SOLVE LOCAL COLLAPSE, examine first some results for problems where the exact answer is known. Figure 8 shows an equal-leg angle in pure compression. This is the most difficult problem since it is not truly length independent. The plate buckles in a single wave between supports. The value for k in Figure 1 continues to diminish with increasing aspect ratio. Theory[(2)] indicates the buckling load at an aspect ratio 5.0 to be about 10% higher than at an aspect ratio of infinity. Results in Figure 9 show good agreement with a difference of 8.5%.

Local buckling of a square box beam in pure compression is shown in Figure 10. This case gives ideal simple-simple boundary conditions. SLC gives excellent agreement within 0.5% of theory. The open and total eigenvalues are not applicable in this case and should be ignored.

Excellent agreement is also seen in Figure 11, which shows the SLC results for a channel section in pure compression. SLC results differ by only 1.5% from theory.

The compression flange buckling of a box beam in pure bending is shown in Figure 12. Comparison is made with an MSC/NASTRAN Rigid Format 5 analysis presented at MSC/NASTRAN User's Conference in 1976. Results for the closed section eigenvalue agree within 1%.

[(2)] S. P. Timoshenko and J. M. Goodier, Theory of Elastic Stability, New York: McGraw-Hill Book Company, Inc., 1961

The excellent agreement obtained for these test problems gives confidence in the validity of the SOLVE LOCAL COLLAPSE function in GRAFAX. The program is in productive use in a design environment. Two sample problems from actual design use follow.

The first example is a closed section beam subject to bending and axial load. The resulting stresses at each NODE are shown in Figure 13. This figure was produced using the SOLVE STRESS RECOVERY function in GRAFAX. The likely candidate for buckling is the plate segment between NODES 4 and 5. It is long and most highly stressed in compression. The SLC analysis in Figure 14 confirms this as it is seen that the local buckling is concentrated in this plate segment.

The second example is an open section subject to a complicated loading producing stresses shown in Figure 15. The SLC analysis in Figure 16 shows the local buckling mode and eigenvalue.

SUMMARY

In summary, SOLVE LOCAL COLLAPSE is seen to be an MSC/NASTRAN interactive graphics post-processor which calculates the local buckling load and mode shape for thin-wall CBAR and CBEAM elements. SLC takes advantage of the fact that local buckling is simply a two-dimensional problem in a great majority of practical applications. Because of this, SOLVE LOCAL COLLAPSE can provide an economical analysis of local buckling in thin wall beams.

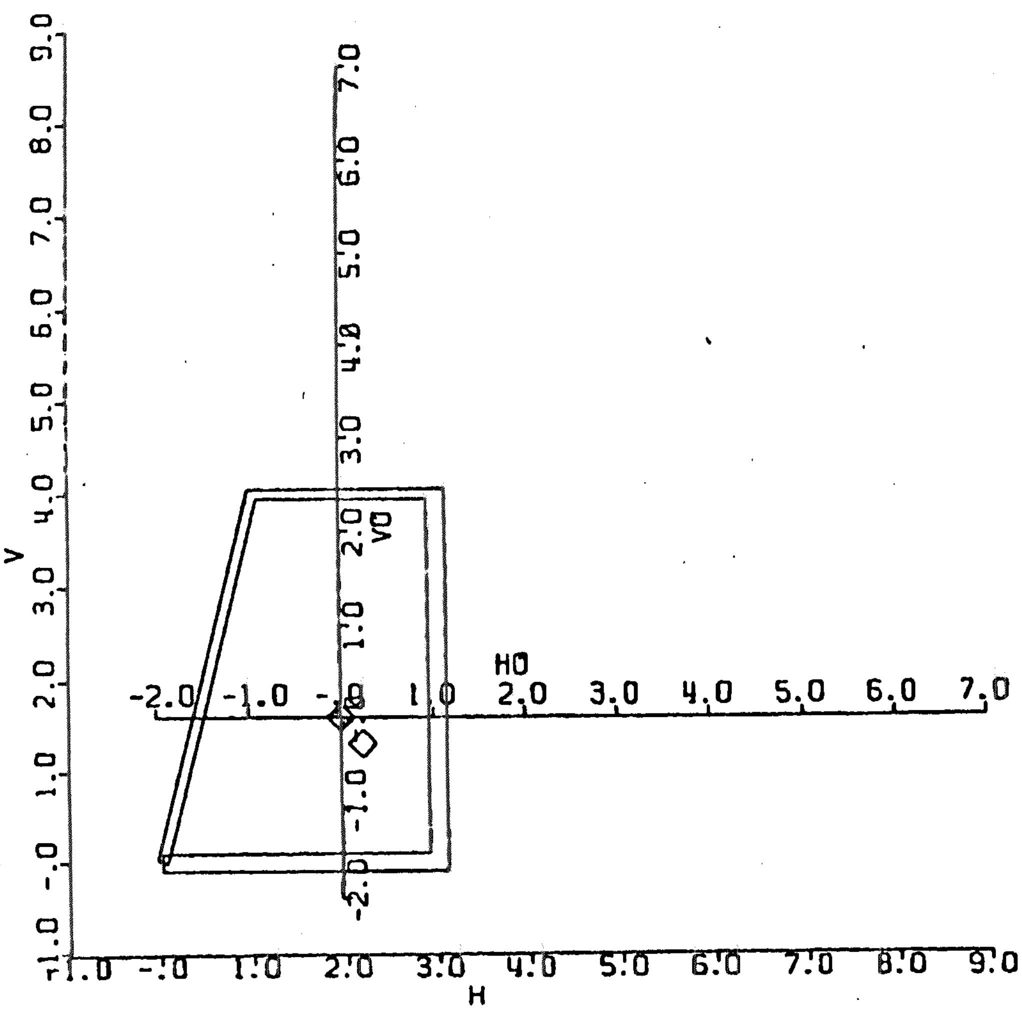
FIGURE 1. EXAMPLE THIN-WALL SECTION DATA

```
 1 MID      5
 2 PID      17
 3 NODE     1        0.       0.
 4 NODE     2        3.       0.
 5 NODE     3        3.       4.
 6 NODE     4        1.       4.
 7 LINE     1        1        2        .2
 8 LINE     2        2        3        .2
 9 LINE     3        3        4        .1
10 LINE     4        4        1        .1
L I S T E D
ENTER LINENO OR RANGE TO BE LISTED:
```

