ABSTRACT

AOS/GRAFAX, the commercially-available interactive graphics system for pre- and post-processing MSC/NASTRAN, has been expanded to accommodate multilevel superelements. The VIEW function now has the following additional features:

- prepare GRID card SEID for user-selected substructures.
- create secondary superelement exterior GRIDs and CSUPER card.
- plot and add undeformed and deformed superelements by SEID sets.

A new function (SUPER) reorders exterior GRIDs optimally for cost-effective boundary and residual-structure superelement solutions. Practical applications of these features are presented.

BACKGROUND

MSC/NASTRAN multilevel superelements have proven to be cost-effective (1)* in static and dynamic applications using mirror-image secondary superelements. Secondary superelements are defined in terms of a primary and a series of exterior GRIDs by means of a CSUPER card. Accurately locating these exterior GRIDs and editing changes in the CSUPER card can be tedious.

Choosing substructures (superelements) in a complicated structure is not an easy task. An obvious choice may be at boundaries between physical sub-assemblies (1, 2). However a complex structure may require substructuring merely to reduce superelement size or accommodate local redesign. SEMAP statistics and edited SEID changes on GRID cards (or added SESET cards) are required to resubstructure.

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*See references at end of paper.

The SEUPPLOT and SEPLOT commands are ineffective for secondary superelements in current MSC/NASTRAN plots. It would be convenient to show complete structure deformed and undeformed plots when using mirror-image or identical substructures.

Any GRID that is exterior to any superelement can not benefit from resequencing (3). Hence, residual and CSUPER GRIDs (along with others) are used with user-supplied GID. Reordering exterior GID for optimum matrix banding in boundary and residual-structure superelements is desirable for cost-effective superelement solution.

The VIEW function of the MSC/NASTRAN pre- and post-processing interactive graphics system, AOS/GRAFAX (4), has been expanded to accommodate multilevel superelements. The following additional features are available.

- create exterior GRIDs and the CSUPER card for secondary superelements.
- prepare GRID card SEID for substructures selected interactively.
- display undeformed plots (pre-processing) and deformed plots (post-processing) for all superelements. (The GRAPH, REPORT, and PRINT functions continue to support post-processing of superelement subcases.)

A new function, SUPER, optimally reorders exterior GID for cost-effective solution. Also, solution-time statistics are displayed for boundary and residual-structure superelements. Element connections are reformatted and a data file prepared.

INTERACTIVE SUBSTRUCTURING EXAMPLE

Figure 1 shows a weldment substructured into two superelements (SEID 16 and 17). The figure shows SE 17 with large DOF and bandwidth primarily because of a fine mesh required for one plate. Table 1 shows computer seconds (normalized to 1000) for stiffness matrix decomposition and FBS statistics for the two superelements.

Figure 2 illustrates an alternative substructuring between SE 16 and SE 17. A few hundred DOF removed from SE 17 are included in SE 16 with a dramatic decrease in bandwidth. The revised substructures removed a "structural loop" (see Figure 1) where a closed loop of steel in SE 17 was opened. Table 1 shows that total solution time is reduced by over 50%.

The AOS/GRAFAX user selects structural components desired for a primary superelement by displaying them on the interactive graphics terminal with one of the following commands:

- Plot Element Property - plot selected element type with given PID.
- Add Element Property - add elements with selected PID to plot on graphics display.
- Plot Location - plot all elements within a specified three-dimensional region.
- Zoom - plot an enlarged portion of the model.

A Divide Model (DM) command assigns a user-specified SEID to all GRIDs displayed. Boundary GRIDs will have an SEID for the last structure to be displayed. A Plot Superelement (PSE) command will display the selected SEID. An Add Superelement (ASE) command may be used to add additional superelements to the interactive graphics display.

Figure 3 shows a sequence of commands to select the plates in the original SE 16 (see Figure 1). A Divide Model (DM 16) assigns SEID = 16 to all GRIDs displayed in Figure 3c.

SECONDARY SUPERELEMENT GENERATION

Figure 4 shows a generated mirror-image secondary superelement (SEID=30) from a primary (SEID=10). The user enters an MIR command and the axis being reversed (X axis in Figure 4). Secondary exterior GRIDs are generated based on the location of primary exterior GRIDs. The CSUPER card is also prepared. Similar commands are available for identical secondaries. A plot (as shown in Figure 4) verifies that the secondary superelement has been generated.

Figure 5 shows a vehicle frame finite element model plotted using the MIR, DM, PSE and ASE features of AOS/GRAFAX.

DEFORMED SHAPE POST-PROCESSING

AOS/GRAFAX has always had a Plot Deformed Shape (PDS) command in the VIEW function with an undeformed shape overlay in a dash pattern optional. This has been augmented to Plot Deformed Superelement (PDSE) or Add Deformed Superelement (ADSE). Figure 6 shows a single primary superelement deformed shape (with undeformed overlay) and a combination of primary and secondary superelements displayed by specifying SEID sets and the appropriate subcase numbers.

IDENTICAL-SECONDARY BOUNDARY-SE-MATRIX BANDING

Figure 7 shows a primary superelement (SEID=10) and an identical secondary (SEID=20). Two SE 10 GRIDs and matching SE 20 GRIDs are placed in the residual structure (SE 0) to perhaps later change constraints. All 30 boundary GRIDs are included in a boundary superelement, SE 5. The figure also shows the superelement tree and SEMAP data.

Figure 8 shows SE 5 stiffness matrix graphically for two choices of user-supplied GIDs. It is obvious that a better banded matrix results if SE 5 GIDs increase from left to right (see Figure 7). Superelement solution for all superelements require stiffness matrix decomposition (proportinal to bandwidth squared) and all but the residual structure require FBS (proportional to bandwidth) to form the transformation matrix GO. Hence, proper user GID choice for exterior (unresequenced) GRIDs can have a significant impact on problem solution cost.

RESIDUAL STRUCTURE MATRIX BANDING EXAMPLE

Residual structure GRIDs are exterior to upstream superelements and user-supplied GID determine stiffness matrix banding for decomposition during solution.

Table 2 shows SEMAP statistics for a 401 GRID residual structure in a single-level superelement analysis with six upstream superelements. The table also shows GRID interaction based on SEMAP statistics.

Figure 9 shows SE 0 stiffness matrix graphically with GID increasing from A to K. Table 3 tabulates data from Figure 9 and Table 2 to determine RMS bandwidth for the residual structure using the original GID.

It is by no means easy to examine Figure 9 and determine an optimum method to reorder residual GID to improve matrix banding. However, assume the order shown in Figure 10 was chosen. The figure shows a better banded matrix and Table 3 shows RMS bandwidth decreased from 666 to 526. Decomposition time (proportional to bandwidth squared) is reduced by almost 40%. Clearly, reordering residual GID is desirable if an automated procedure is available.

