DEPARTMENT OF MECHANICAL ENGINEERING AND MECHANICS
COLLEGE OF ENGINEERING AND TECHNOLOGY
OLD DOMINION UNIVERSITY
NORFOLK, VIRGINIA 23508

COMPONENT MODE SYNTHESIS AND LARGE
DEFLECTION VIBRATION OF COMPLEX
STRUCTURES
VOLUME 1: EXAMPLES OF NASTRAN® MODAL SYNTHESIS
CAPABILITY

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By

Chuh Mei, Principal Investigator

and

Mo-How Shen

Final Report
For the period ended January 31, 1987

Prepared for the
National Aeronautics and Space Administration
Langley Research Center
Hampton, VA 23665

Under
Research Grant NAG-1-301
Mr. Joseph E. Walz, Technical Monitor
SDD-Structural Dynamics Branch

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SUMMARY

This report illustrates the use of NASTRAN® modal synthesis capability for some small examples. A classical truss problem is examined and the results for accuracy are compared to existing results from other methods. This problem is examined using both fixed interface modes and free interface modes. The solution is carried out for an applied dynamic load down as far as recovery of forces in individual members as a function of time. Another small beam problem is used to compare different means of "combining" substructures.

INTRODUCTION

During the past twenty years, a body of technology has developed within the general field of structural dynamics that has been identified by the term modal synthesis. Modal synthesis is a Rayleigh-Ritz approach using systematically derived displacement functions. It is used to formulate and solve the large eigen problems which arise in dynamic analysis of complex structural systems. Solutions are approximate in the sense that the motion of the structure is constrained to linear combinations of a limited number of modes or displacement functions characterizing the behavior of independent substructures.

Several researchers have formulated various modal synthesis procedures in an attempt to reduce computation errors and minimize computer costs. Hurty developed the first modal synthesis method capable of analyzing structures with redundant interface connections in references 1 and 2. He treated the structure as an assembly of connected components, or substructures, each of which is analyzed separately to derive a set of modes or displacement shapes from which a set of generalized coordinates applicable to the complete structure is synthesized. Craig and Bampton (ref. 3) simplified Hurty's formulation by combining two groups of coordinate functions which Hurty had defined separately. A number of survey papers have been written by Hou, Goldman, Benfield and Hruda in references 4 to 7. Some methods are found to be more suitable for certain applications than others. Yet, experience has shown that no single approach is generally preferred over the others.

The complexity of aerospace structures increased enormously during the last two decades. A new challenge is presented by the proposed space station (ref. 8) in that it is an evolving structure that cannot be ground tested because final configuration may not be known when the first component is put into space. Therefore, the component mode synthesis method may be applied for the dynamic analysis of such large structure system in space. A widely used tool for structural analysis, the NASTRAN® computer program, contains a modal synthesis capability but, other than the demonstration problem presented in reference 5, little is publicly known about its capabilities.

The purpose of the present report is to examine some of the capabilities of this program. This is done by examining two simple problems, a truss and a beam.

NUMERICAL EXAMPLES

The modal synthesis procedure in NASTRAN® is applied to two simple structures. One is a redundant truss confined to lie in a plane but free to move in this plane. It is composed entirely of ROD elements (no bending stiffness for all). This example is used to examine convergence characteristics of the modal synthesis procedure and also to illustrate the transient response capability all the way down to obtaining stresses in rod members as a function of time. The second example is a free-free beam. It is used to examine different ways to "combine" substructures to yield frequency for the total structure.

Truss Example

The redundant truss example is the one used in reference 5 to compare eight different modal synthesis procedures. The full truss model is shown in figure 1(a) and its two components shown in figure 1(b). Component A consists of five equal bays and has a total of 18 joints. Component B consists of four equal bays and has a total of 15 joints. All members in the components have identical properties. At the interface of the components in the full truss model, the vertical member has twice the area of other members. Basic geometric and material properties are presented in table I along with the prescribed load for a transient response analysis. An additional run was made with the full model subdivided into three components with three bays in each component.

The basic run sequence and substructure operation are shown in figure 2. In the figure capitalized letters inside of rectangular blocks indicate names of psuedostructures used in the analysis. Capitalized letters adjacent to, or on, the flow diagram indicate the names of modules that perform a certain function in the computer program. At the top of figure 2, the Phase 1 operations formulate the finite element stiffness and mass matrices using Rigid Format 2. For the convergence study the Phase 2 runs on Rigid Format 3 were repeated using a different number of modes from the individual components. Also Phase 2 runs were using free interface modes as well as the fixed interface modes. A limited amount of data is presented for three components and naturally a Phase 1 run must be made for this component.

A transient response analysis was made on this free-free truss structure for an axial load applied to the right end of the truss. The load was applied for 0.12 seconds and then removed. In order to apply a load at grid point 42 in component B, this grid point must be included on a BOUNDARY card. Thus, additional degrees of freedom are created corresponding to this point. The structure was represented by eight modes from component A, six modes from component B, and the eight interface modes for a total of twenty-two modes. The modes for the individual component were determined with the interface fixed. The standard procedure will obtain displacements back in the individual component. However, member forces and stresses are not determined automatically, but can be obtained through a simple procedure in a few steps. In the first step a run is made with DIAG 17 turned on to put the DMAP sequence on the punch file with an EXIT scheduled after statement 1. A small substructure deck is included to allow the appropriate commands that interface to the Substructures Operating File (SOF) to be generated. This punch file is subsequently saved and altered to replace the RECOVER module with the SDR2 module which can recover element forces and stresses. The listing of this DMAP sequence and run stream is contained in Appendix A.

Beam Example

This example consists of a beam composed of seven components as shown in figure 3(a). All subbeams have a constant length, area and uniform mass properties. Each component consists of ten equal elements and has a total of 11 joints as shown in figure 3(b). Basic geometric and material properties for each subbeam are presented in table II. A lumped mass formulation is used (no rotary inertia) and, therefore, there are 213 stiffness degrees of freedom in the problem, but only 142 eigenvalues.

Three different ways of "combining" substructures are illustrated in figures 3(c), 3(d), and 3(e). The basic run sequences and substructure operations for each case are shown in figures 4 thru 6. For all cases, the substructuring Phase 1 operations formulate the finite element stiffness and mass matrices for subbeam A using Rigid Format 3. The structural matrices contained in BBASIC, CBASIC, ..., FBASIC are generated as needed by using EQUIV operation. The basic subbeams are reduced to modal coordinates and combined together following the procedures shown in figures 4 thru 6. The eigenvalues of the total beam are obtained by using the MRECOVER command. The driver decks and sample bulk data for cases 1, 2 and 3 are listed in Appendices B, C and D. Only fixed interface modes were used but two sets of runs were made using a different number of modes from the subbeams.

RESULTS

For assessing the accuracy of the modal synthesis procedure, two and three truss components with fixed or free interface connection are run to determine frequencies and compared to results for full model. Percentage errors in frequency for the combined systems of 12, 20, 28 and 36 degrees of freedom are shown in tables III thru VI. Here degrees of freedom include not only the number of flexible modes used but also any interface modes. Thus, for example, for 12 degrees of freedom results, since there are six interface modes, only six flexible modes can be shown. Based on the lowest frequency criterion then four modes were chosen from component A and two modes from component B.

Figures 7 thru 11 are nondimensional plots that indicate the relative accuracy obtained by modal synthesis procedures. Also shown on the figures are results taken directly from reference 5 in which several other procedures are compared. From figures 7 to 10 it can be seen that modes derived with the interfaces fixed yield better results than modes derived with the interface free.

For the transient response run the percentage error in displacement for grid points 41, 42, and 43 of component B are shown in table VII. These results were produced from the 20 degrees of freedom model. The axial force in elements 111-113 and 143 of component B are shown in table VIII.

The full beam shown in figure 2 was run to determine its natural frequencies and used as a comparison of results obtained with the various "combination" procedures. Table IX shows the percentage error in frequency for the various "combination" procedures when 62 degrees of freedom are used. These 62 degrees of freedom correspond to approximately 47% of the total degrees of freedom in the full model. All three "combination" procedures yield good results. However, case 1 uses considerably less CYBER 75 CPU time than the other two cases (53.8 CPU seconds corresponds to 65.3 seconds, 59.1 seconds, respectively). Another run for case 1 was made using 19% of total degrees of freedom, and 55% frequencies were obtained with less than 1% error in frequency.

ACKNOWLEDGEMENT

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Table I. Truss Geometric and Material Properties

Typical frame width (see fig. 1(b))	$a = 1.015$ m (40")
Typical frame height (see fig. 1(b))	$h = 0.762$ m (30")
Cross-sectional area of members	$A = 1.935\ cm^2$ ($0.3\ in^2$)
Young's modulus	$E = 1.422\times10^4\ \frac{Kg}{m^2}$ (10^7 psi)
Density	$\rho = 272.517\ \frac{Kg\text{-}sec^2}{m^4}$ ($2.5\times10^{-4}\ \frac{lbf\text{-}sec^2}{in^4}$)
Transient loads	$P_{42} =$ 2.2×10^3 Kg(10^3 lbf) $0<t<0.12S$ 0 $t>0.12S$

Table II. Beam Geometric and Material Properties

Typical component length (see fig. 3(b))	ℓ = 2.54 m (100")
Cross section of beam	A = 3.613 cm^2 (0.56 in^2)
Young's modulus	E = 1.422×10^4 $\frac{Kg}{m^2}$ (10^7psi)
Density	ρ = 282.437 $\frac{Kg\text{-}sec^2}{m^4}$ (2.591×10^{-4} $\frac{lbf\text{-}sec^2}{in^4}$
Total beam length	L = 15.78 m (700")

Table III. Frequency for Full Truss and Percent Error in Frequency for Two Modal Synthesis Models Using 12 Degrees of Freedom

Mode No.	Full Truss (Hz)	Free Interface (%)	Fixed Interface (%)
1	65.7771	29.88	0.0015
2	136.3306	4.32	0.0022
3	175.5505	21.9	0.0314
4	202.7780	7.35	0.0198
5	260.3387	3.49	0.0536
6	316.2614	5.12	0.0227
7	334.1522	61.41	4.21
8	347.1668	142.05	6.439
9	388.1286	183.78	0.97

Table IV. Frequency for Full Truss and Percent Error in Frequency for Two Modal Synthesis Models Using 20 Degrees of Freedom

Mode No.	Full Truss (Hz)	Free Interface (%)	Fixed Interface (%)	3 Components Fixed Interface
1	65.7771	19.23	0.00074	0.00351
2	136.3306	2.82	0.00044	-0.03425
3	175.5505	8.2	0.0087	-0.00915
4	202.7780	2.67	0.0087	0.02232
5	260.3387	2.23	0.0091	-0.00355
6	316.2614	2.0	0.0078	-0.03588
7	334.1522	0.65	0.75	0.00521
8	347.1668	3.9	0.088	0.00469
9	388.1286	0.3	0.23	-0.01105
10	394.1834	0.3	0.1	-0.00029
11	414.9853	1.9	0.18	-0.00924
12	451.2226	8.57	0.078	-0.00182
13	466.3475	8.5	0.14	0.00130
14	504.7402	7.8	0.41	0.01524
15	507.2363	39.7	1.32	0.03394
16	537.3632	58.4	2.0	0.01038
17	575.3048	114.65	0.7	0.00005

Table V. Frequency for Full Truss and Percent Error in Frequency for Two Modal Synthesis Models Using 28 Degrees of Freedom