FIGURE 2. EXAMPLE GRAFAX SECTION SOLUTION

19-FEB-79

```
GRAFAX
PBAR          17        5    2.012    4.482    2.416    4.157
+PA0017   -1.602   -1.941   -1.602    1.059    2.398    1.059    2.398   -0.941
+PB0017    0.513    0.293    0.689
ENTER A SECTION COMMAND:
```



SECTION 17

CENTROID
1.941 , 1.602

SHEAR CENTER
2.183 , 1.315

IVH
.689

IH	IV
4.482	2.416

TORSION CONSTANT
4.1567

PERIMETER AREA
2.0123

KVV	KHV	KHH
1.9898	-.3842	3.4913

WARPING CONSTANT
0.0000

PLASTIC MOMENT
FACTORS

VP	HP
2.0556	2.7346

FIGURE 3. COMPRESSIVE-BUCKLING COEFFICIENTS FOR FLAT RECTANGULAR PLATES.

$$\sigma_{cr} = K_c \frac{\pi^2 E}{12(1-\nu^2)} \left(\frac{t}{b}\right)^2$$

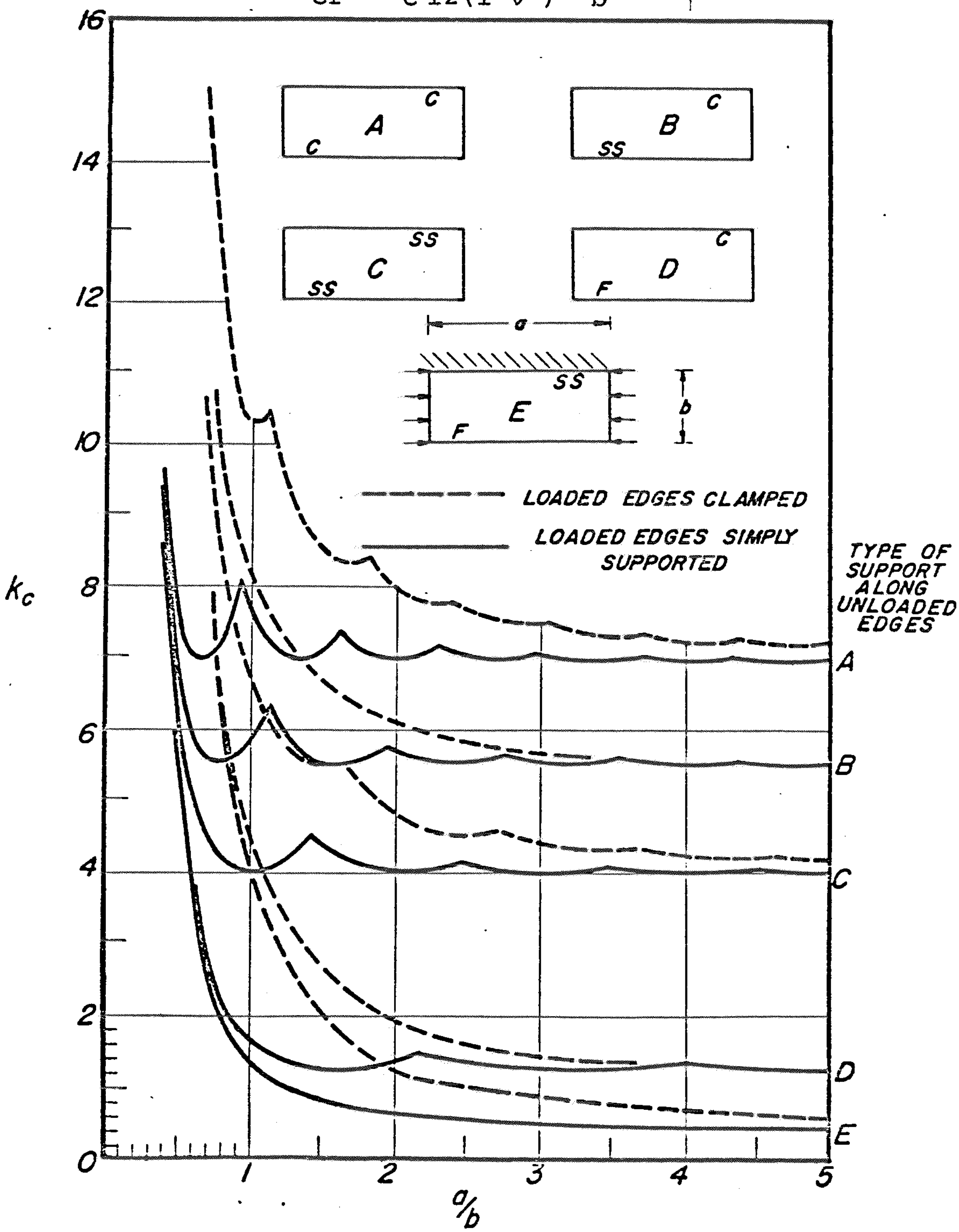


FIGURE 4. NODES USED IN SOLVE LOCAL COLLAPSE

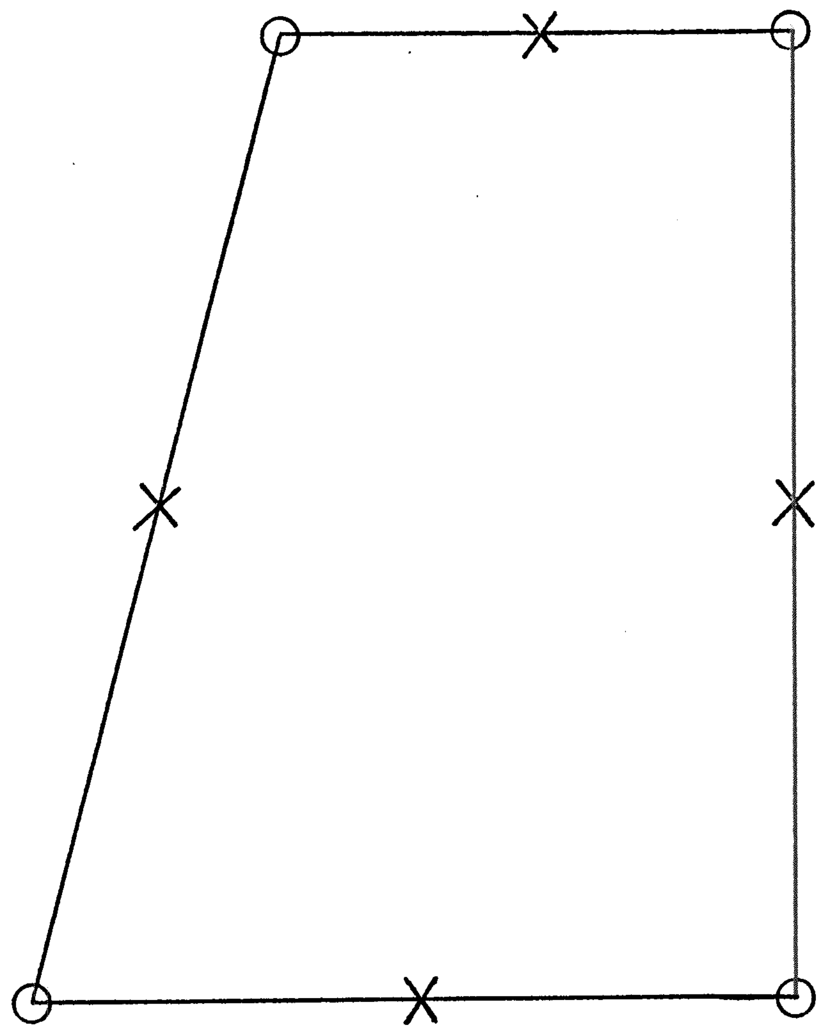


FIGURE 5:

```
A O S   G R A F A X   M A J O R   F U N C T I O N S   M E N U

PRE-PROCESSOR FUNCTIONS
    DIGIT   ---- DIGITIZE DATA FROM DRAWING
    EDIT    ---- EDIT OR GENERATE DATA
 -> SECTION ---- CALCULATE BEAM PROPERTIES
    VIEW    ---- VIEW UNDEFORMED MODEL

POST-PROCESSOR FUNCTIONS
 -> SECTION ---- CALCULATE BEAM COLLAPSE COEFFICIENT
    GRAPH   ---- GRAPH FEA OUTPUT
    PRINT   ---- DISPLAY FEA OUTPUT
    REPORT  ---- SUMMARIZE FEA OUTPUT
    VIEW    ---- VIEW DEFORMED MODEL

SPECIAL FUNCTIONS
    END     ---- END SESSION