AOS/GRAFAX EXTERIOR GID REORDERING EXAMPLE

A new function, SUPER, has been added to AOS/GRAFAX to be used in conjunction with the SEMAP file from a superelement data base to reorder GID for exterior GRIDs found in boundary and residual-structure superelements. SEMAP data (Table 2) and a GRID resequencing program are used to reorder GID by GRID groups.

Figure 11 shows typical commands in an AOS/GRAFAX session for the residual-structure GRIDs described above (see Figures 9, 10, and Tables 2, 3). Figure 12 shows initial and reordered GRID groups from the automatic renumbering option. Figure 13 compares matrix displays for original and reordered GRID groups (compare with Figure 9 and Figure 10, which was based on the SUPER function resequencing results). Figure 14 shows RMS bandwidth and stiffness matrix decomposition time and cost estimate. An FBS and MPYAD output would be displayed for boundary superelements.

The SUPER function only resequences GID by GRID groups (GID increases monotonically within a group). Element connectivities are changed and the user may also request a connectivity summary and data file. Figure 14 statistics have been found to be quite accurate, whereas the MSC/NASTRAN SEQP module gives no matrix decomposition data for the residual structure and inaccurate data for boundary superelements.

CONCLUSIONS

The expanded VIEW function in AOS/GRAFAX has been used successfully to create and plot (deformed and undeformed shape) primary and secondary superelements. Exterior GRIDs have been successfully reordered in boundary and residual-structure superelements for cost-effective solutions. Also complicated weldments were resubstructured using AOS/GRAFAX with expanded functions to accommodate superelements. Superelement sequences in MSC/NASTRAN should be enhanced to either resequence exterior GRIDs or accept a user-supplied reordering card (similar to the SEQGP card) to resequence exterior GRIDs.

REFERENCES

(1) Lawson, D. W., et al, "MSC/NASTRAN Superelements in Structures with Reflective Symmetry", Proceedings of the Conference on Finite Element Methods and Technology, Pasadena, CA, March 13-14, 1980.

(2) Brewer, T. J., "The Use of a Pilot Model to Develop Superelement Skills", Proceedings of First Chautauqua on Finite Element Modeling, Harwichport, MA, Sept. 15-17, 1980, pp. 215-224.

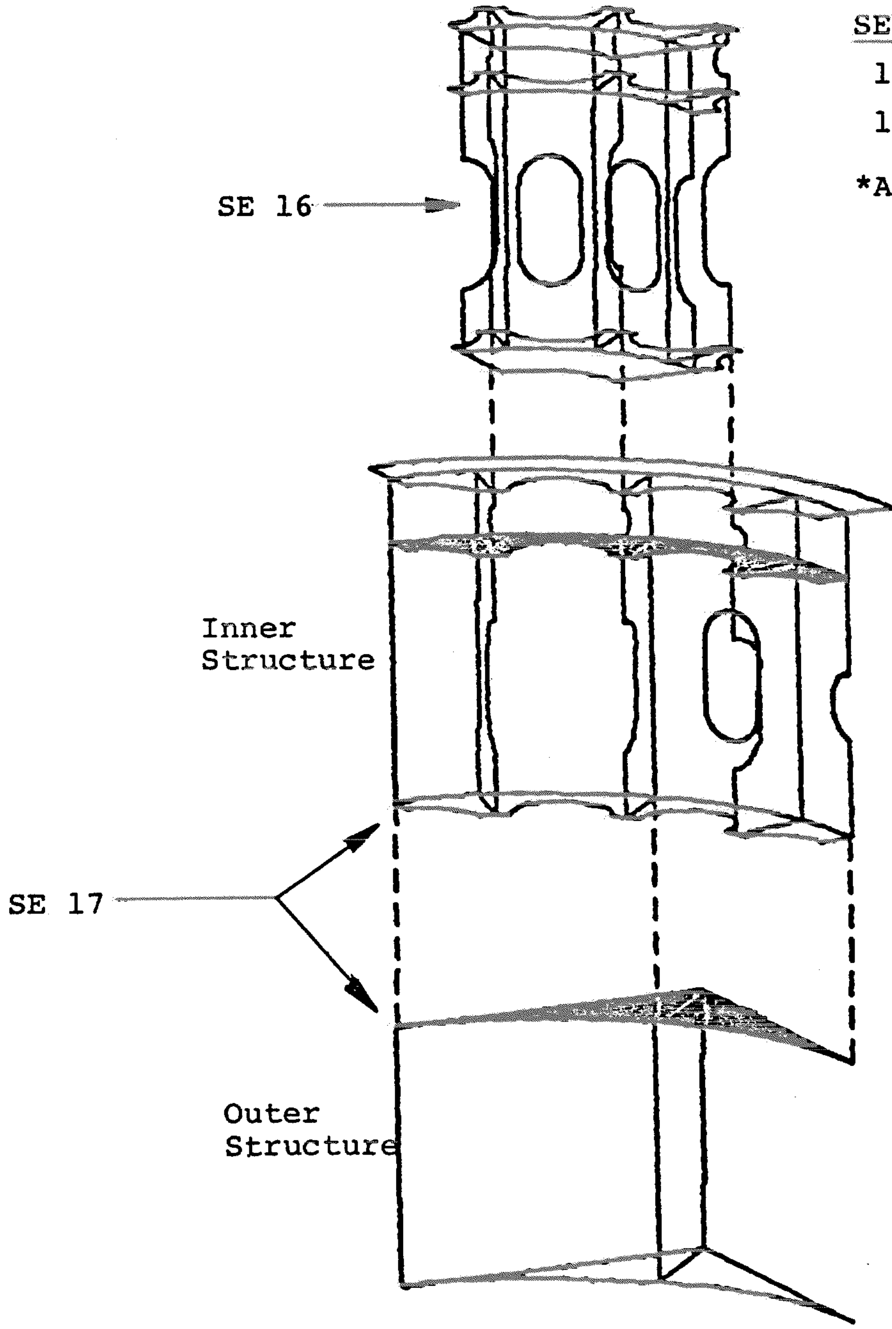
(3) Joseph, J. A., Editor "MSC/NASTRAN User's Manual", The MacNeal-Schwendler Corporation, Los Angeles, CA, May, 1980, Section 1.12.

(4) Lambert, J. L., "GRAFAX - Interactive Pre- and Post-Processor for MSC/NASTRAN", Proceedings of the MSC/NASTRAN User's Conference, Pasadena, CA, March 15-16, 1979.