Mode No.	Full Truss (Hz)	Free Interface (%)	Fixed Interface (%)	Mode No.	Full Truss (Hz)	Free Interface (%)	Fixed Interface (%)
1	65.7771	8.9	0.00035	18	600.7099	0.19	0.18
2	136.3306	1.2	0.00037	19	628.5009	1.0	0.19
3	175.5505	5.1	0.0017	20	659.4299	0.2	0.075
4	202.7780	1.08	0.0039	21	668.5250	1.64	0.457
5	260.3387	0.99	0.0067	22	678.8447	9.0	0.143
6	316.2614	0.85	0.0029	23	681.8918	20.1	0.006
7	334.1522	0.4	0.19	24	690.5944	27.5	0.291
8	347.1668	1.58	0.03	25	750.0817	70.5	1.062
9	388.1286	0.08	0.12				
10	394.1834	0.03	0.04				
11	414.9853	0.9	0.06				
12	451.2226	3.0	0.03				
13	466.3475	2.6	0.0245				
14	504.7402	0.16	0.197				
15	507.2363	0.4	0.14				
16	537.3632	0.59	0.59				
17	575.3048	0.71	0.254				

Table VI. Frequency for Full Truss and Percent Error in Frequency for Two Modal Synthesis Models Using 36 Degrees of Freedom

Mode No.	Full Truss (Hz)	Free Interface (%)	Fixed Interface (%)	Mode No.	Full Truss (Hz)	Free Interface (%)	Fixed Interface (%)
1	65.7771	6.71	0.00023	18	600.7099	0.011	0.0565
2	136.3306	0.809	0.00015	19	628.5009	0.183	0.0151
3	175.5505	1.185	0.00034	20	659.4299	0.029	0.0154
4	202.7780	0.84	0.00252	21	668.5250	1.574	0.1027
5	260.3387	0.713	0.00161	22	678.8447	0.495	0.021
6	316.2614	0.689	0.0019	23	681.8918	1.650	0.00062
7	334.1522	0.092	0.0676	24	690.5944	1.085	0.0622
8	347.1668	1.096	0.0159	25	750.0817	0.220	0.0673
9	388.1286	0.072	0.0301	26	757.5138	0.202	0.186
10	394.1834	0.012	0.00822	27	788.2198	0.642	0.552
11	414.9853	0.651	0.0244	28	792.7149	4.107	0.0786
12	451.2226	1.969	0.00734	29	824.4077	3.734	0.149
13	466.3475	0.592	0.00442	30	840.6797	2.215	0.0964
14	504.7402	0.039	0.0139	31	854.6771	7.767	0.1146
15	507.2363	0.047	0.0255	32	883.3126	9.033	0.268
16	537.3632	0.443	0.160	33	909.3136	41.970	0.794
17	575.3048	0.147	0.0730				

Table VII. Transient Response and Percent Error in Displacement

Grid Pts. / Times	Full Truss	B Substr.	$\frac{F-B}{F}$ %	Full Truss	B. Substr.	$\frac{F-B}{F}$ %	Full Truss	B Substr.	$\frac{F-B}{F}$ %
	28	41		29	42		30	43	
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0015	0.4786243	0.4785015	0.02566	0.499332	0.4993054	0.00533	0.4786243	0.4785015	0.02566
0.0030	2.070906	2.070847	0.00285	2.089915	2.089938	-0.00110	2.070906	2.070847	0.00285
0.0045	4.794056	4.793882	0.00363	4.813719	4.813558	0.00334	4.794056	4.793882	0.00363
0.0060	8.662573	8.662563	0.00012	8.682871	8.683060	-0.00218	8.662573	8.662563	0.00012
0.0075	13.65921	13.65901	0.00146	13.67806	13.67781	0.00183	13.65921	13.65901	0.00146
0.0090	19.79589	19.79587	0.00010	19.81609	19.81619	-0.00050	19.79589	19.79587	0.00010
0.0105	27.07146	27.07133	0.00048	27.09119	27.09122	-0.00011	27.07146	27.07133	0.00048
0.0120	35.47588	35.47573	0.00042	35.49501	35.49476	0.00070	35.47588	35.47573	0.00042

Table VIII. The Axial Force in Elements of B Substructure

Times	Element No. 111	112	113
0.0	0.0	0.0	0.0
0.003	235.1038	282.6908	235.1038
0.006	252.9327	304.9388	252.9327
0.009	179.1082	254.5373	179.1082
0.012	137.4126	223.7419	137.4126

Times	Element No. 141	142	143
0.0	0.0	0.0	0.0
0.003	185.0618	951.0315	185.0618
0.006	199.0282	1021.000	199.0282
0.009	177.9509	1021.209	177.9509
0.012	159.4311	959.688	159.4311

Table IX. Percent Frequency Error Using 62 Degrees of Freedom

Mode No.	Full Beam (Hz)	Case 1 (Hz)	(%)	Case 2	(%)	Case 3	(%)
1	15.13289	15.13290	0.0000665	15.13291	0.000132	15.13293	0.000264
2	41.69619	41.69637	0.000432	41.69685	0.001583	41.69673	0.001295
3	81.70638	81.70777	0.001701	81.71215	0.007062	81.71170	0.006511
4	135.0071	135.0132	0.004518	135.0395	0.023999	135.0395	0.023999
5	140.3144	140.3154	0.000713	140.3343	0.014182	140.3182	0.002708
6	201.5912	201.6091	0.008879	201.7213	0.064537	201.6405	0.015576
7	280.5578	280.5662	0.002994	280.6451	0.031116	280.7314	0.061877
8	281.4407	281.4865	0.016273	281.6908	0.088864	281.8770	0.015502
9	374.5384	374.5812	0.011427	374.6278	0.023869	374.8512	0.083516
10	420.6751	420.6842	0.002163	421.1304	0.108231	421.0158	0.080989
11	480.8666	480.9641	0.020276	482.2726	0.292389	482.8321	0.408741
12	560.5507	560.6017	0.009098	561.7351	0.211292	561.4299	0.156846
13	600.4075	600.6184	0.035126	605.3069	0.816012	604.0111	0.600192
14	700.1585	700.2570	0.014068	701.7052	0.220907	703.3938	0.462081
15	733.1426	733.6937	0.075169	745.0415	1.622999	740.1181	0.951452
16	839.4147	839.5912	0.021027	845.1065	0.678068	840.3091	0.106550
17	879.0530	880.5704	0.172618	929.3795	5.725081	912.3958	3.793036

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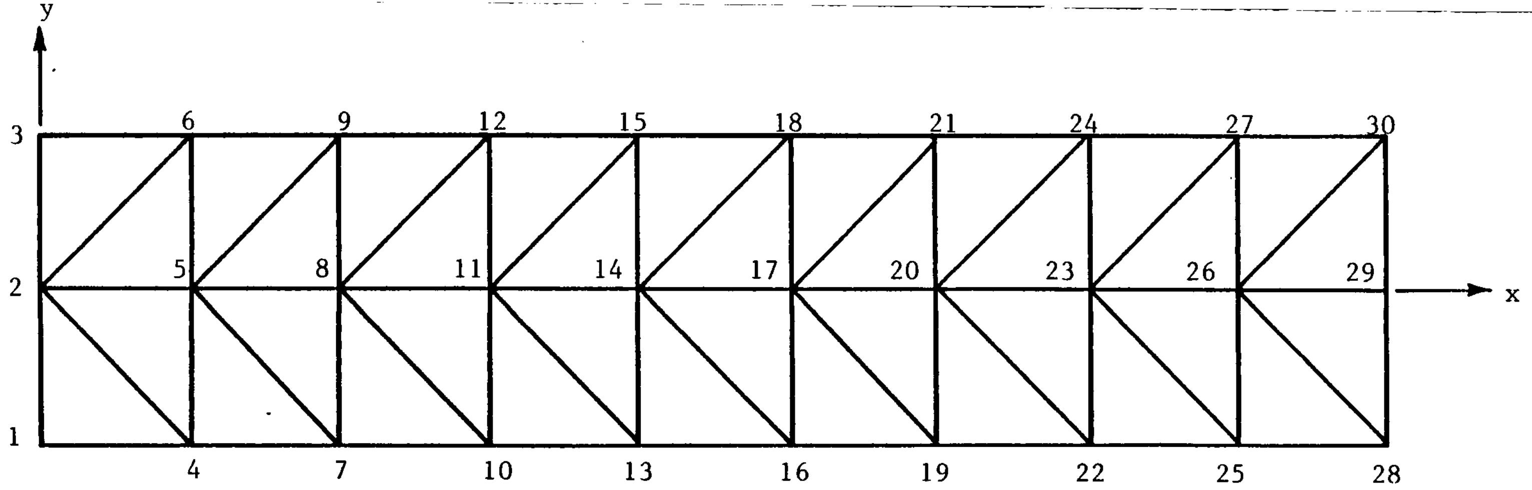
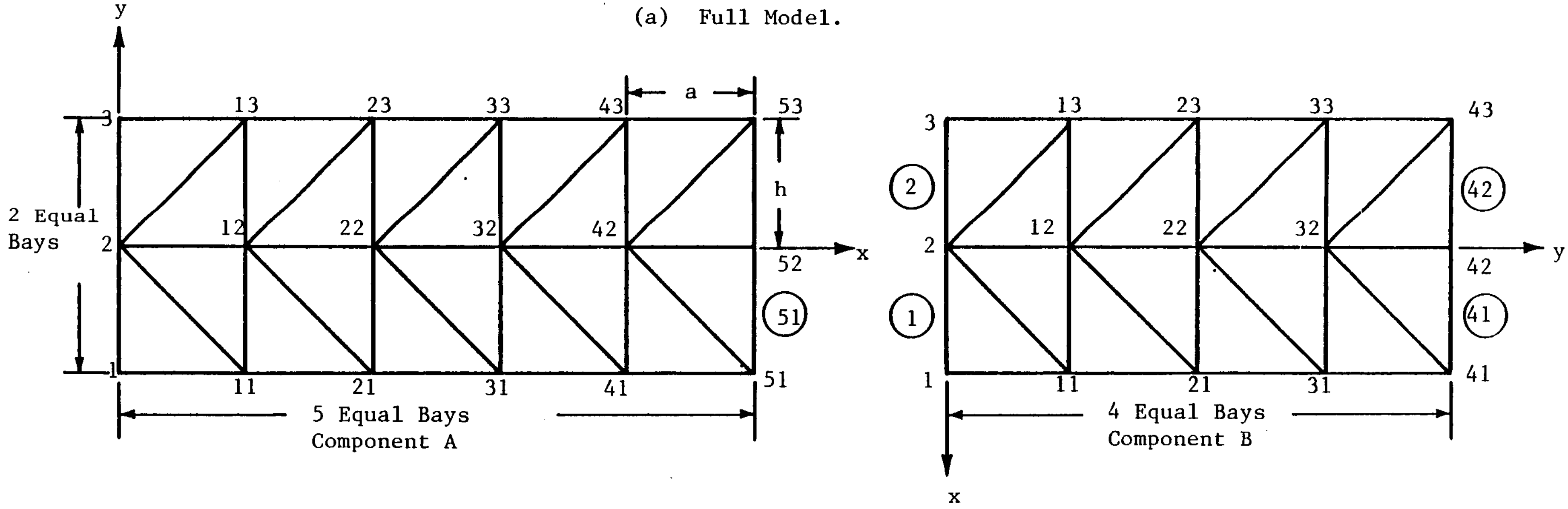
Table IX. Percent Frequency Error Using 62 Degrees of Freedom (concluded)

Mode No.	Full Beam (Hz)	Case 1 (Hz)	(%)	Case 2	(%)	Case 3	(%)
18	978.2478	978.7669	0.053064	1000.558	2.280629	993.7466	1.584343
19	1038.119	1042.146	0.387913			1119.255	7.815674
20	1116.602	1117.016	0.037076				
21	1210.321	1222.255	0.986019				
22	1254.366	1254.961	0.047434				
23	1391.513	1392.356	0,060582				
24	1395.636	1400.455	0.345291				
25	1527.959	1529.241	0.083903				
26	1594.042	1617.311	1.459748				
27	1663.636	1665.641	0.120519				
28	1798.475	1801.4451	0.165140				
29	1805.515	1849.961	2.461680				
30	1932.408	1941.881	0.490217				
31	2030.027	2070.290	1.983373				
32							
33							
34							



(a) Full Model.



(b) Substructured Model.

Figure 1. Truss Model.