    HELP    ---- DISPLAY MAJOR FUNCTIONS MENU
    RUN     ---- CREATE, EDIT & SUBMIT A BATCH RUN DECK

ENTER WORD AT LEFT TO PERFORM FUNCTION DESCRIBED.


E N T E R   A   F U N C T I O N :
```

FIGURE 6:

```
S E C T I O N   H E L P   M E N U

COMMAND
   A   ---- ADD
   C   ---- CHANGE
   CS  ---- CHARACTER SIZE ------------------------- (VALUE)
   DD  ---- DIGITIZE DATA
   D   ---- DELETE
   H   ---- CREATES THIS DISPLAY
   HC  ---- HARD COPY
   L   ---- LIST
   LO  ---- LIST OUTPUT
   LS  ---- LINE SIZE ------------------------------ (VALUE)
   NP  ---- NEW PAGE
   P   ---- PLOT
   R   ---- RETURN
   RB  ---- RING BELL
   RSD ---- RETRIEVE SECTION DATA ------------------ (PID)
   SC  ---- SOLVE CENTROIDAL
-> SLC ---- SOLVE LOCAL COLLAPSE
   SP  ---- SOLVE PRINCIPAL
   SSR ---- SOLVE STRESS RECOVERY

         D I G I T I Z I N G   S U B C O M M A N D S

    C ---- CONNECT TO EXISTING NODE WITH A LINE
    J ---- START FROM EXISTING NODE WITH A LINE
    O ---- RE-ORIENT DRAWING ON TABLET
    T ---- CHANGE THICNESS
    P ---- DIGITIZE A STRESS RECOVERY POINT


ENTER A SECTION COMMAND:
```

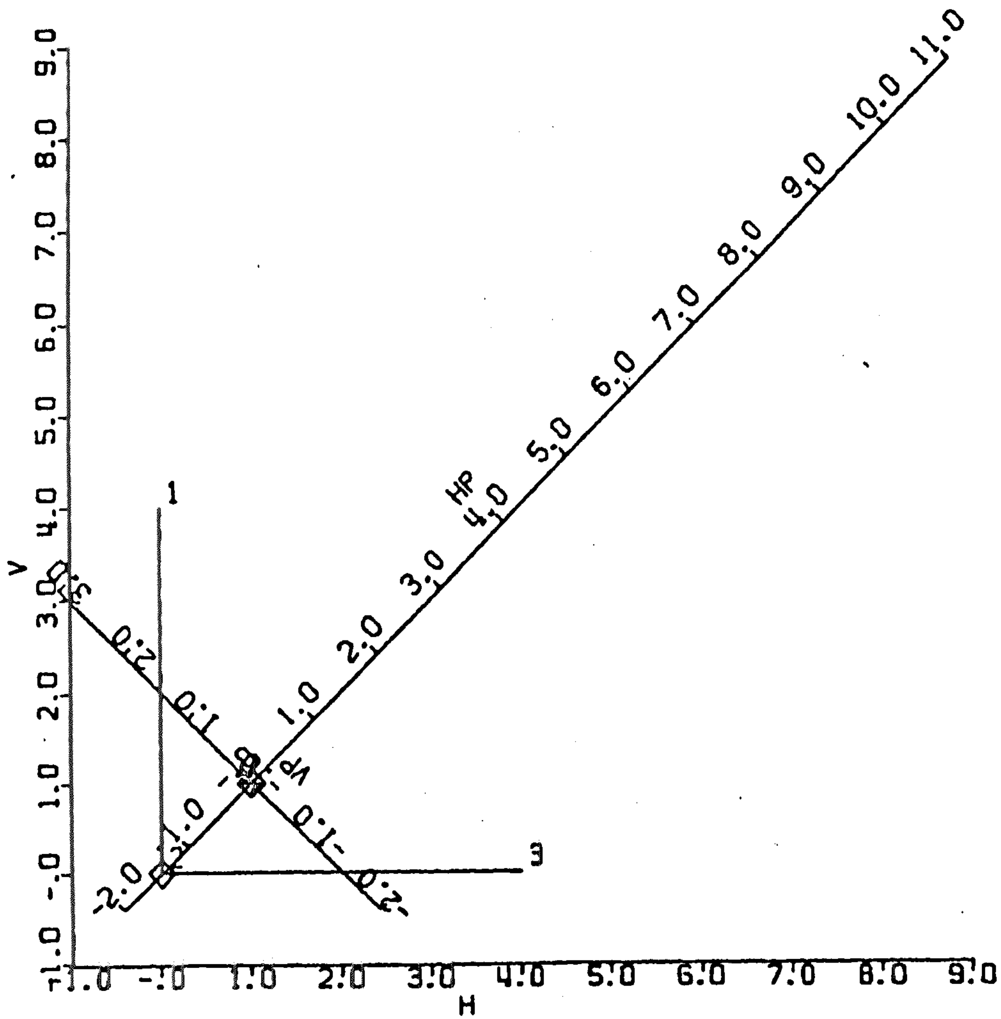
FIGURE 7. GRAFAX RESPONSES AND SAMPLE USER ENTRIES FOR SOLVE LOCAL COLLAPSE

```
ENTER A SECTION COMMAND:
SLC
ENTER SUBCASE NUMBER:
1
ENTER BEAM ELEMENT ID:
37
ENTER END A OR B:
A
```