MODEL SIZE*
(GRID DOF;
Bandwidth, GRIDs)

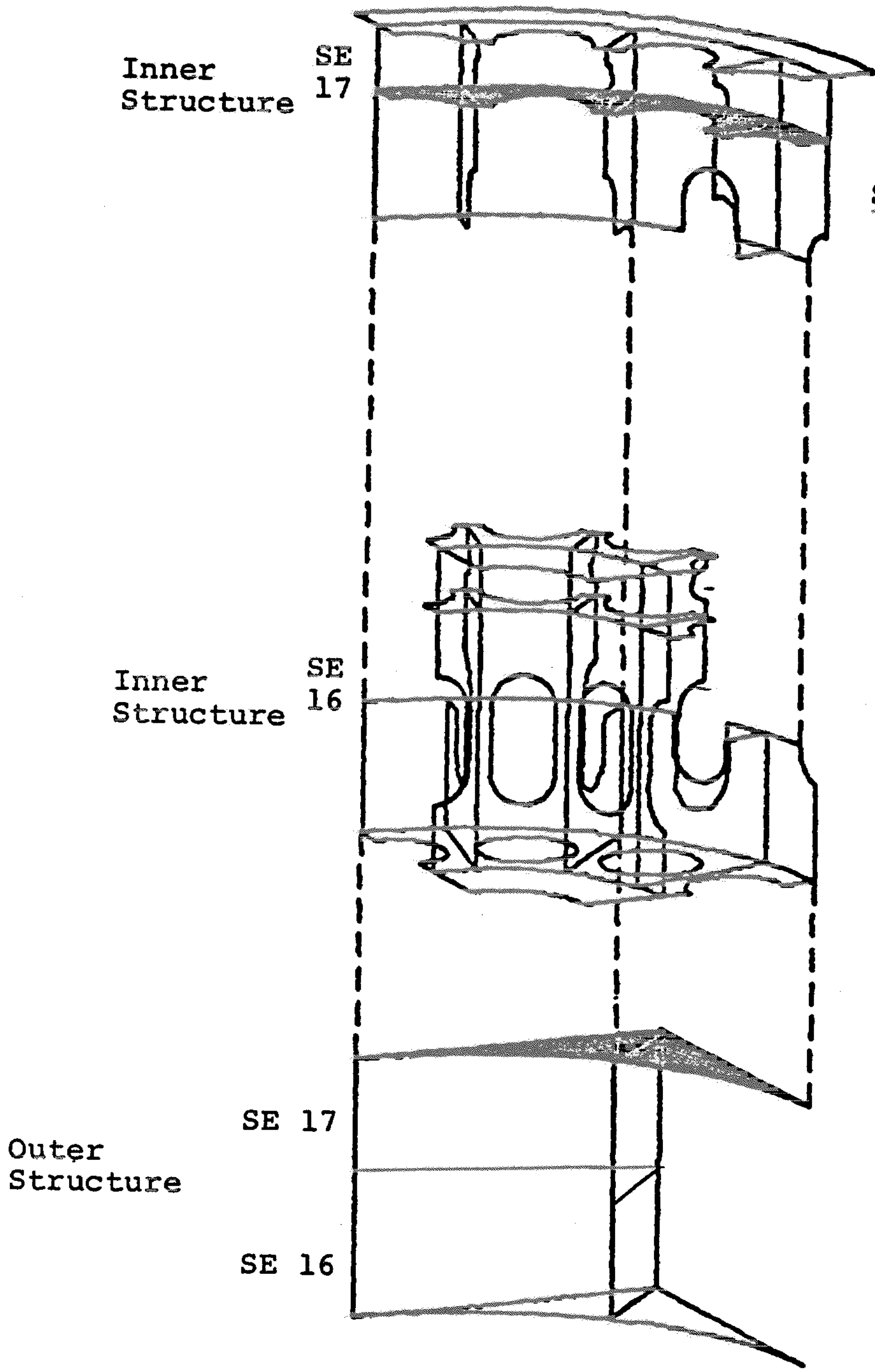
SEID	DOF	BW(RMS)
16	1452	12.2
17	7071	76.5

*Also see Table 1



NOTE:
Shaded area has
very fine mesh

FIGURE 1. PLATE ELEMENT STRUCTURE, SE 16 AND SE 17, ORIGINAL MODEL



MODEL SIZE*
(GRID DOF
Bandwidth, GRIDs)

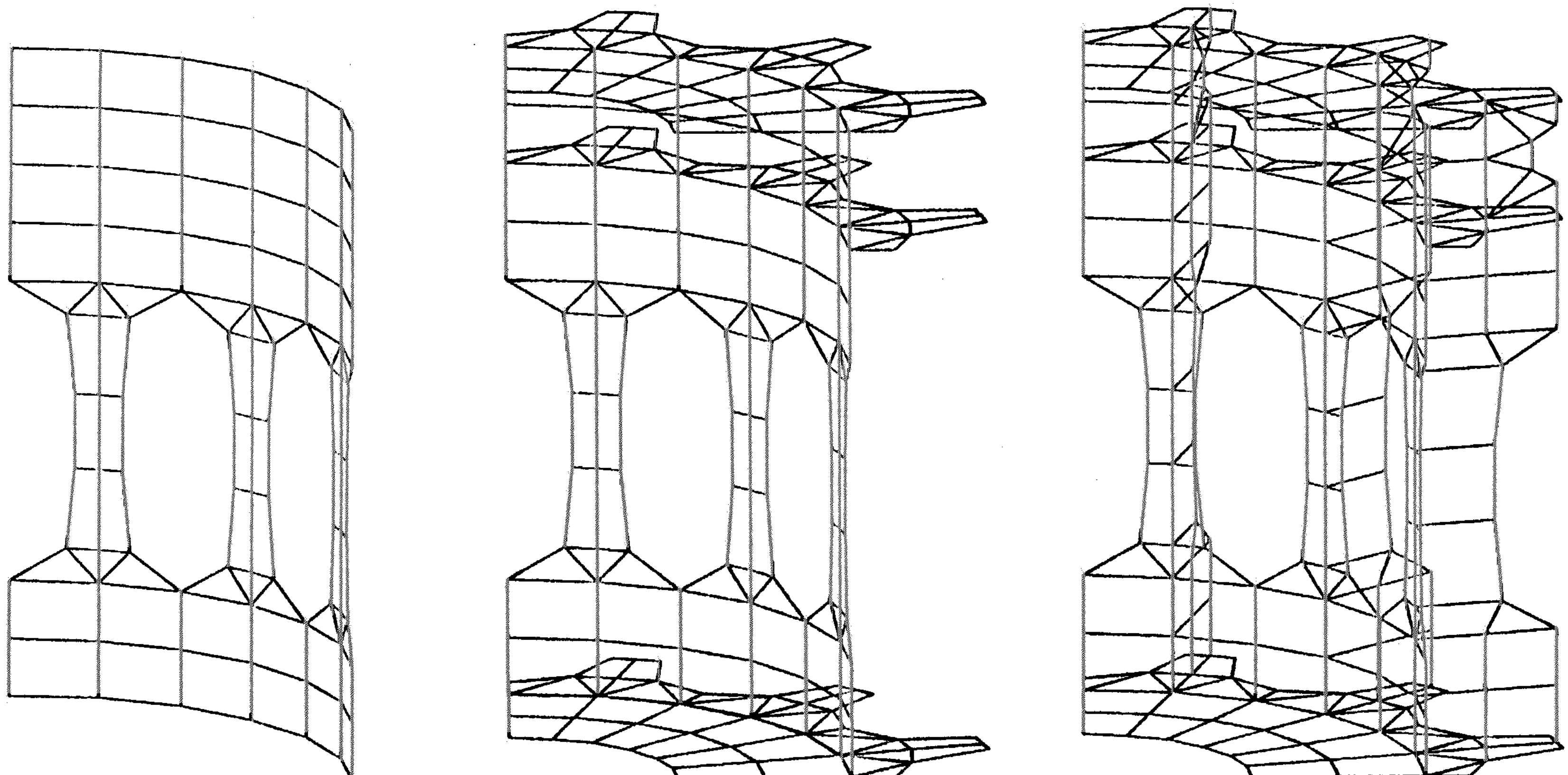
SEID	DOF	BW(RMS)
16	2158	20.9
17	6365	39