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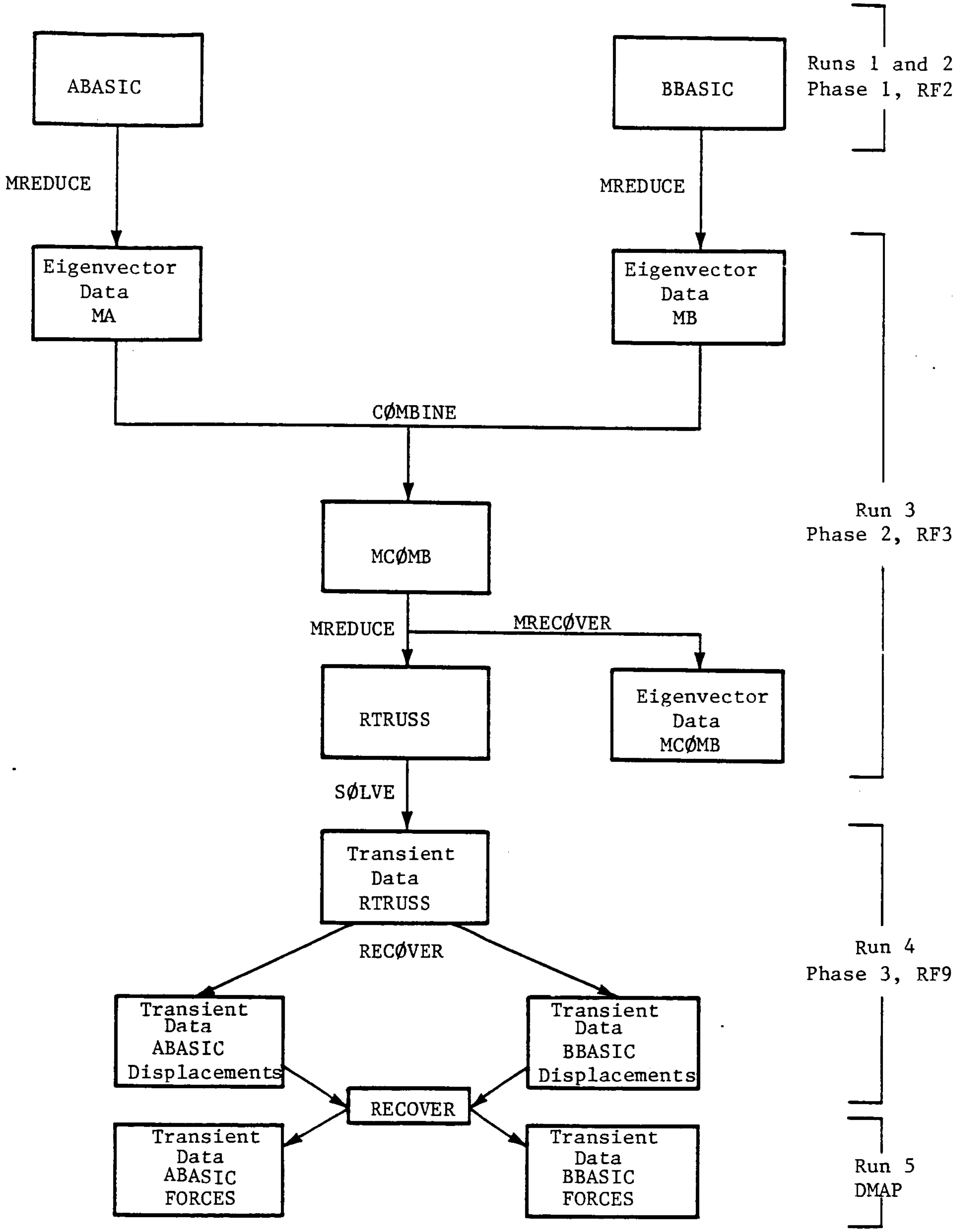
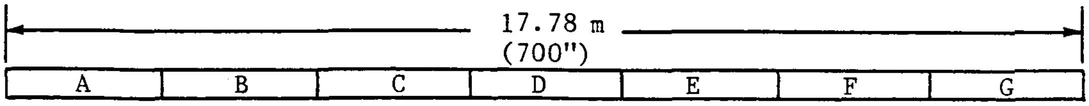
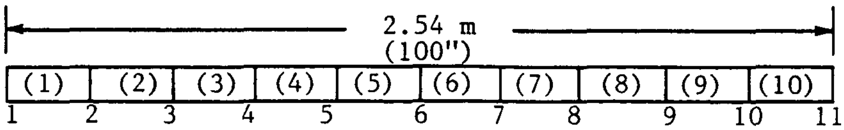


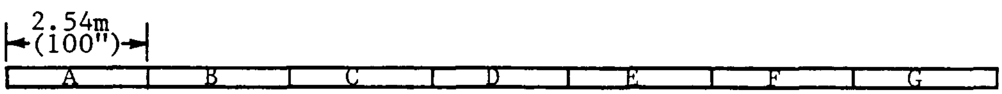
Figure 2. Substructure Formulation Tree and Solution Sequence



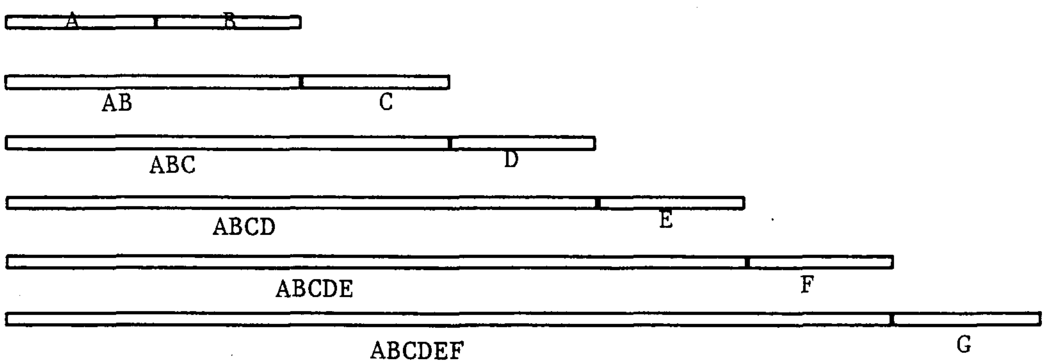
(a) Total beam model.



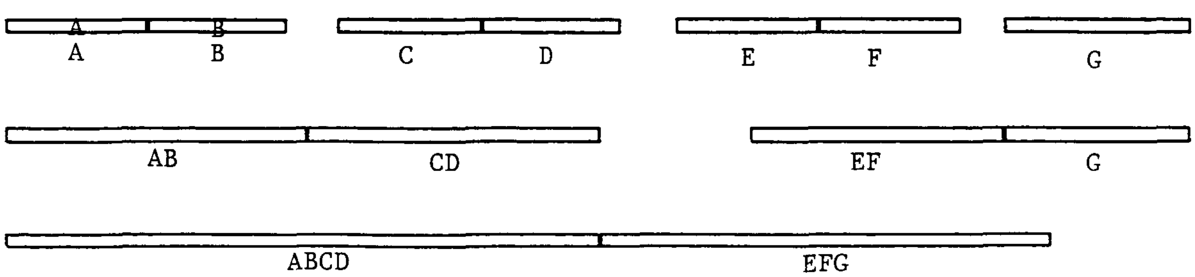
(b) Representative finite element model of any component.



(c) Case 1 - All components combined simultaneously.



(d) Case 2 - Components combined sequentially.



(e) Case 3 - Components combined in pairs. Pairs then combined sequentially.

Figure 3. Total Beam Model and Various Subdivided Representations.