FIGURE 8. SOLVE STRESS RECOVERY FOR EQUAL-LEG ANGLE IN COMPRESSION

GRAFAX SUBCASE 1 16-FEB-79

ENTER A SECTION COMMAND:



END A OF ELEMENT 37

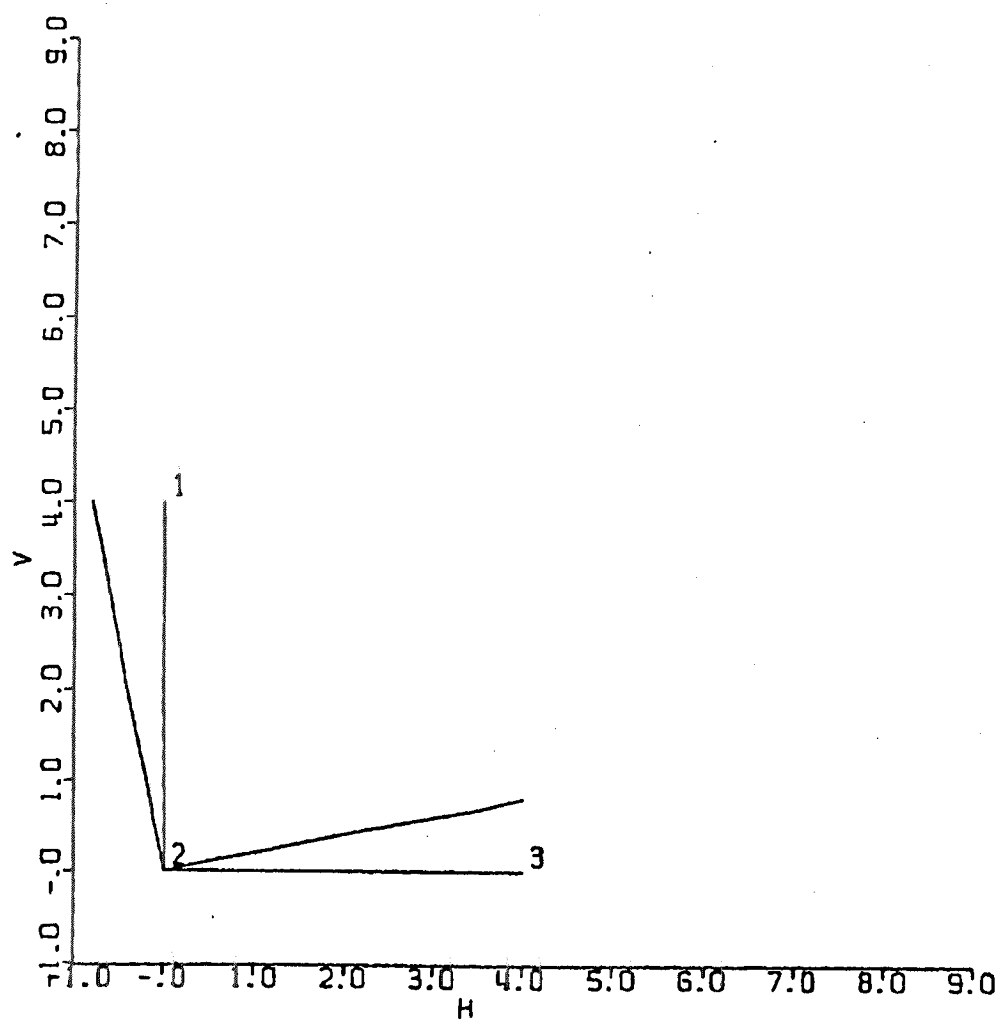
SECTION	52
MODULUS	.30000E+08
NU	.25000

NODE	STRESS
1	-624.9998
2	-624.9998
3	-624.9998

FIGURE 9. SOLVE LOCAL COLLAPSE FOR EQUAL-LEG ANGLE IN COMPRESSION

GRAFAX SUBCASE 1 15-FEB-79

ENTER A SECTION COMMAND:



END A OF ELEMENT 37

SECTION	52
MODULUS	.30000E+08
NU	.25000

EIGEN VALUE 52.054

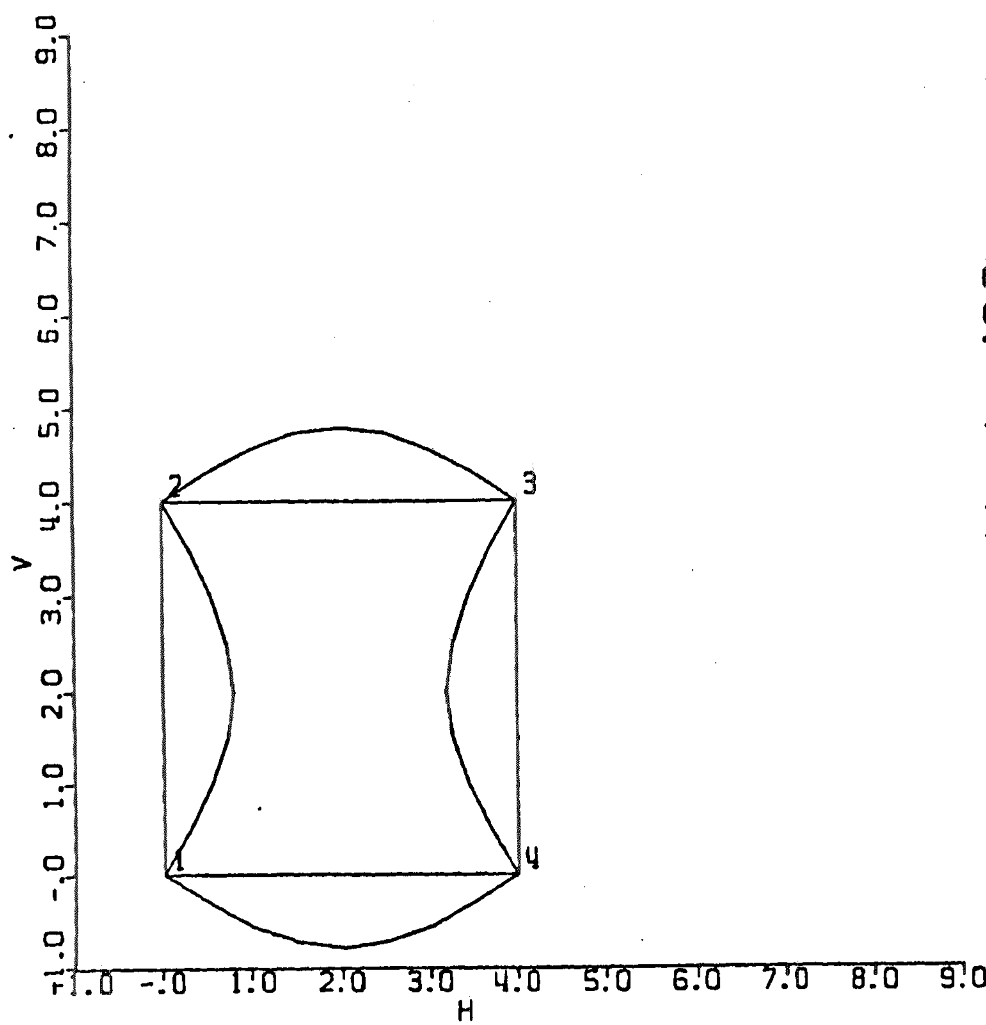
THEORY 48.

DIFFERENCE 8.5%

FIGURE 10. SOLVE LOCAL COLLAPSE FOR SQUARE BOX IN COMPRESSION

GRAFAX SUBCASE 1 25-OCT-78

ENTER A SECTION COMMAND:



END A OF ELEMENT 37

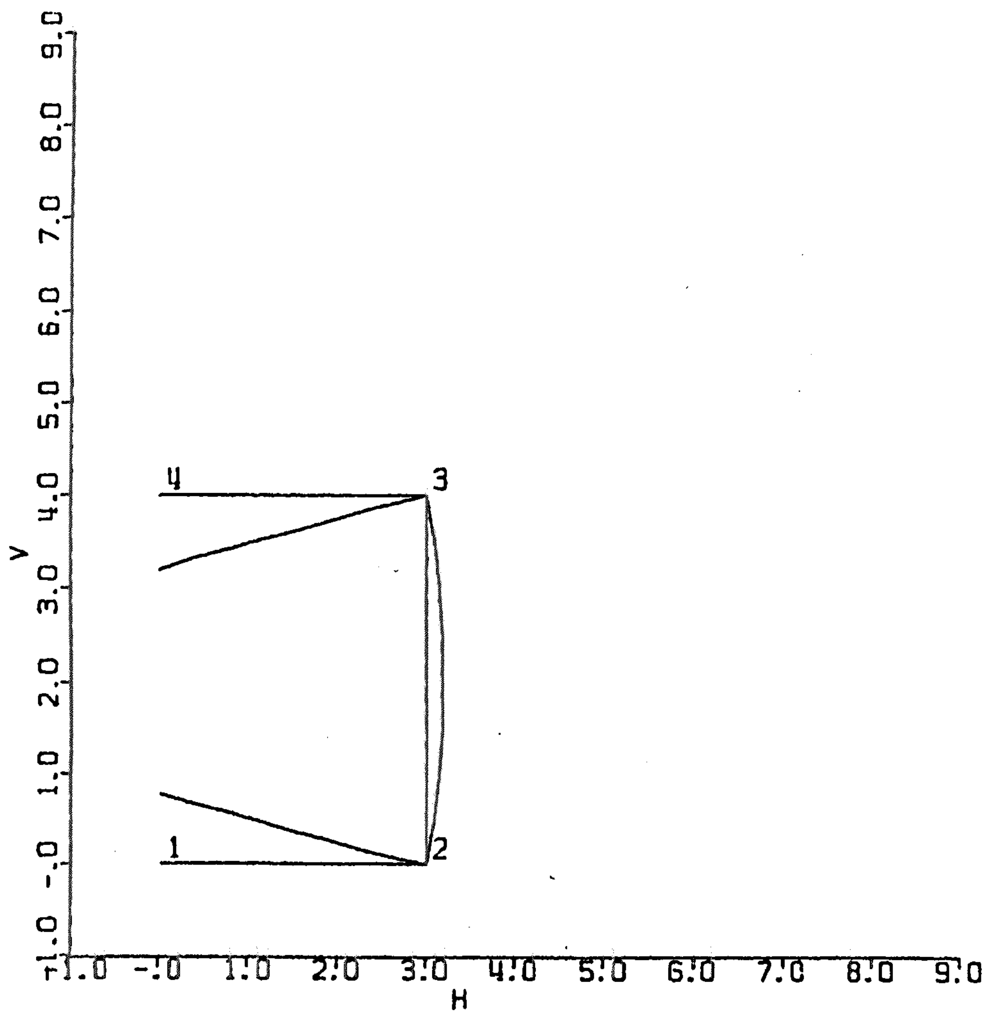
SECTION	41
MODULUS	.30000E+08
NU	.25000

CLOSED EIGENVALUE	845.77
OPEN EIGENVALUE	146.86
TOTAL EIGENVALUE	992.63
THEORY	842
DIFFERENCE	0.5%

FIGURE 11. SOLVE LOCAL COLLAPSE FOR CHANNEL IN PURE COMPRESSION

GRAFAX SUBCASE 1 28-SEP-78

ENTER A SECTION COMMAND:



END B OF ELEMENT 37

SECTION	46
MODULUS	.30000E+08
NU	.25000
EIGEN VALUE	206.05
THEORY	203
DIFFERENCE	1.5%

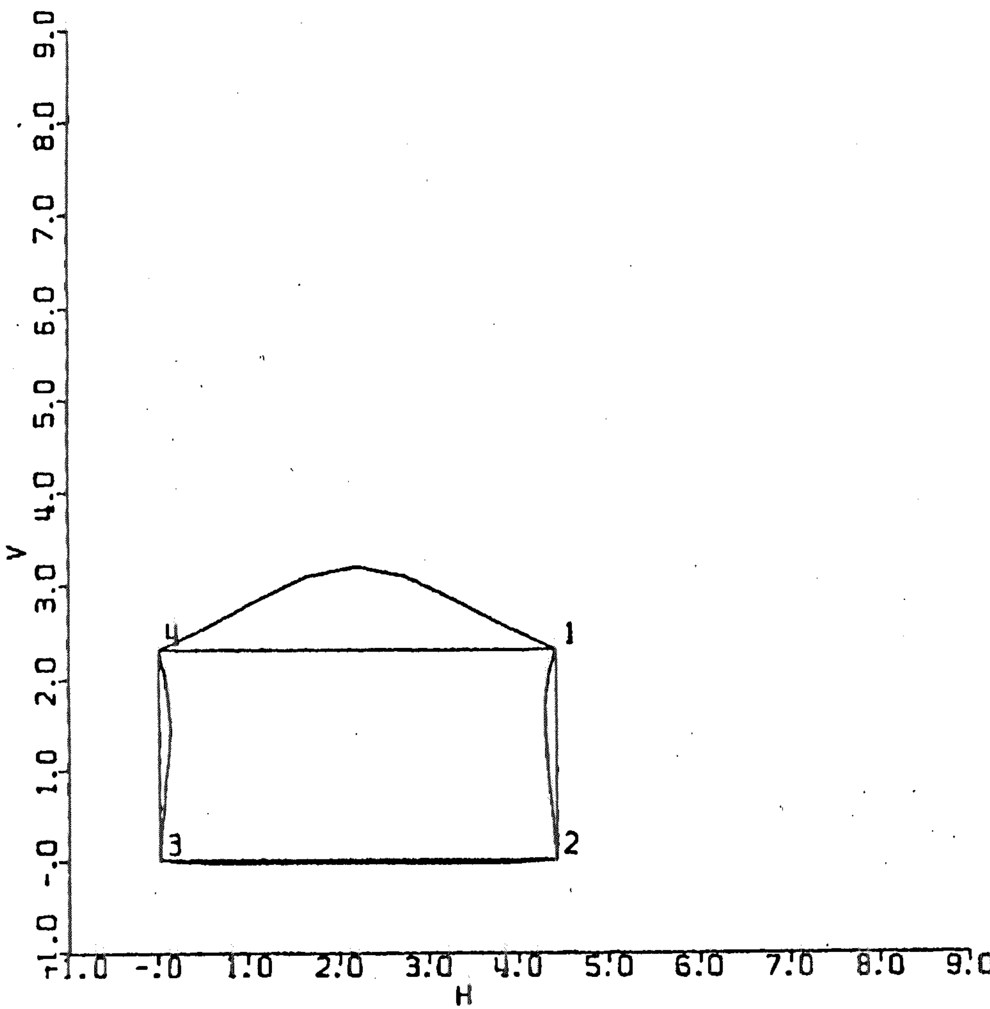
FIGURE 12. SOLVE LOCAL COLLAPSE FOR BOX BEAM IN PURE BENDING

GRAFAX
BEAM BUCKLING

SUBCASE 1

15-FEB-79

ENTER A SECTION COMMAND:



END A OF ELEMENT 1

SECTION	3
MODULUS	.30000E+08
NU	.25000

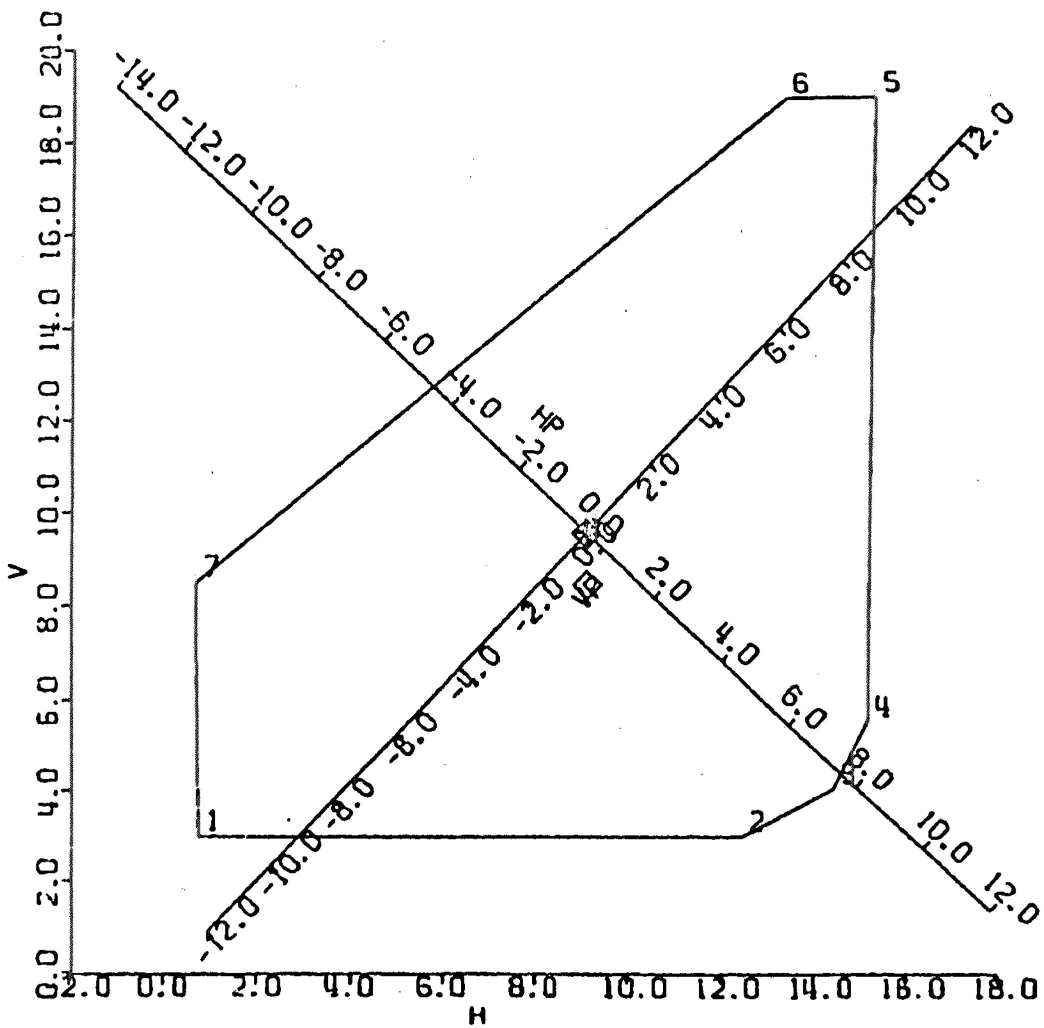
CLOSED EIGENVALUE	50.131
OPEN EIGENVALUE	10.681
TOTAL EIGENVALUE	60.812