*Also see Table 1

NOTE:
Shaded area has very fine mesh.

FIGURE 2. PLATE ELEMENT STRUCTURE, SE 16 AND SE 17, REVISED MODEL

RX= -75.   RY=   0.   RZ=   0.   MODEL: DMSE1   09-FEB-81
ENTER A VIEW COMMAND:



a. Plot Property 1 - Barrel

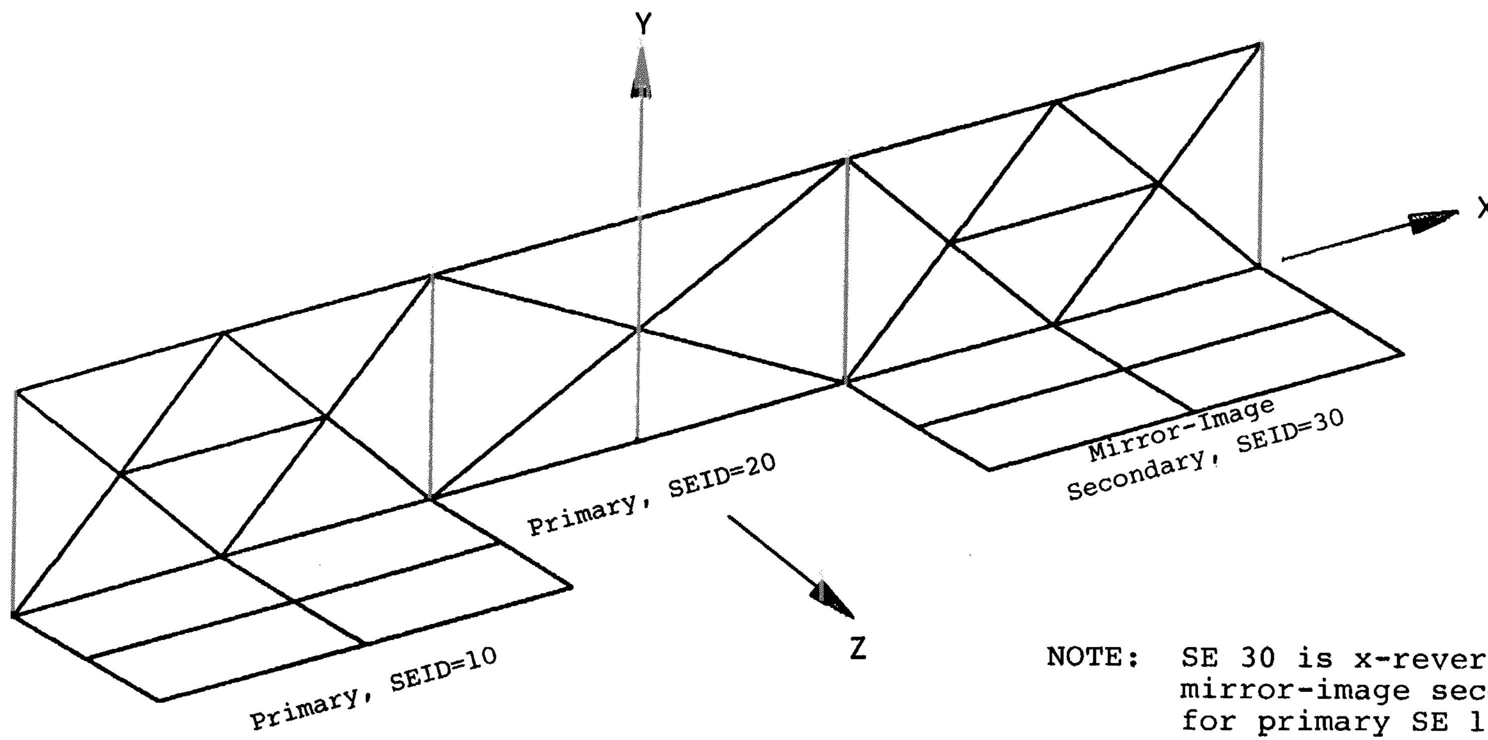
b. Add Property 2 - Horizontal Plates

c. Add Property 3 - Vertical Stiffeners

FIGURE 3. AOS/GRAFAX DIVIDE MODEL EXAMPLE (ORIGINAL SE 16)