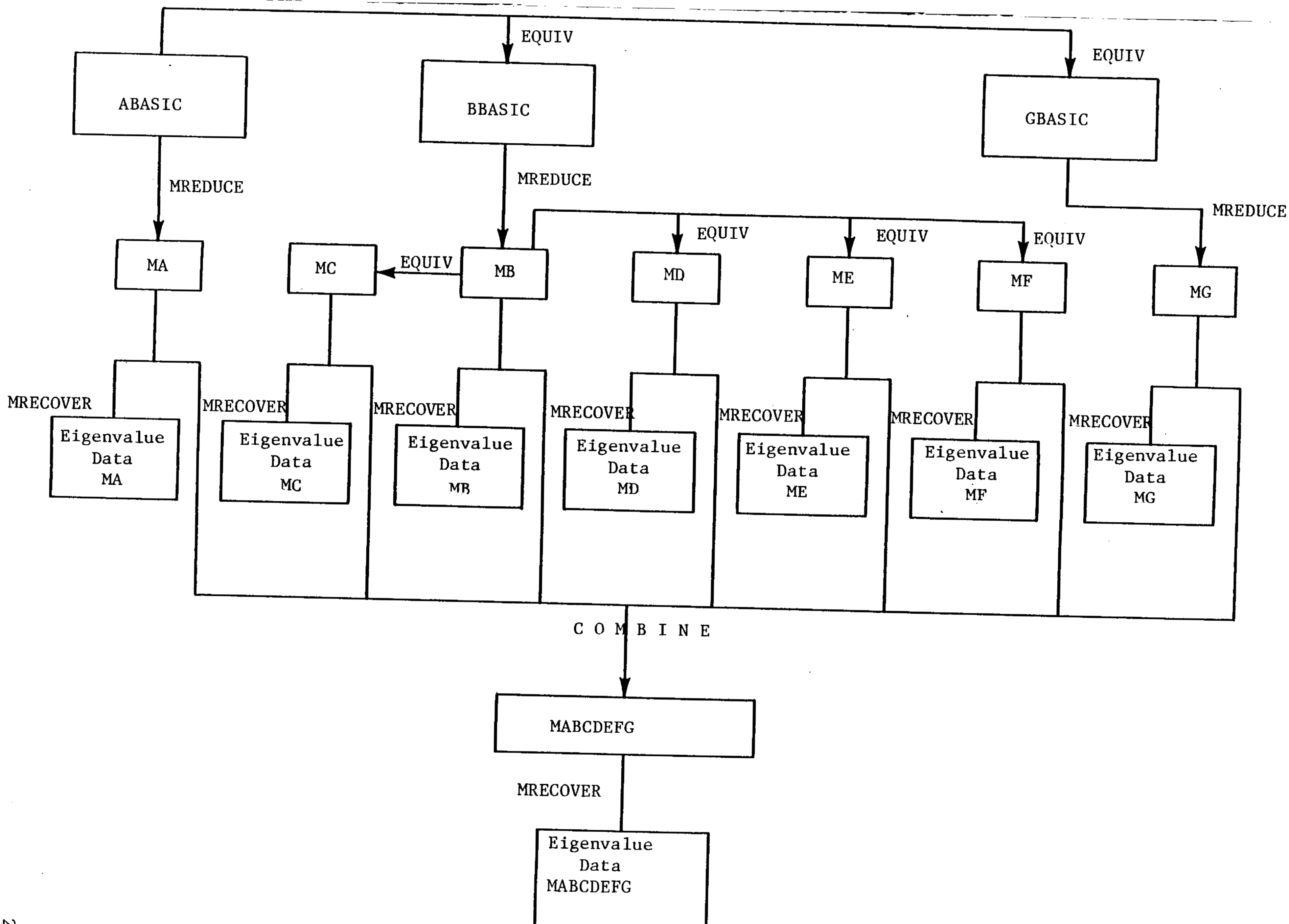


Figure 4. Case 1 Subbeam Formulation Tree and Solution Sequence

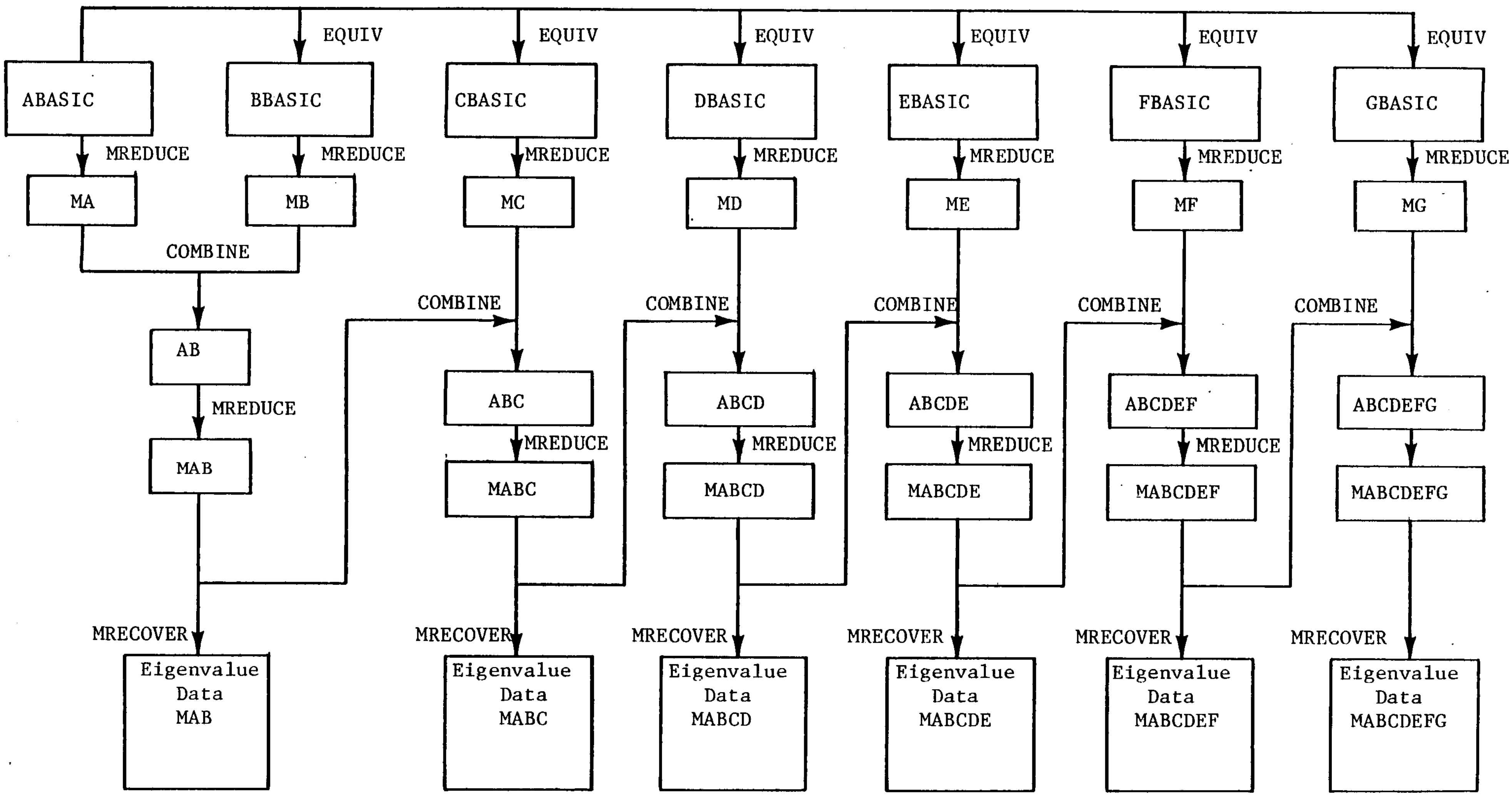


Figure 5. Case 2 Subbeam Formulation Tree and Solution Sequence.

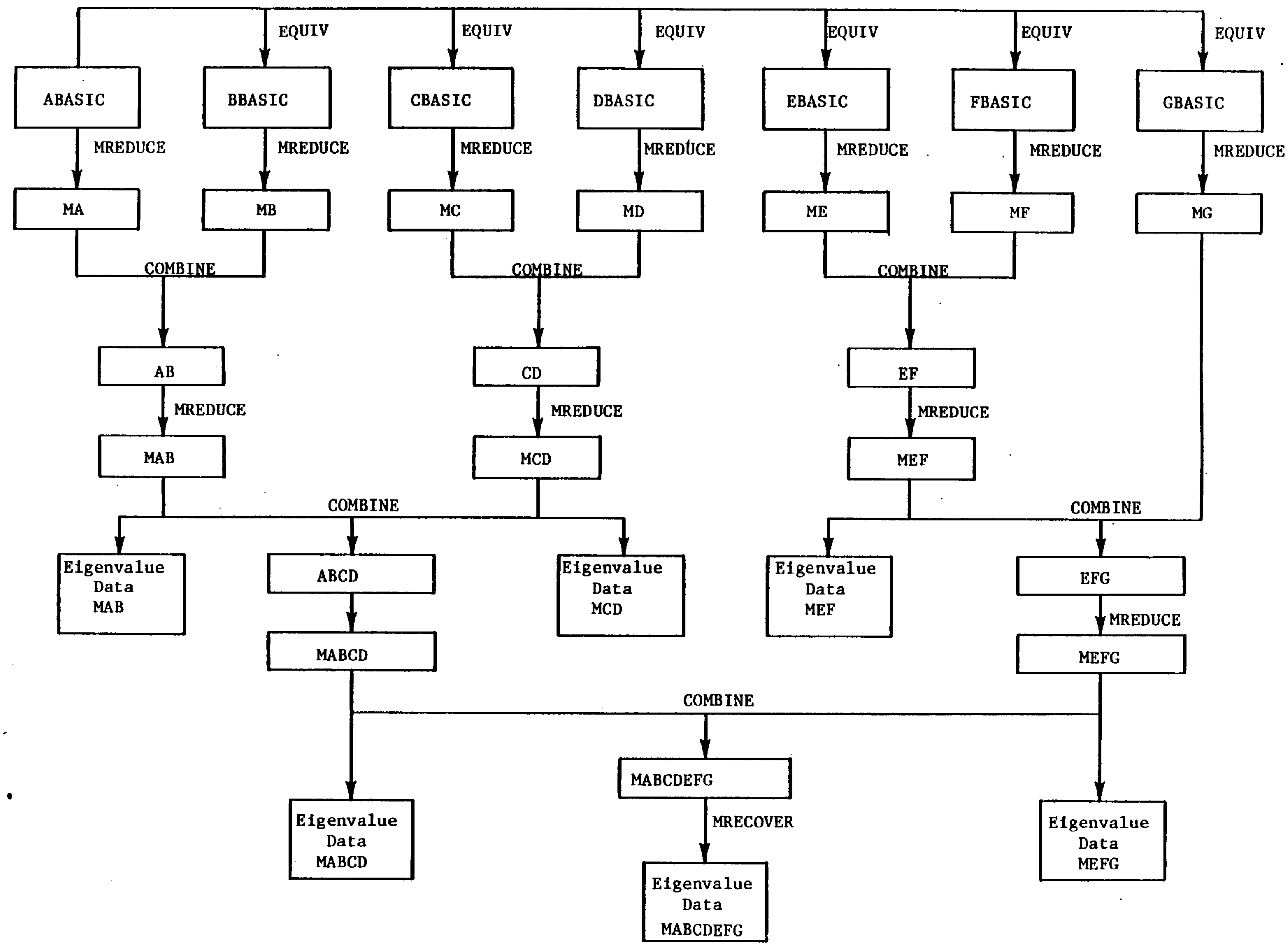


Figure 6. Case 3 Subbeam Formulation Tree and Solution Sequence

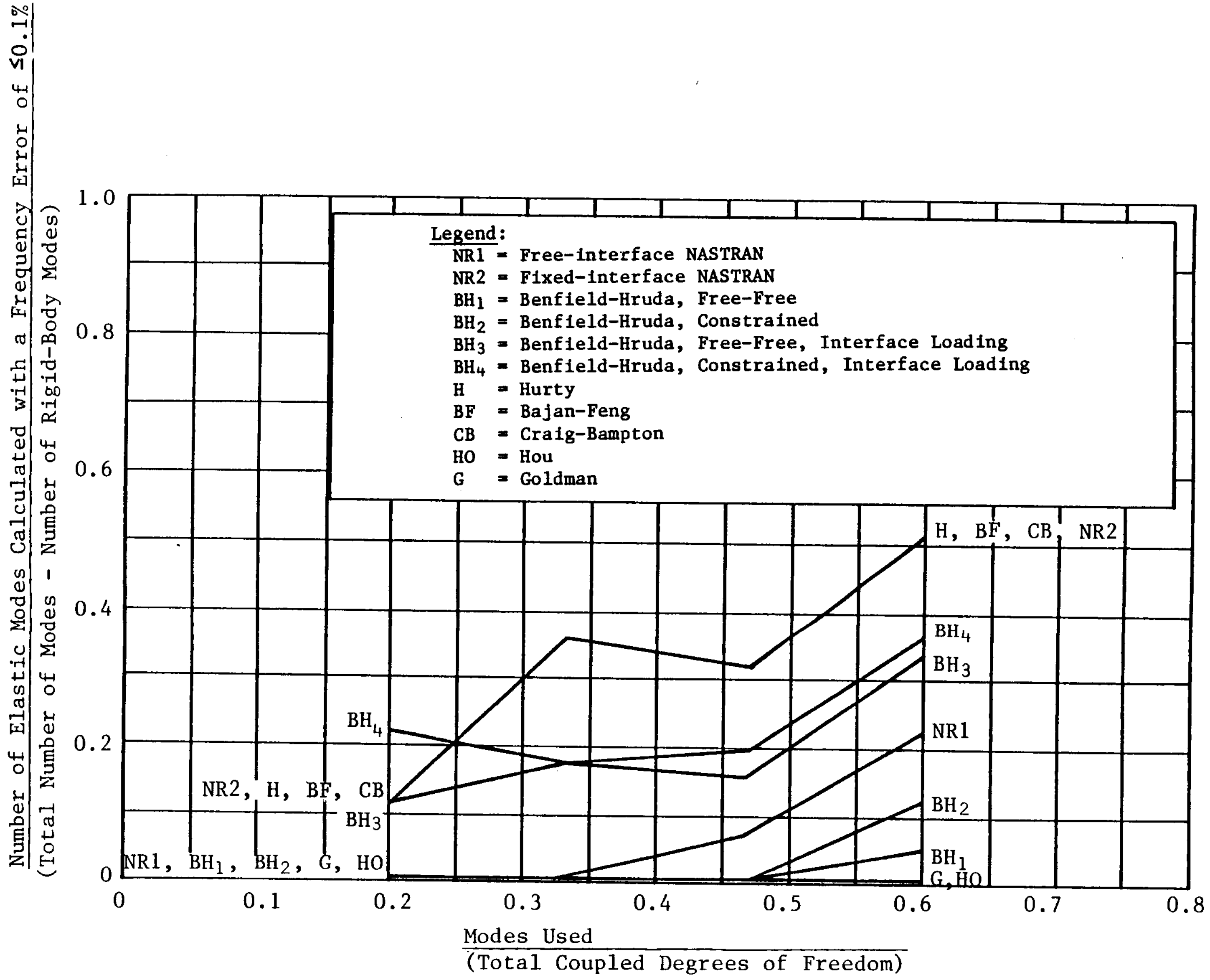


Figure 7. Comparison of Methods with Frequency Error of 0.1%.