MSC/NASTRAN RF5	50.7
DIFFERENCE	1%

FIGURE 13. SOLVE STRESS RECOVERY FOR CLOSED SECTION SUBJECT TO BENDING AND AXIAL LOAD

CRAFAX SUBCASE 1 15-FEB-79

ENTER A SECTION COMMAND:



END A OF ELEMENT 37

SECTION	37
MODULUS	.30000E+08
NU	.25000

NODE	STRESS
1	353.9070
2	-71.0086
3	-158.8910
4	-211.2321
5	-434.2646
6	-363.8430
7	263.0168

FIGURE 14. SOLVE LOCAL COLLAPSE FOR CLOSED SECTION SUBJECT TO BENDING AND AXIAL LOAD

GRAFAX SUBCASE 1 Ø3-NOV-78

ENTER A SECTION COMMAND:

END A OF ELEMENT 37

SECTION	42
MODULUS	3ØØØØE+Ø8
NU	.25ØØØ

CLOSED EIGENVALUE	115.15
OPEN EIGENVALUE	77.195
TOTAL EIGENVALUE	192.34

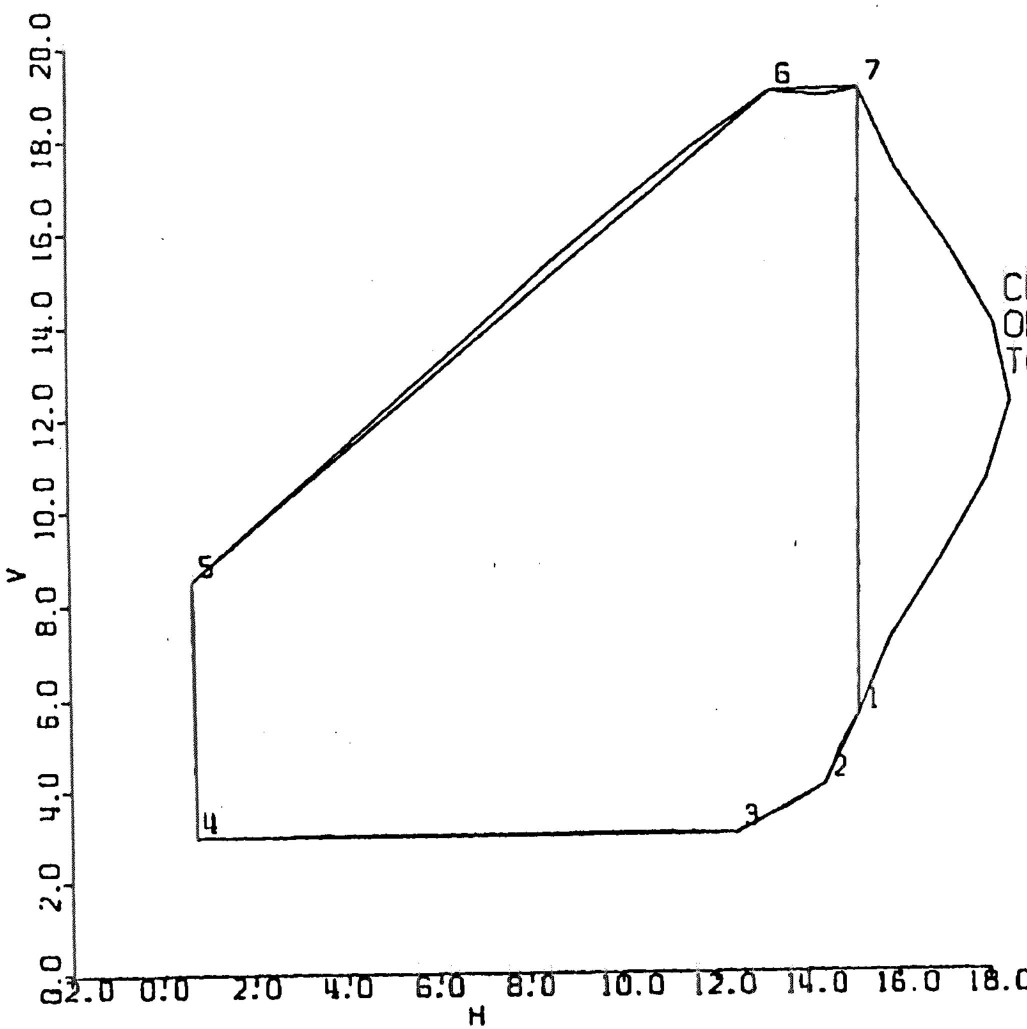


FIGURE 15. SOLVE STRESS RECOVERY FOR OPEN SECTION
SUBJECT TO BENDING AND AXIAL LOAD

CRAFAX SUBCASE 1 22-Feb-79

ENTER A SECTION COMMAND:

END A OF ELEMENT 19

SECTION	19
MODULUS	29528.
NU	0.30000

NODE	STRESS
1	-24.5545
2	-18.4601
3	-55.4024
4	-45.9148
5	-16.7054
6	-11.9188

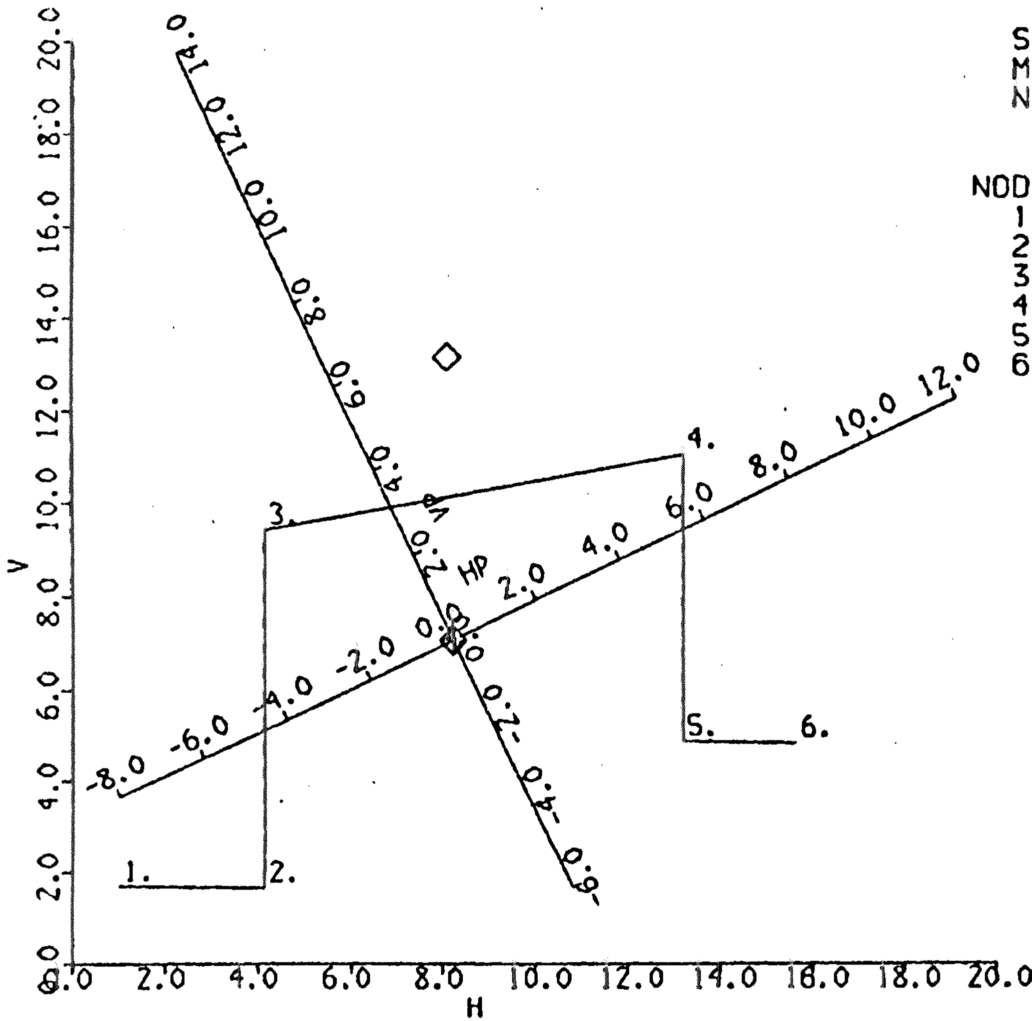
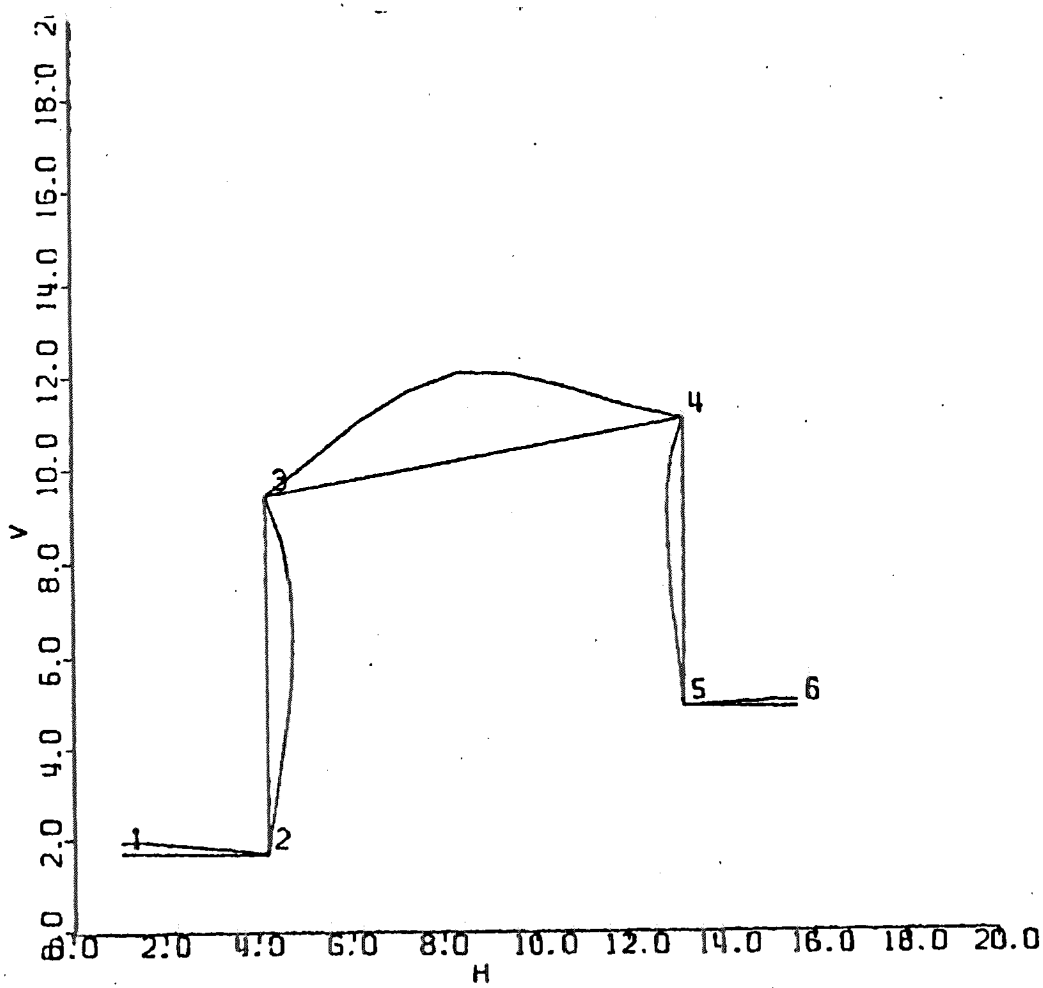


FIGURE 16. SOLVE LOCAL COLLAPSE FOR AN OPEN SECTION SUBJECT TO BENDING AND AXIAL LOAD

CRAFAX SUBCASE 1 22-FEB-79



END A OF ELEMENT 19

SECTION	19
MODULUS	.44950E+07
NU	.30000

EIGEN VALUE 161.70