RX= 25. RY= 35. RZ= 0. MODEL: ERTESTPL 09-FEB-81
ENTER A VIEW COMMAND:
ASE 30

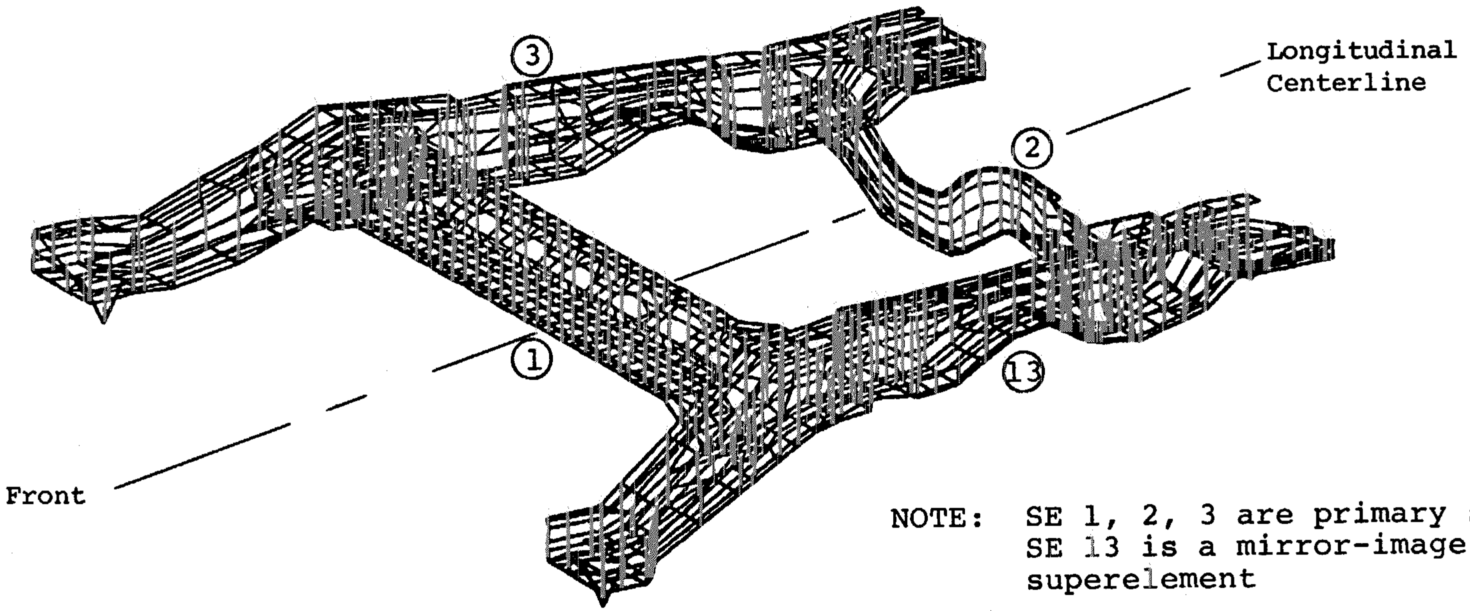
ENTER A VIEW COMMAND:



NOTE: SE 30 is x-reversal mirror-image secondary for primary SE 10.

FIGURE 4. UNDEFORMED PLOT BY SEID

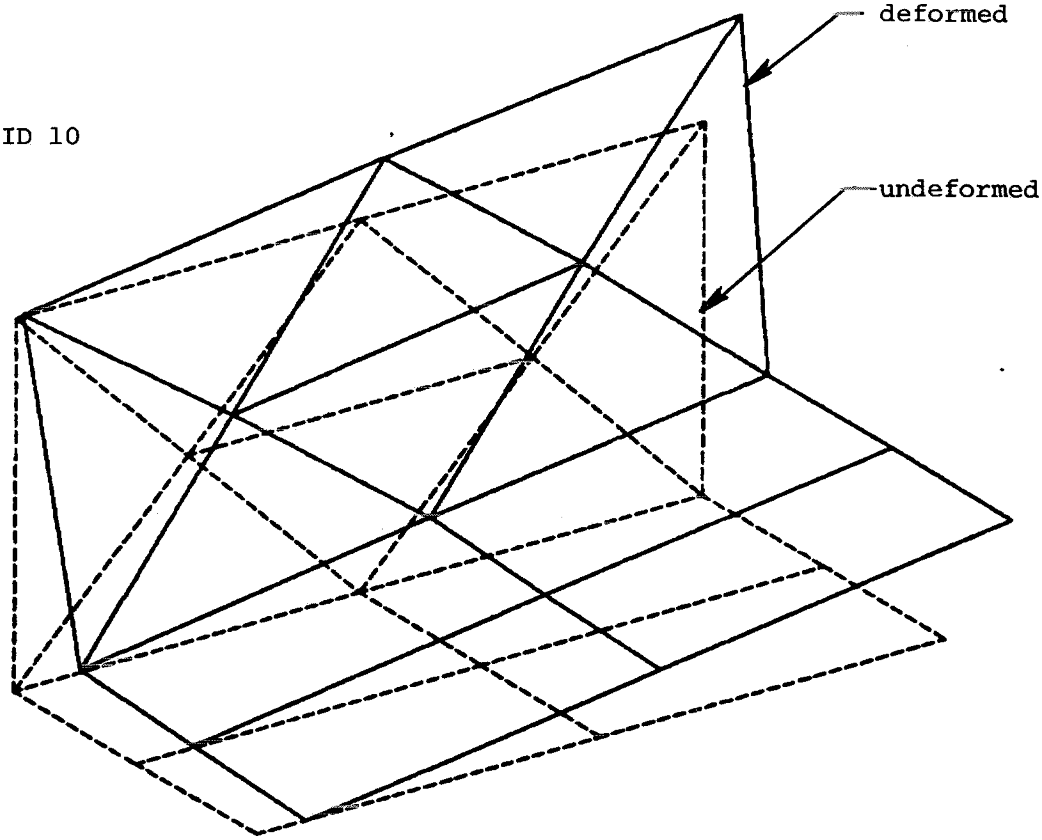
RX= 70. RY= 0. RZ= 30. MODEL: RSCRA3 09-FEB-81
ENTER A VIEW COMMAND:
ASE 13



NOTE: SE 1, 2, 3 are primary superelements
SE 13 is a mirror-image secondary superelement