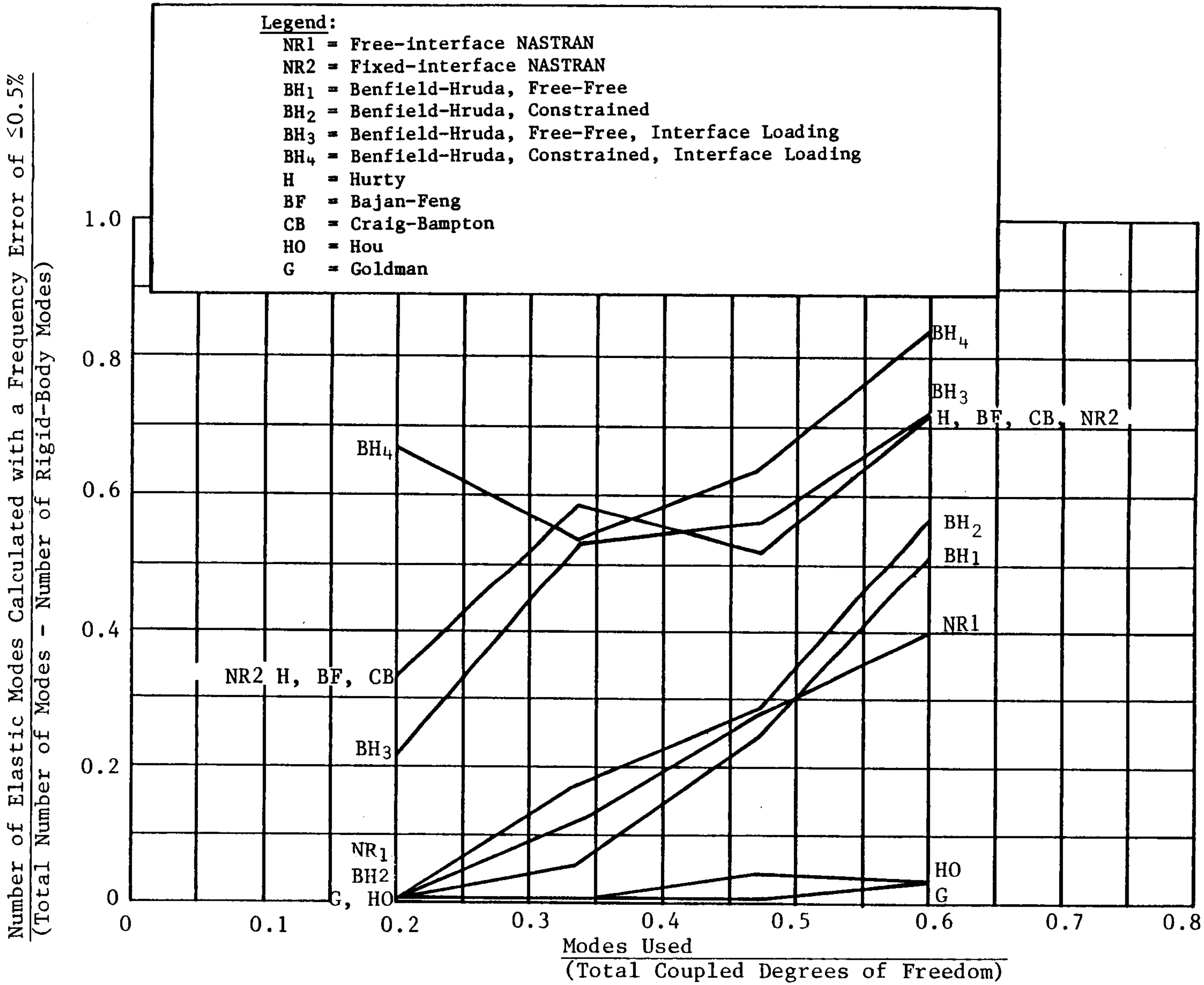


Figure 8. Comparison of Methods with Frequency Error of 0.5%.

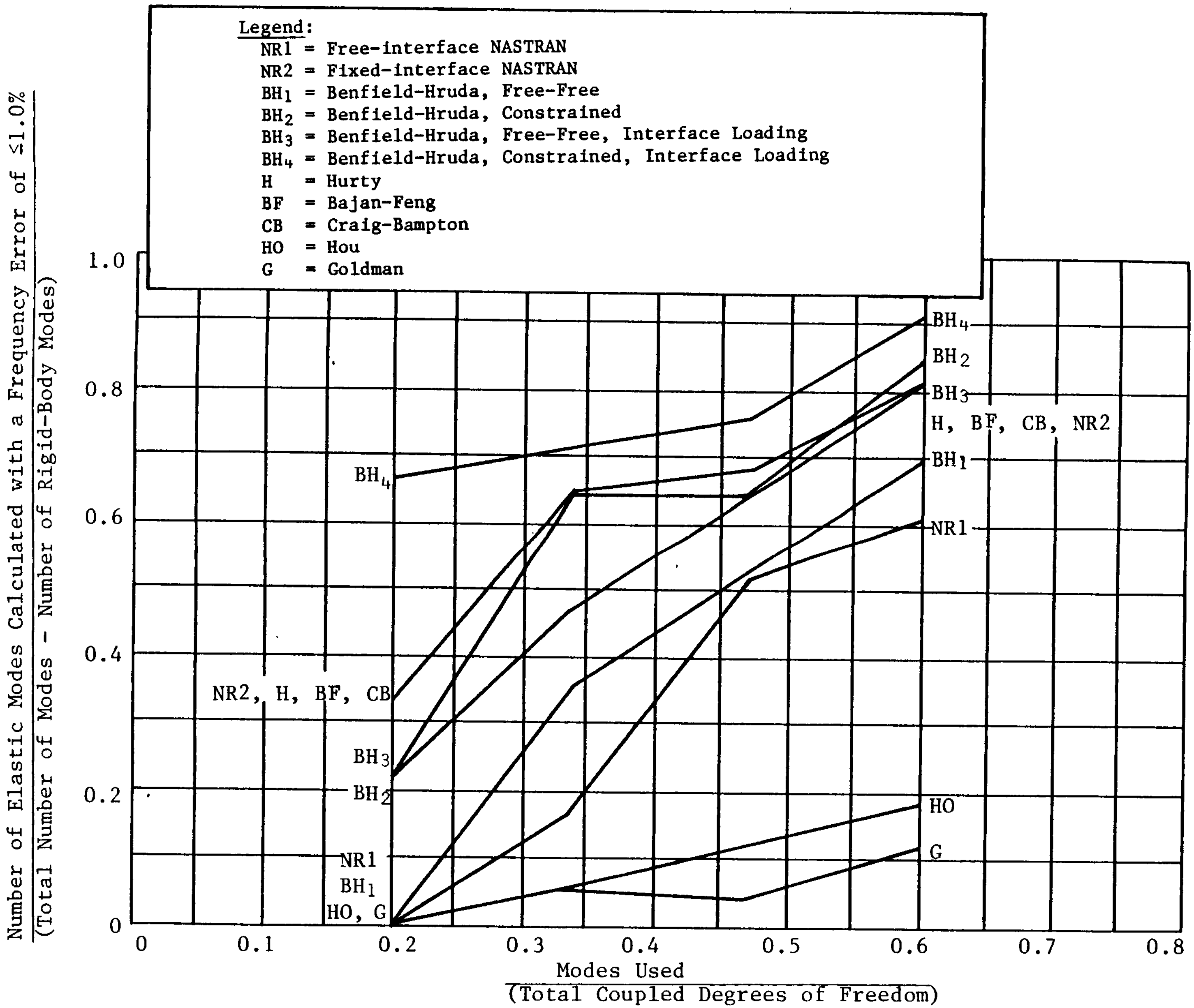


Figure 9. Comparison of Methods with Frequency Error of 1.0%.

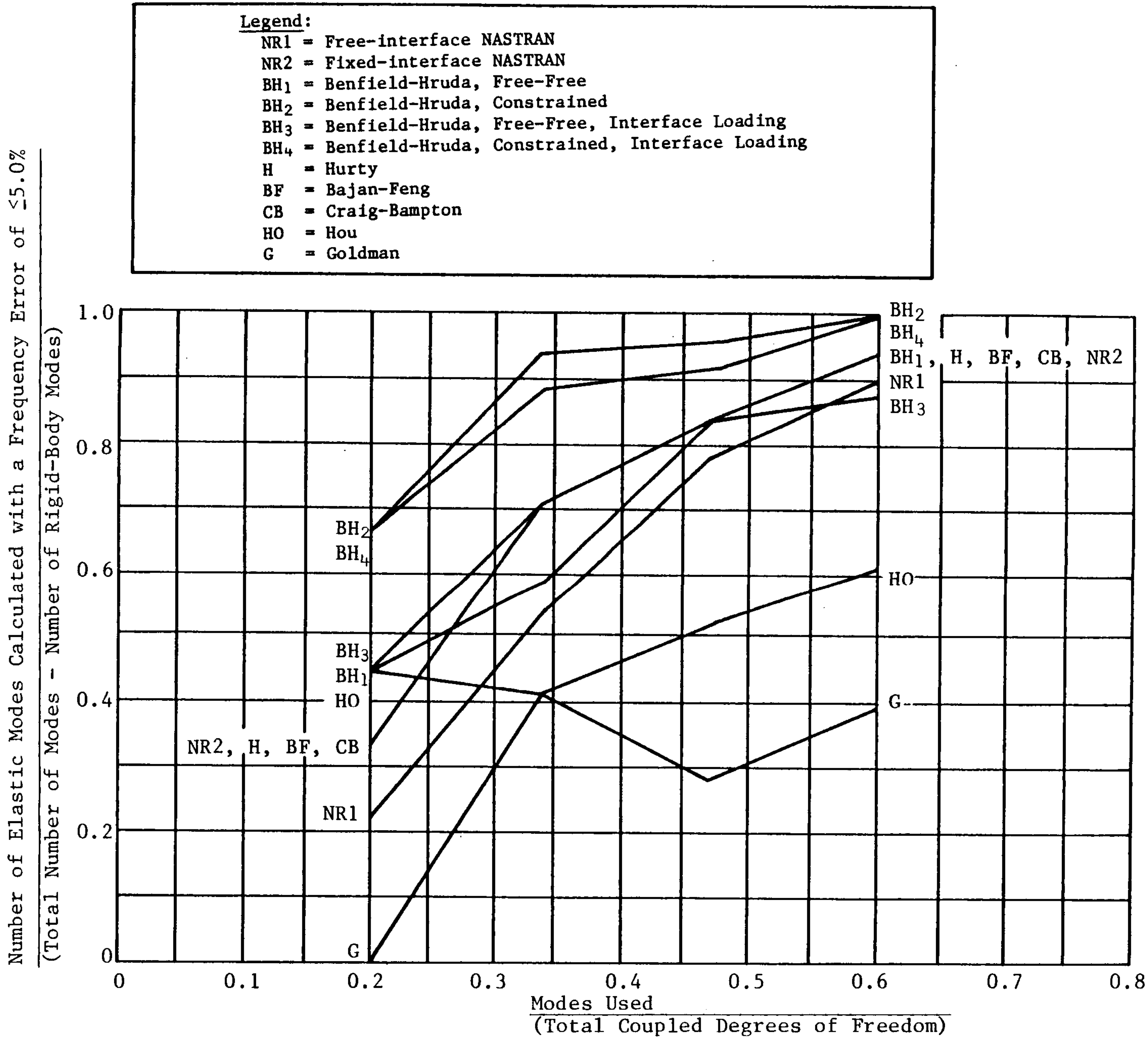


Figure 10. Comparison of Methods with Frequency Error of 5.0%.