FIGURE 5. AOS/GRAFAX VIEW OF VEHICLE FRAME MODEL

a. SEID 10



b. SEID 10, 20, 30

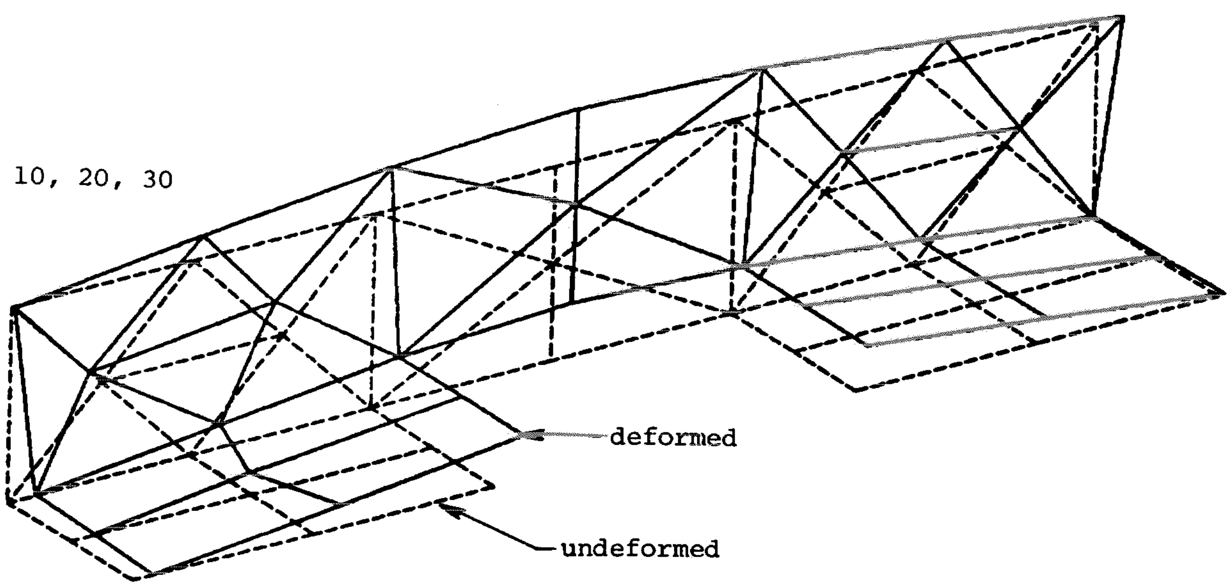
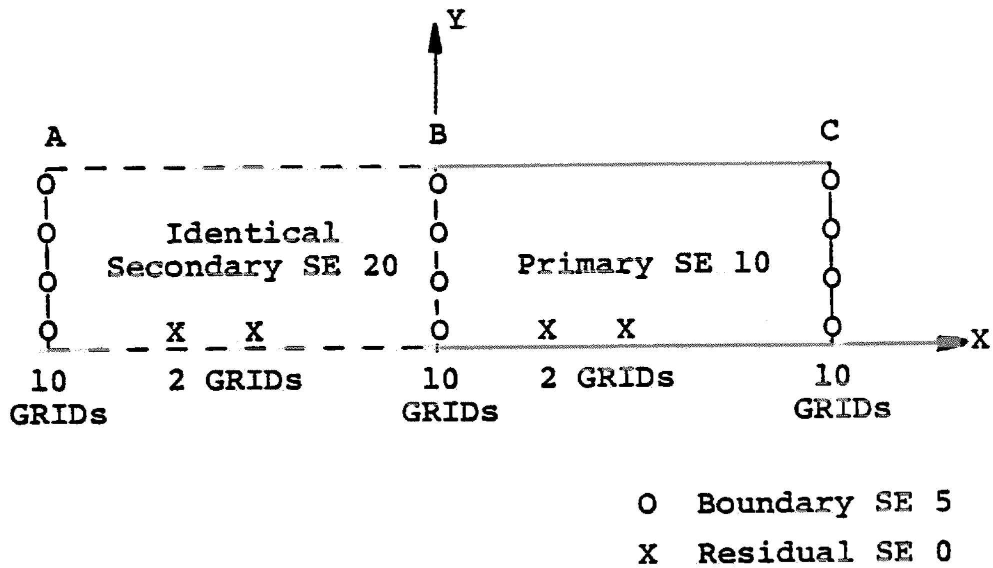
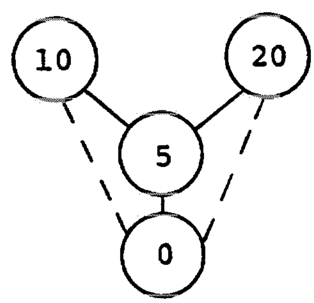