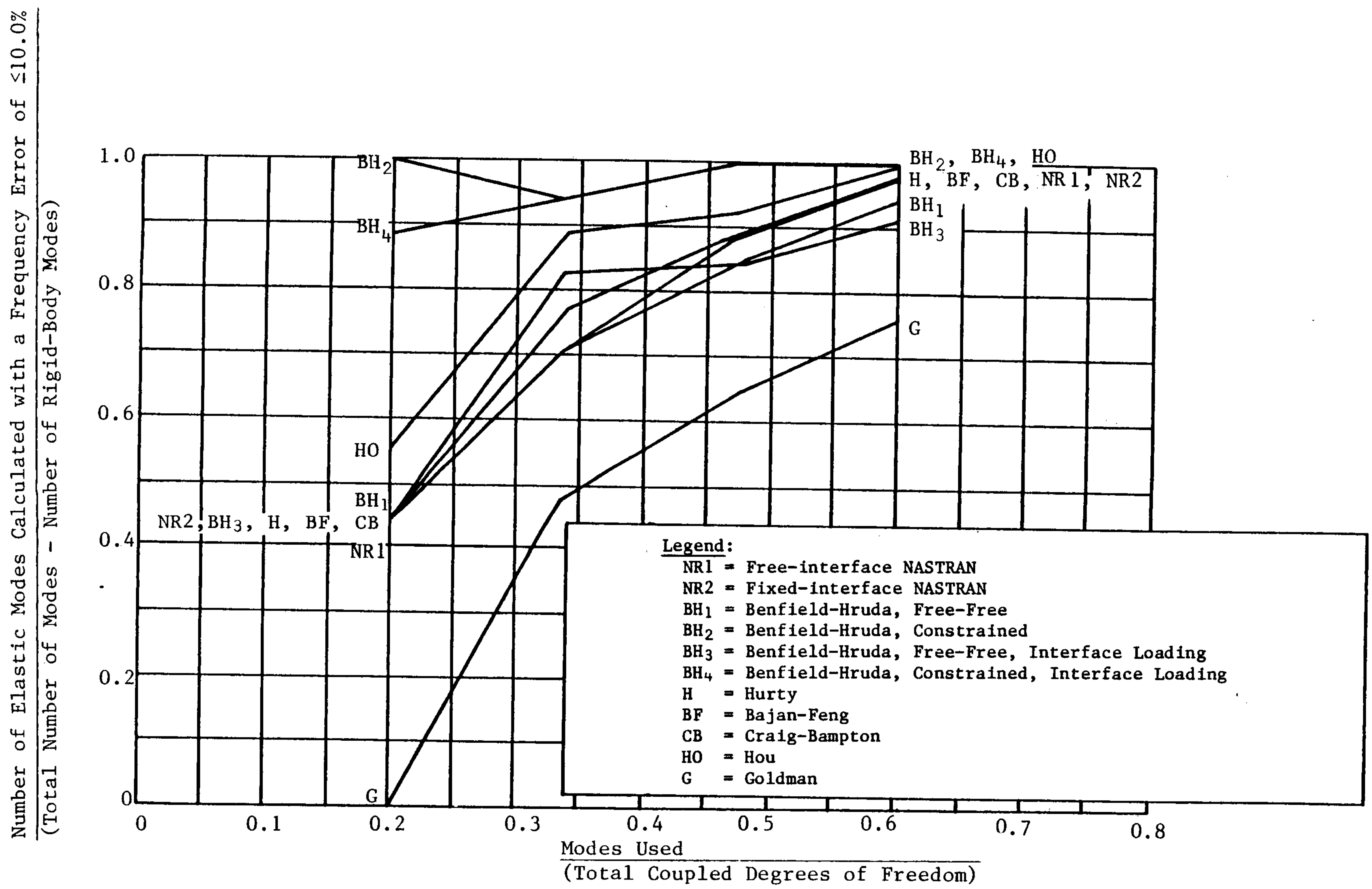


Figure 11. Comparison of Methods with Frequency Error of 10.0%.

APPENDICES

APPENDIX A. Driver decks and sample bulk data for two components truss problem.

```
NASTRAN FILES = UMF $ CDC AND IBM
ID        DEM2031,NASTRAN
APP DISP,SUBS
SOL 2,0
TIME 3
CEND
SUBSTRUCTURE PHASE1
PASSWORD = MDLSYN
SOF(1) = FT19,500,NEW $ CDC AND IBM
NAME = ABASIC
SOFPRINT TOC
ENDSUBS
TITLE = TRUSS DYNAMIC ANALYSIS USING AUTOMATED MODAL SYNTHESIS
LABEL = SUBSTRUCTURE 1, RUN 1, PHASE 1, RF 2
SUBTITLE = NASTRAN DEMONSTRATION PROBLEM NO. 2-3-1
BEGIN BULK
CROD    1       1       1       2
CROD    2       1       2       3
CROD    11      1       11      12
CROD    12      1       12      13
CROD    21      1       21      22
CROD    22      1       22      23
CROD    31      1       31      32
CROD    32      1       32      33
CROD    41      1       41      42
CROD    42      1       42      43
CROD    51      1       51      52
CROD    52      1       52      53
CROD    111     1       1       11
CROD    112     1       2       12
CROD    113     1       3       13
CROD    121     1       11      21
CROD    122     1       12      22
CROD    123     1       13      23
CROD    131     1       21      31
CROD    132     1       22      32
CROD    133     1       23      33
CROD    141     1       31      41
CROD    142     1       32      42
CROD    143     1       33      43
CROD    151     1       41      51
CROD    152     1       42      52
CROD    153     1       43      53
CROD    212     1       2       13
CROD    221     1       12      21
CROD    211     1       2       11
CROD    222     1       12      23
CROD    231     1       22      31
CROD    232     1       22      33
CROD    241     1       32      41
CROD    242     1       32      43
CROD    251     1       42      51
CROD    252     1       42      53
GRDSET                                                          3456
GRID    1               .0      -30.0   .0
GRID    2               .0      .0      .0
GRID    3               .0      30.0    .0
GRID    11              40.0    -30.0   .0
GRID    12              40.0    .0      .0
GRID    13              40.0    30.0    .0
GRID    21              80.0    -30.0   .0
```

```
GRID    22              80.0    .0      .0
GRID    23              80.0    30.0    .0
GRID    31              120.0   -30.0   .0
GRID    32              120.0   .0      .0
GRID    33              120.0   30.0    .0
GRID    41              160.0   -30.0   .0
GRID    42              160.0   .0      .0
GRID    43              160.0   30.0    .0
GRID    51              200.0   -30.0   .0
GRID    52              200.0   .0      .0
GRID    53              200.0   30.0    .0
MAT1    1       10.0+6          .3      2.5-4
PROD    1       1       .3
ENDDATA
&
NASTRAN FILES = UMF $ CDC AND IBM
ID      DEM2032,NASTRAN
APP DISP,SUBS
SOL 2,0
TIME 3
CEND
SUBSTRUCTURE PHASE1
PASSWORD = MDLSYN
SOF(1) = FT19,500 $ CDC AND IBM
NAME = BBASIC
SOFPRINT TOC
ENDSUBS
TITLE = TRUSS DYNAMIC ANALYSIS USING AUTOMATED MODAL SYNTHESIS
SUBTITLE = NASTRAN DEMONSTRATION PROBLEM NO. 2-3-2
LABEL = SUBSTRUCTURE 2, RUN 2, PHASE 1, RF 2
BEGIN BULK
CROD    1       1       1       2
CROD    2       1       2       3
CROD    11      1       11      12
CROD    12      1       12      13
CROD    21      1       21      22
CROD    22      1       22      23
CROD    31      1       31      32
CROD    32      1       32      33
CROD    41      1       41      42
CROD    42      1       42      43
CROD    111     1       1       11
CROD    112     1       2       12
CROD    113     1       3       13
CROD    121     1       11      21
CROD    122     1       12      22
CROD    123     1       13      23
CROD    131     1       21      31
CROD    132     1       22      32
CROD    133     1       23      33
CROD    141     1       31      41
CROD    142     1       32      42
CROD    143     1       33      43
CROD    211     1       2       11
CROD    212     1       2       13
CROD    221     1       12      21
CROD    222     1       12      23
CROD    231     1       22      31
CROD    232     1       22      33
CROD    241     1       32      41
CROD    242     1       32      43
GRDSET                                                  3456
GRID    1               30.0    .0      .0
GRID    2               .0      .0      .0
GRID    3               -30.0   .0      .0
GRID    11              30.0    40.0    .0
GRID    12              .0      40.0    .0
```

```
GRID    13              -30.0   40.0    .0
GRID    21              30.0    80.0    .0
GRID    22              .0      80.0    .0
GRID    23              -30.0   80.0    .0
GRID    31              30.0    120.0   .0
GRID    32              .0      120.0   .0
GRID    33              -30.0   120.0   .0
GRID    41              30.0    160.0   .0
GRID    42              .0      160.0   .0
GRID    43              -30.0   160.0   .0
MAT1    1       10.0+6          .3      2.5-4
PROD    1       1       .3
ENDDATA
&

&
NASTRAN FILES = UMF $ CDC AND IBM
ID      DEM2033,NASTRAN
APP DISP,SUBS
SOL 3,0
TIME 5
CEND
SUBSTRUCTURE PHASE2
PASSWORD = MDLSYN
SOF(1) = FT19,500 $ CDC AND IBM
OPTIONS K,M,P
SOFPRINT TOC
MREDUCE ABASIC
 NAME MA
 BOUNDARY 5
 FIXED 5
METHOD 19
 OUTPUT 1,5,6,9,10
SOFPRINT TOC
MREDUCE BBASIC
 NAME MB
 BOUNDARY 4
FIXED 4
METHOD 29
 OUTPUT 1,5,6,9,10
SOFPRINT TOC
MREDUCE CBASIC
NAME MC
BOUNDARY 7
FIXED 7
METHOD 39
 OUTPUT 1,5,6,9,10
SOFPRINT TOC
COMBINE MA,MB,MC
 NAME MCOMB
 TOLERANCE 0.001
 OUTPUT 2,7,12
 COMPONENT MB
  TRANSFORM 20
 COMPONENT MC
  TRANSFORM 40
SOFPRINT TOC
MREDUCE MCOMB
 NAME RTRUSS
 BOUNDARY 42
 METHOD 90
 NMAX 18
 OUTPUT 1,5,6,9,10
SOFPRINT TOC
ENDSUBS
TITLE = TRUSS DYNAMIC ANALYSIS USING AUTOMATED MODAL SYNTHESIS
SUBTITLE = NASTRAN DEMONSTRATION PROBLEM NO. 2-3-4
LABEL = MODAL REDUCE, COMBINE, MODAL RECOVERY, RUN 4, PHASE 2, RF 3
BEGIN BULK
```

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```
BDYC     42         BBASIC   42
BDYC     4          BBASIC   3
BDYC     5          ABASIC   1
BDYC     7          CBASIC   2
BDYS1    1          12       31         32         33
BDYS1    3          12       1          2          3          31         32         33
BDYS1    2          12       1          2          3
BDYS1    42         1        2
EIGR     19         GIV      .0         10000.0               6                                +E1
+E1      MAX
EIGR     39         GIV      .0         10000.0               6                                +E4
+E4      MAX
EIGR     29         GIV      .0         10000.0               6                                +E3
+E3      MAX
EIGR     90         GIV      .0         10000.0               20                               +E2
+E2      MAX
TRANS    20                  240.0      30.0       .0         240.0      30.0       1.0        +T2
+T2      200.0      30.0     0.0
TRANS    40                  240.0      .0         .0         240.0      .0         1.0        +T1
+T1      240.0      -100.0   0.0
ENDDATA
#
NASTRAN FILES = UMF $ CDC AND IBM
ID        DEM2035,NASTRAN
APP DMAP,SUBS
BEGIN     DISP 09 - DIRECT TRANSIENT RESPONSE ANALYSIS - APR. 1982 $
PRECHK    ALL $
FILE      UDVT=APPEND/TOL=APPEND $
PARAM     //*MPY*/CARDNO/0/0 $
GP1       GEOM1,GEOM2,/GPL,EQEXIN,GPDT,CSTM,BGPDT,SIL/S,N,LUSET/  S,N,
          NOGPDT/ALWAYS=-1 $
PLTTRAN   BGPDT,SIL/BGPDP,SIP/LUSET/S,N,LUSEP $
PURGE     USET,GM,GO,KAA,BAA,MAA,K4AA,PST,KFS,QP,EST,ECT,PLTSETX,PLTPAR,
          GPSETS,ELSETS/NOGPDT $
COND      LBL5,NOGPDT $
GP2       GEOM2,EQEXIN/ECT $
PARAML    PCDB//*PRES*////JUMPPLOT $
PURGE     PLTSETX,PLTPAR,GPSETS,ELSETS/JUMPPLOT $
COND      P1,JUMPPLOT $
PLTSET    PCDB,EQEXIN,ECT/PLTSETX,PLTPAR,GPSETS,ELSETS/S,N,NSIL/S,N,
          JUMPPLOT=-1 $
PRTMSG    PLTSETX// $
PARAM     //*MPY*/PLTFLG/1/1 $
PARAM     //*MPY*/PFILE/0/0 $
COND      P1,JUMPPLOT $
PLOT      PLTPAR,GPSETS,ELSETS,CASECC,BGPDT,EQEXIN,SIL,,ECT,,/PLOTX1/
          NSIL/LUSET/S,N,JUMPPLOT/S,N,PLTFLG/S,N,PFILE $
PRTMSG    PLOTX1// $
LABEL     P1 $
GP3       GEOM3,EQEXIN,GEOM2/SLT,GPTT/NOGRAV $
TA1       ECT,EPT,BGPDT,SIL,GPTT,CSTM/EST,GEI,GPECT,,/LUSET/S,N,NOSIMP=
          -1/1/S,N,NOGENL=-1/S,N,GENEL $
PURGE     K4GG,GPST,OGPST,MGG,BGG,K4NN,K4FF,K4AA,MNN,MFF,MAA,BNN,BFF,BAA,
          KGGX/NOSIMP/OGPST/GENEL $
COND      LBL1,NOSIMP $
```

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```
PARAM    //*ADD*/NOKGGX/1/0 $
PARAM    //*ADD*/NOMGG/1/0 $
PARAM    //*ADD*/NOBGG=-1/1/0 $
PARAM    //*ADD*/NOK4GG/1/0 $
EMG      EST,CSTM,MPT,DIT,GEOM2,/KELM,KDICT,MELM,MDICT,BELM,BDICT/    S,
         N,NOKGGX/S,N,NOMGG/S,N,NOBGG/S,N,NOK4GG//C,Y,COUPMASS/C,Y,
         CPBAR/C,Y,CPROD/C,Y,CPQUAD1/C,Y,CPQUAD2/C,Y,CPTRIA1/C,Y,
         CPTRIA2/C,Y,CPTUBE/C,Y,CPQDPLT/C,Y,CPTRPLT/C,Y,CPTRBSC $
PURGE    KGGX,GPST/NOKGGX/MGG/NOMGG $
COND     LBLKGGX,NOKGGX $
EMA      GPECT,KDICT,KELM/KGGX,GPST $
LABEL    LBLKGGX $
COND     LBLMGG,NOMGG $
EMA      GPECT,MDICT,MELM/MGG,/-1/C,Y,WTMASS=1.0 $
LABEL    LBLMGG $
COND     LBLBGG,NOBGG $
EMA      GPECT,BDICT,BELM/BGG, $
LABEL    LBLBGG $
COND     LBLK4GG,NOK4GG $
EMA      GPECT,KDICT,KELM/K4GG,/NOK4GG $
LABEL    LBLK4GG $
PURGE    MNN,MFF,MAA/NOMGG $
PURGE    BNN,BFF,BAA/NOBGG $
COND     LBL1,GRDPNT $
COND     ERROR3,NOMGG $
GPWG     BGPDP,CSTM,EQEXIN,MGG/OGPWG/V,Y,GRDPNT=-1/C,Y,WTMASS $
OFP      OGPWG,,,,,//S,N,CARDNO $
LABEL    LBL1 $
EQUIV    KGGX,KGG/NOGENL $
COND     LBL11,NOGENL $
SMA3     GEI,KGGX/KGG/LUSET/NOGENL/NOSIMP $
LABEL    LBL11 $
PARAM    //*MPY*/NSKIP/0/0 $
GP4      CASECC,GEOM4,EQEXIN,GPDT,BGPDT,CSTM,GPST/RG,,USET,ASET/ LUSET/
         S,N,MPCF1/S,N,MPCF2/S,N,SINGLE/S,N,OMIT/S,N,REACT/S,N,NSKIP/S,
         N,REPEAT/S,N,NOSET/S,N,NOL/S,N,NOA/C,Y,ASETOUT/ S,Y,AUTOSPC $
PURGE    GM,GMD/MPCF1/GO,GOD/OMIT/KFS,PST,QP/SINGLE $
COND     LBL4,GENEL $
COND     LBL4,NOSIMP $
PARAM    //*EQ*/GPSPFLG/AUTOSPC/0 $
COND     LBL4,GPSPFLG $
GPSP     GPL,GPST,USET,SIL/OGPST/S,N,NOGPST $
OFP      OGPST,,,,,//S,N,CARDNO $
LABEL    LBL4 $
EQUIV    KGG,KNN/MPCF1/MGG,MNN/MPCF1/ BGG,BNN/MPCF1/K4GG,K4NN/MPCF1 $
COND     LBL2,MPCF1 $
MCE1     USET,RG/GM $
MCE2     USET,GM,KGG,MGG,BGG,K4GG/KNN,MNN,BNN,K4NN $
LABEL    LBL2 $
EQUIV    KNN,KFF/SINGLE/MNN,MFF/SINGLE/BNN,BFF/SINGLE/K4NN,K4FF/SINGLE $
COND     LBL3,SINGLE $
```

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```
SCE1      USET,KNN,MNN,BNN,K4NN/KFF,KFS, ,MFF,BFF,K4FF $
LABEL     LBL3 $
EQUIV     KFF,KAA/OMIT $
EQUIV     MFF,MAA/OMIT $
EQUIV     BFF,BAA/OMIT $
EQUIV     K4FF,K4AA/OMIT $
COND      LBL5,OMIT $
SMP1      USET,KFF,,,/GO,KAA,KOO,LOO,,,,, $
COND      LBLM,NOMGG $
SMP2      USET,GO,MFF/MAA $
LABEL     LBLM $
COND      LBLB,NOBGG $
SMP2      USET,GO,BFF/BAA $
LABEL     LBLB $
COND      LBL5,NOK4GG $
SMP2      USET,GO,K4FF/K4AA $
LABEL     LBL5 $
PARAM     //*ADD*/DRY/1  /0 $
LABEL     LBSBEG $
DPD       DYNAMICS,GPL,SIL,USET/GPLD,SILD,USETD,TFPOOL,DLT,,,NLFT,TRL,,
          EQDYN/LUSET/S,N,LUSETD/NOTFL/S,N,NODLT/NOPSDL/  NOFRL/S,N,
          NONLFT/S,N,NOTRL/NOEED//S,N,NOUE $
COND      ERROR1,NOTRL $
PURGE     PNLD/NONLFT$
EQUIV     GO,GOD/NOUE/GM,GMD/NOUE $
PARAM     //*NOP*/ALWAYS=-1 $
SSG1      SLT,BGPDT,CSTM,SIL,EST,MPT,GPTT,EDT,MGG,CASECC,DIT/PG/LUSET/
          NSKIP $
SSG2      USET,GM,  ,KFS,GO,,PG/QR,PO,PS,PL $
RCOVR3    ,PG,PS,  ,  /UDVT,QAS,PPT,PST,   ,   ,TOL /9   /*ABASIC  */
          NOUE $
SDR1      USETD,,UDVT,,,GOD,GMD,PST,KFS,,/UPV,,QP/1/*DYNAMICS* $
LABEL     LBL17 $
EQUIV     CASECC,CASEXX/ALWAYS $
SDR2      CASEXX,CSTM,MPT,DIT,EQDYN,SILD,,,BGPDP,TOL,,UPV,EST,XYCDB,
          PPT/OPP1,OQP1,OUPV1,OES1,OEF1,PUGV/*TRANRESP* $
SDR3      OPP1,OQP1,OUPV1,OES1,OEF1,/OPP2,OQP2,OUPV2,OES2,OEF2, $
OFP       OPP2,OQP2,OUPV2,OEF2,OES2,//S,N,CARDNO $
COND      P2,JUMPPLOT $
PLOT      PLTPAR,GPSETS,ELSETS,CASEXX,BGPDT,EQEXIN,SIP,,PUGV,GPECT,OES1/
          PLOTX2/NSIL/LUSEP/JUMPPLOT/PLTFLG/S,N,PFILE $
PRTMSG    PLOTX2// $
LABEL     P2 $
XYTRAN    XYCDB,OPP2,OQP2,OUPV2,OES2,OEF2/XYPLTT/*TRAN*/*PSET*/S,N,PFILE/
          S,N,CARDNO $
XYPLOT    XYPLTT// $
LABEL     LBL18 $
SOFUT     //DRY/*TOC        */*SOFP*/0  /*          */*       */*       */*       */
          *    */*    */*    * $
LABEL     LBSEND $
```

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```
JUMP       FINIS $
LABEL      ERROR1 $
PRTPARM    //-1/*DIRTRD* $
LABEL      ERROR3 $
PRTPARM    //-3/*DIRTRD* $
LABEL      FINIS $
PURGE      DUMMY/ALWAYS $
END        $
TIME 3
DIAG 14
CEND
SUBSTRUCTURE PHASE3
PASSWORD = MDLSYN
SOF(1) = FT19,500 $ CDC AND IBM
ENDSUBS
TITLE = TRUSS DYNAMIC ANALYSIS USING AUTOMATED MODAL SYNTHESIS
DLOAD = 101
TSTEP = 40
OLOAD = ALL
DISP = ALL
FORCE = ALL
BEGIN BULK
CROD    1       1       1       2
CROD    2       1       2       3
CROD    11      1       11      12
CROD    12      1       12      13
CROD    21      1       21      22
CROD    22      1       22      23
CROD    31      1       31      32
CROD    32      1       32      33
CROD    41      1       41      42
CROD    42      1       42      43
CROD    111     1       1       11
CROD    112     1       2       12
CROD    113     1       3       13
CROD    121     1       11      21
CROD    122     1       12      22
CROD    123     1       13      23
CROD    131     1       21      31
CROD    132     1       22      32
CROD    133     1       23      33
CROD    141     1       31      41
CROD    142     1       32      42
CROD    143     1       33      43
CROD    212     1       2       13
CROD    211     1       2       11
CROD    221     1       12      21
CROD    222     1       12      23
CROD    231     1       22      31
CROD    232     1       22      33
CROD    241     1       32      41
CROD    242     1       32      43
```

APPENDIX A. (concluded)

GRDSET							3456
GRID	1		30.0	.0	.0		
GRID	2		.0	.0	.0		
GRID	3		-30.0	.0	.0		
GRID	11		30.0	40.0	.0		
GRID	12		.0	40.0	.0		
GRID	13		-30.0	40.0	.0		
GRID	21		30.0	80.0	.0		
GRID	22		.0	80.0	.0		
GRID	23		-30.0	80.0	.0		
GRID	31		30.0	120.0	.0		
GRID	32		.0	120.0	.0		
GRID	33		-30.0	120.0	.0		
GRID	41		30.0	160.0	.0		
GRID	42		.0	160.0	.0		
GRID	43		-30.0	160.0	.0		
MAT1	1	10.0+6		.3	2.5-4		
PROD	1	1	.3				
DAREA	980	42	1	1.0+3			
TLOAD2	101	980		5	0.0	0.12	
TSTEP	40	40	3.0-3	5	~~0.0~~	~~0.12~~	
ENDDATA							
/EOF							

11.30.27.UCLP, DDLP00948, 0.423KLNS.