FIGURE 6. DEFORMED AND UNDEFORMED PLOTS BY SEID



a. Primary and identical secondary Superelements



b. Superelement Tree

GRIDs	Interior to:	Exterior to:
A	5	20
B	5	10,20
C	5	10
or		
A,B	5	20
B,C	5	10

c. GRID Interaction

FIGURE 7. IDENTICAL SECONDARY AND BOUNDARY SUPERELEMENT MODEL

GRID Groups, Increasing GID →

	B	C	A
B	B-B	B-C	A-B
C	B-C	C-C	0
A	A-B	0	A-A

a. Superelement 5 matrix, GRID order: B,C,A

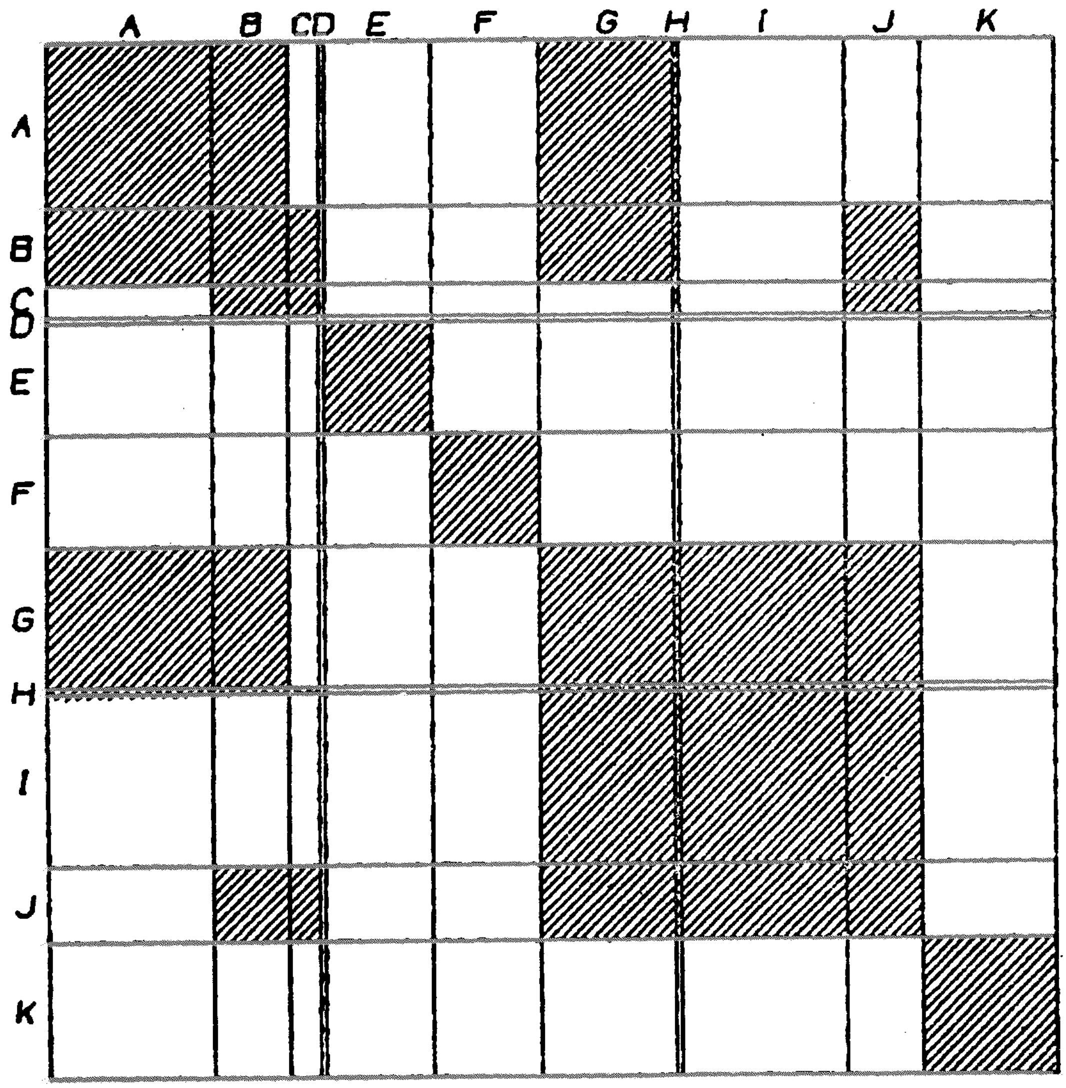
GRID Groups, Increasing GID →

	A	B	C
A	A-A	A-B	0
B	A-B	B-B	B-C
C	0	B-C	C-C

b. Superelement 5 matrix, GRID order: A,B,C

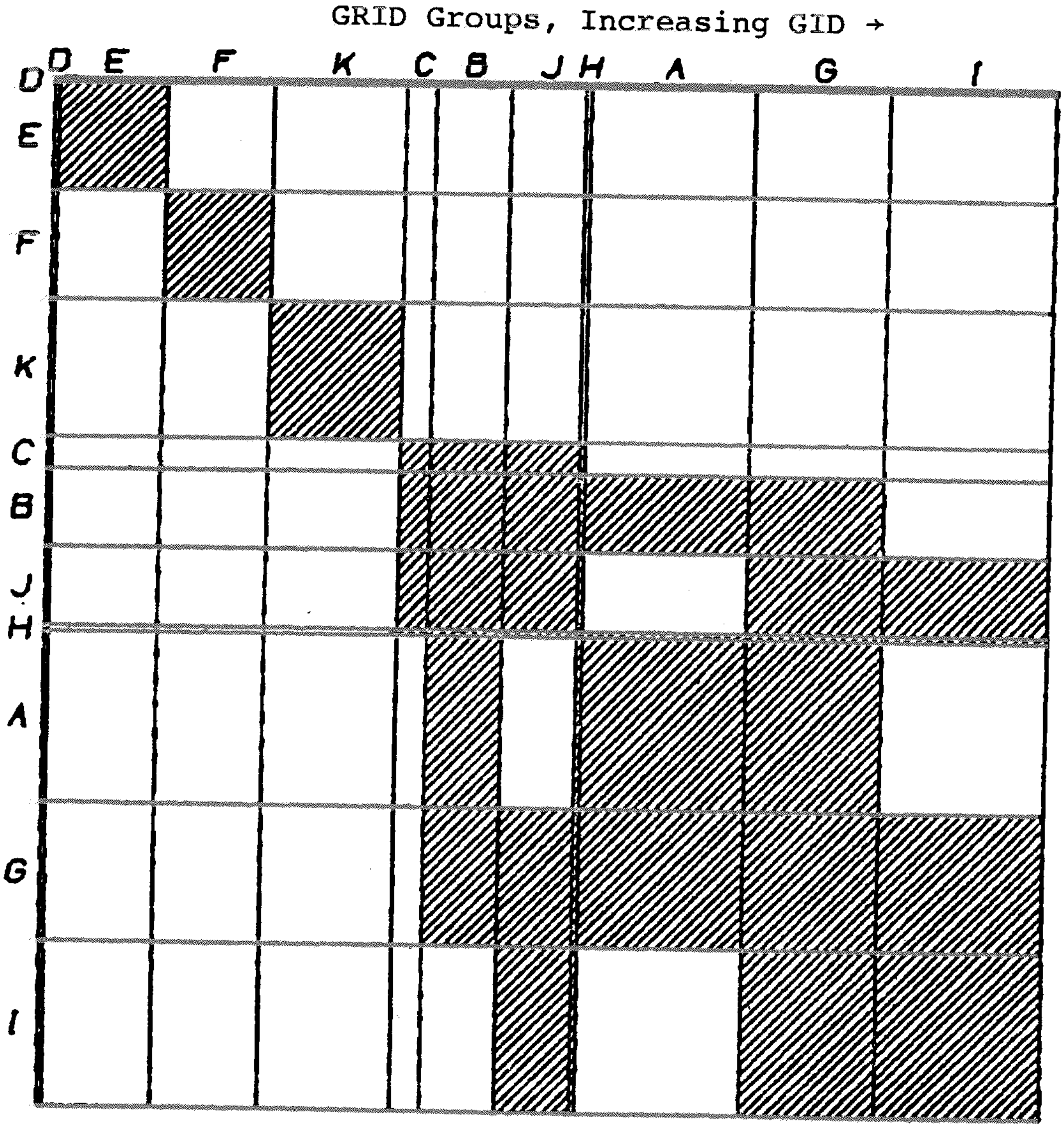
FIGURE 8. BOUNDARY SUPERELEMENT MATRIX BANDING, IDENTICAL SUPERELEMENT

GRID Groups, Increasing GID →



NOTES: Shaded area has nonzero terms
Area proportional to number of GRIDs (Table 2)
RMS Bandwidth: 666 DOF (Table 3)

FIGURE 9. SUPERELEMENT RESIDUAL STRUCTURE MATRIX, ORIGINAL GID



NOTES: Shaded area has nonzero terms
Area proportional to number of GRIDs (Table 2)
RMS Bandwidth: 526 DOF (Table 3)

FIGURE 10. SUPERELEMENT RESIDUAL STRUCTURE MATRIX, REORDERED GID

```
0

                    SUMMARY OF GRID CONNECTIVITY
(* - WARNING - GRIDS ARE NOT CONSECUTIVELY NUMBERED!)
  STARTING   NUMBER OF   INTERNAL TO                    EXTERNAL TO
  GRID ID      GRIDS     SUPERELEMENT                   SUPERELEMENT

*     1015         66          0          10
*     3101         30          0           9      10
      5200         12          0           9
*     5212          2          0
*     6001         43          0           4
*     6601         43          0           3
*     8001         54          0          10      20
      8095          2          0           9      10      20
*    11015         66          0          20
*    13101         30          0           9      20
*    20041         53          0          50
FOR SUPERELEMENT        0:
    NUMBER OF O-SET GRIDS =        401
    NUMBER OF A-SET GRIDS =          0
IS THE NUMBER OF O-SET GRIDS CORRECT?
ENTER YES OR NO:
YES
IS THE NUMBER OF A-SET GRIDS CORRECT?
ENTER YES OR NO:
YES
*** CHOICES OF OPERATION ***
1 --- RENUMBER GRIDS AUTOMATICALLY
2 --- RENUMBER GRIDS BY USER SPECIFIED STARTING GRID ID
3 --- CHANGE INTERNAL SEIDS
4 --- ADD CONNECTIONS BETWEEN GROUPS
ENTER DESIRED OPERATION NUMBER:
```

FIGURE 11. AOS/GRAFAX SUPER FUNCTION COMMANDS FOR RESIDUAL GRID REORDERING

SUMMARY OF GRID CONNECTIVITY

(* - WARNING - GRIDS ARE NOT CONSECUTIVELY NUMBERED!)

	STARTING GRID ID	NUMBER OF GRIDS	INTERNAL TO SUPERELEMENT		EXTERNAL TO SUPERELEMENT	
*	1015	66	0	10		
*	3101	30	0	9	10	
	5200	12	0	9		
*	5212	2	0			
*	6001	43	0	4		
*	6601	43	0	3		
*	8001	54	0	10	20	
	8095	2	0	9	10	20
*	11015	66	0	20		
*	13101	30	0	9	20	
*	20041	53	0	50		

a. Original GID (See Figure 11)

	STARTING GRID ID	NUMBER OF GRIDS	INTERNAL TO SUPERELEMENT		EXTERNAL TO SUPERELEMENT	
*	5212	2	0			
*	6001	43	0	4		
*	6601	43	0	3		
*	20041	53	0	50		
	22374	12	0	9		
	22398	30	0	9	10	
	22458	30	0	9	20	
	22518	2	0	9	10	20
	22522	66	0	10		
	22654	54	0	10	20	
	22762	66	0	20		

b. Reordered GID

FIGURE 12. SUPER FUNCTION GID REORDERING RESULT

NOTE: Each symbol represents approximately 20 GRIDS

* - diagonal terms

O - Off diagonal terms

```
***0      000
***0      000
***0      000
000*0     000   0
   0*       0   0
     *
      **
      **
        **
        **
0000      **00000
0000      **00000
00000     00*0000
          000***0
          000***0
          000***0
   00     000000*
                 **
                 **
```

a. Original Matrix

```
*
 **
 **
   **
   **
     **
     **
       *000
       0*0000000
       00*0   00000
       000*000000000
        0 0***00
        0 0***00
        0 0***00
        000000**000
        000000**000
         00    00***
         00    00***
         00    00***
```

b. Resequenced Matrix

FIGURE 13. AOS/GRAFAX GRAPHICAL REPRESENTATION OF MATRIX

```
WOULD YOU LIKE A COST ESTIMATION?:
ENTER YES OR NO:
YES
WOULD YOU LIKE THE RMS CALCULATED?
ENTER YES OR NO:
YES
ENTER THE DEGREES OF FREEDOM PER GRID FOR THE O-SET GRIDS:
6

THE RMS VALUE =      666.27
```

	TIME(IBM SEC)	COST($)	
DECOMP	1815.70	1000	←Normalized
FBS	0.0	0.0	
MPYAD	0.0	0.0	

a. Original bandwidth and matrix decomposition time

```
AUTOMATIC RESEQUENCING IS COMPLETE!

WOULD YOU LIKE A SUMMARY OF THIS CONNECTIVITY?
ENTER YES OR NO:
NO
WOULD YOU LIKE A COST ESTIMATION?:
ENTER YES OR NO:
YES
ENTER THE DEGREES OF FREEDOM PER GRID FOR THE O-SET GRIDS:
6

THE RMS VALUE =      525.62
```

	TIME(IBM SEC)	COST($)	
DECOMP	1130.01	622	← Normalized
FBS	0.0	0.0	
MPYAD	0.0	0.0	

b. Renumbered bandwidth and matrix decomposition time

FIGURE 14. AOS/GRAFAX EXTERIOR GID RESEQUENCE RESULTS

TABLE 1

SUPERELEMENT PLATE MODEL SEMA STATISTICS

SUPERELEMENT		MODEL DOF		BANDWIDTH (RMS) G-SET [2]	BANDWIDTH (RMS) O-SET	SOLUTION TIME [3]	
IDENTIFICATION	FIGURE [1]	o-SET	a-SET	GRIDS	DOF	DECOMP	FBS
SE 17, ORIGINAL	1	6267	804	76.5	428	194	1000
SE 16, ORIGINAL	1	[4]	[4]	12.2	[4]	1	[4]
SE 17, REVISED	2	5585	780	39.0	220	42	497
SE 16, REVISED	2	1444	714	20.9	-	3	60

[1] Figure showing model.

[2] SEQP statistics.

[3] Normalized.

[4] SEMA not done.

TABLE 2

LARGE SINGLE-LEVEL SUPERELEMENT MODEL RESIDUAL STRUCTURE GRIDs AND SEMAP STATISTICS

SEMAP

GRID Group	No. of GRIDs	Cumulative No. of GRIDs	Exterior to SE				
A	66	66			10		
B	30	96		9	10		
C	12	108		9			
D	2	110					
E	43	153	4				
F	43	196	3				
G	54	250			10	20	
H	2	252		9	10	20	
I	66	318				20	
J	30	348		9		20	
K	53	401					50

GRID INTERACTION

GRID Group Interaction	Exterior to SE
B-C,B-H,B-J,C-H,C-J,H-J	9
A-B,A-G,A-H,B-G,B-H,G-H	10
G-H,G-I,G-J,H-I,H-J,I-J	20

TABLE 3

LARGE SINGLE-LEVEL SUPERELEMENT MODEL RESIDUAL STRUCTURE RMS BANDWIDTH STATISTICS

.Column Width (W)*..		Column Length (L)*..		.....$WL^2/10^6$**......	
Original	Reordered	Original	Reordered	Original	Reordered
66	2	252	2	4.19	0.
30	43	348	43	3.63	0.08
12	43	282	43	0.95	0.08
2	53	2	53	0.	0.15
43	12	43	74	0.08	0.07
43	30	43	194	0.08	1.13
54	30	348	260	6.54	2.03
2	2	348	260	0.24	0.14
66	66	152	182	1.52	2.19
30	54	282	248	2.38	3.32
53	66	53	218	0.15	3.14
401	401			Σ = 19.76	12.33

*See Figures 9 and 10 and Table 2.

**RMS bandwidth for symmetric decomposition (6 DOF/GRID):

$= 3\ (\Sigma WL^2/401)^{1/2}$ DOF

= 666 - Original GID

= 526 - Reordered GID