APPENDIX B. Driver decks and sample bulk data for beam problem of case 1.

```
NASTRAN FILES = UMF $ CDC AND IBM
ID      DEM2031,NASTRAN
APP DISP,SUBS
SOL 3,0
TIME 3
CEND
SUBSTRUCTURE PHASE1
PASSWORD = MDLSYN
SOF(1) = FT17,500,NEW $ CDC AND IBM
NAME = ABASIC
SOFPRINT TOC
ENDSUBS
TITLE = BEAM  DYNAMIC ANALYSIS USING AUTOMATED MODAL SYNTHESIS
LABEL = SUBSTRUCTURE 1, RUN 1, PHASE 1, R6 2
BEGIN BULK
BAROR           1                               10.0    10.0    0.0     1
CBAR    1       1       1       2
CBAR    2       1       2       3
CBAR    3       1       3       4
CBAR    4       1       4       5
CBAR    5       1       5       6
CBAR    6       1       6       7
CBAR    7       1       7       8
CBAR    8       1       8       9
CBAR    9       1       9       10
CBAR    10      1       10      11
GRDSET                                                  345
GRID    1               0.      0.      0.
GRID    2               10.     0.      0.
GRID    3               20.     0.      0.
GRID    4               30.     0.      0.
GRID    5               40.     0.      0.
GRID    6               50.     0.      0.
GRID    7               60.     0.      0.
GRID    8               70.     0.      0.
GRID    9               80.     0.      0.
GRID    10              90.     0.      0.
GRID    11              100.    0.      0.
PBAR    1       1       .56     63.
MAT1    1       10.0+6          .3      2.591-4
ENDDATA
&

NASTRAN FILES = UMF $ CDC AND IBM
ID      DEM2032,NASTRAN
APP DISP,SUBS
SOL 3,0
TIME 5
CEND
SUBSTRUCTURE PHASE2
PASSWORD = MDLSYN
SOF(1) = FT17,500 $ CDC AND IBM
EQUIV ABASIC,BBASIC
PREFIX B
EQUIV ABASIC,GBASIC
PREFIX G
MREDUCE ABASIC
NAME MA
BOUNDARY 20
FIXED 20
METHOD 1
MREDUCE BBASIC
NAME MB
BOUNDARY 2
```

APPENDIX B. (concluded)

```
FIXED 2
METHOD 2
MREDUCE GBASIC
NAME MG
BOUNDARY 3
FIXED 3
METHOD 3
EQUIV MB,MC
PREFIX C
EQUIV MB,MD
PREFIX D
EQUIV MB,ME
PREFIX E
EQUIV MB,MF
PREFIX F
COMBINE MA,MB,MC,MD,ME,MF,MG
NAME ABCDEFG
TOLERANCE 0.01
OUTPUT 2,7,12
COMPONENT MB
TRANSFORM 2
COMPONENT MC
TRANSFORM 3
COMPONENT MD
TRANSFORM 4
COMPONENT ME
TRANSFORM 5
COMPONENT MF
TRANSFORM 6
COMPONENT MG
TRANSFORM 7
MREDUCE ABCDEFG
NAME BEAM
BOUNDARY 20
METHOD 22
OUTPUT 1,5,6,9,10
SOFPRINT TOC
ENDSUBS
TITLE=BEAM DYNAMIC ANALYSIS USING AUTOMATED MODAL SYNTHESIS
SUBTITLE=NASTRAN DEMONSTRATION PROBLEM NO. 2-3-2
LABEL=MODAL REDUCE,COMBINE,MODAL,RECOVERY,RUN2,PHASE2
BEGIN BULK
BDYC    2       BBASIC  50
BDYC    3       GBASIC  40
BDYC    20      ABASIC  30
BDYS1   30      126     11
BDYS1   40      126     1
BDYS1   50      126     1       11
TRANS   2               100.    0.      0.      100.    0.      1.      +T2
+T2     150.    0.      0.
TRANS   3               200.    0.      0.      200.    0.      1.      +T3
+T3     250.    0.      0.
TRANS   4               300.    0.      0.      300.    0.      1.      +T4
+T4     350.    0.      0.
TRANS   5               400.    0.      0.      400.    0.      1.      +T5
+T5     450.    0.      0.
TRANS   6               500.    0.      0.      500.    0.      1.      +T6
+T6     550.    0.      0.
TRANS   7               600.    0.      0.      600.    0.      1.      +T7
+T7     650.    0.      0.
EIGR    1       INV     .0      3000.00 10      10                      +E1
+E1     MAX
EIGR    2       INV     .0      3000.00 10      10                      +E2
+E2     MAX
EIGR    3       INV     .0      3000.00 10      10                      +E3
+E3     MAX
EIGR    22      INV     .0      2000.0  40      40                      +E22
+E22    MAX
ENDDATA
#
```

APPENDIX C. Driver decks and sample bulk data for beam problem of case 2.

```
NASTRAN FILES = UMF $ CDC AND IBM
ID       DEM2031,NASTRAN
APP DISP,SUBS
SOL 3,0
TIME 3
CEND
SUBSTRUCTURE PHASE1
PASSWORD = MDLSYN
SOF(1) = FT17,500,NEW $ CDC AND IBM
NAME = ABASIC
SOFPRINT TOC
ENDSUBS
TITLE = BEAM  DYNAMIC ANALYSIS USING AUTOMATED MODAL SYNTHESIS
LABEL = SUBSTRUCTURE 1, RUN 1, PHASE 1, R6 2
BEGIN BULK
BAROR           1                               10.0    10.0    0.0     1
CBAR    1       1       1       2
CBAR    2       1       2       3
CBAR    3       1       3       4
CBAR    4       1       4       5
CBAR    5       1       5       6
CBAR    6       1       6       7
CBAR    7       1       7       8
CBAR    8       1       8       9
CBAR    9       1       9       10
CBAR    10      1       10      11
GRDSET                                                  345
GRID    1               0.      0.      0.
GRID    2               10.     0.      0.
GRID    3               20.     0.      0.
GRID    4               30.     0.      0.
GRID    5               40.     0.      0.
GRID    6               50.     0.      0.
GRID    7               60.     0.      0.
GRID    8               70.     0.      0.
GRID    9               80.     0.      0.
GRID    10              90.     0.      0.
GRID    11              100.    0.      0.
PBAR    1       1       .56     63.
MAT1    1       10.0+6          .3      2.591-4
ENDDATA
&

NASTRAN FILES = UMF $ CDC AND IBM
ID       DEM2032,NASTRAN
APP DISP,SUBS
SOL 3,0
TIME 5
CEND
SUBSTRUCTURE PHASE2
PASSWORD = MDLSYN
SOF(1) = FT17,500 $ CDC AND IBM
EQUIV ABASIC,BBASIC
PREFIX B
EQUIV ABASIC,CBASIC
PREFIX C
EQUIV ABASIC,DBASIC
PREFIX D
EQUIV ABASIC,EBASIC
PREFIX E
EQUIV ABASIC,FBASIC
PREFIX F
EQUIV ABASIC,GBASIC
PREFIX G
MREDUCE ABASIC
NAME MA
```

```
BOUNDARY 20
FIXED 20
METHOD 1
MREDUCE BBASIC
NAME MB
BOUNDARY 2
FIXED 2
METHOD 2
MREDUCE CBASIC
NAME MC
BOUNDARY 7
FIXED 7
METHOD 2
MREDUCE DBASIC
NAME MD
BOUNDARY 8
FIXED 8
METHOD 2
MREDUCE EBASIC
NAME ME
BOUNDARY 9
FIXED 9
METHOD 2
MREDUCE FBASIC
NAME MF
BOUNDARY 11
FIXED 11
METHOD 2
MREDUCE GBASIC
NAME MG
BOUNDARY 3
FIXED 3
METHOD 3
COMBINE MA,MB
NAME AB
TOLERANCE 0.01
OUTPUT 2,7,12
COMPONENT MB
TRANSFORM 2
MREDUCE AB
NAME MAB
BOUNDARY 10
FIXED 10
METHOD 22
COMBINE MAB,MC
NAME ABC
TOLERANCE 0.01
OUTPUT 2,7,12
COMPONENT MC
TRANSFORM 3
MREDUCE ABC
NAME MABC
BOUNDARY 21
FIXED 21
METHOD 22
COMBINE MABC,MD
NAME ABCD
TOLERANCE 0.01
OUTPUT 2,7,12
COMPONENT MD
TRANSFORM 4
MREDUCE ABCD
NAME MABCD
BOUNDARY 22
FIXED 22
METHOD 22
```

```
COMBINE MABCD,ME
NAME ABCDE
TOLERANCE 0.01
OUTPUT 2,7,12
COMPONENT ME
TRANSFORM 5
MREDUCE ABCDE
NAME MABCDE
BOUNDARY 23
FIXED 23
METHOD 22
COMBINE MABCDE,MF
NAME ABCDEF
TOLERANCE 0.01
OUTPUT 2,7,12
COMPONENT MF
TRANSFORM 6
MREDUCE ABCDEF
NAME MABCDEF
BOUNDARY 24
FIXED 24
METHOD 22
COMBINE MABCDEF,MG
NAME ABCDEFG
TOLERANCE 0.01
OUTPUT 2,7,12
COMPONENT MG
TRANSFORM 7
MREDUCE ABCDEFG
NAME BEAM
BOUNDARY 20
METHOD 22
OUTPUT 1,5,6,9,10
SOFPRINT TOC
ENDSUBS
TITLE=BEAM DYNAMIC ANALYSIS USING AUTOMATED MODAL SYNTHESIS
SUBTITLE=NASTRAN DEMONSTRATION PROBLEM NO. 2-3-2
LABEL=MODAL REDUCE,COMBINE,MODAL,RECOV5RY,RUN2,P8 S52
BEGIN BULK
BDYC    7       CBASIC  50
BDYC    9       EBASIC  50
BDYC    21      CBASIC  30
BDYC    22      DBASIC  30
BDYC    23      EBASIC  30
BDYC    24      FBASIC  30
BDYC    11      FBASIC  50
BDYC    8       DBASIC  50
BDYC    10      BBASIC  30
BDYC    15      CBASIC  40      DBASIC  30
BDYC    2       BBASIC  50
BDYC    3       GBASIC  40
BDYC    20      ABASIC  30
BDYS1   30      126     11
BDYS1   40      126     1
BDYS1   50      126     1       11
TRANS   4               300.0   0.0     0.0     300.0   0.0     1.0     +T4
+T4     350.0   0.0     0.0
TRANS   6               500.0   0.0     0.0     500.0   0.0     1.0     +T6
+T6     550.0   0.0     0.0
TRANS   2               100.    0.      0.      100.    0.      1.      +T2
+T2     150.    0.      0.
TRANS   3               200.    0.      0.      200.    0.      1.      +T3
+T3     250.    0.      0.
TRANS   5               400.    0.      0.      400.    0.      1.      +T5
+T5     450.    0.      0.
```

APPENDIX C. (concluded)

```
RANS     7                 600.     0.       0.      600.     0.       1.      +T7
T7       650.     0.       0.
IGR      1        INV      .0       3000.00 10       10                         +E1
E1       MAX
IGR      2        INV      .0       3000.00 10       10                         +E2
E2       MAX
IGR      3        INV      .0       3000.00 10       10                         +E3
E3       MAX
IGR      22       INV      .0       1000.0  40       40                         +E22
E22      MAX
NDDATA
```

APPENDIX D. Driver decks and sample bulk data fro beam problem of case 3.

```
NASTRAN FILES = UMF $ CDC AND IBM
ID      DEM2031,NASTRAN
APP DISP,SUBS
SOL 3,0
TIME 3
CEND
SUBSTRUCTURE PHASE1
PASSWORD = MDLSYN
SOF(1) = FT17,500,NEW $ CDC AND IBM
NAME = ABASIC
SOFPRINT TOC
ENDSUBS
TITLE = BEAM  DYNAMIC ANALYSIS USING AUTOMATED MODAL SYNTHESIS
LABEL = SUBSTRUCTURE 1, RUN 1, PHASE 1, R6 2
BEGIN BULK
BAROR           1                               10.0    10.0    0.0     1
CBAR    1       1       1       2
CBAR    2       1       2       3
CBAR    3       1       3       4
CBAR    4       1       4       5
CBAR    5       1       5       6
CBAR    6       1       6       7
CBAR    7       1       7       8
CBAR    8       1       8       9
CBAR    9       1       9       10
CBAR    10      1       10      11
GRDSET                                                  345
GRID    1               0.      0.      0.
GRID    2               10.     0.      0.
GRID    3               20.     0.      0.
GRID    4               30.     0.      0.
GRID    5               40.     0.      0.
GRID    6               50.     0.      0.
GRID    7               60.     0.      0.
GRID    8               70.     0.      0.
GRID    9               80.     0.      0.
GRID    10              90.     0.      0.
GRID    11              100.    0.      0.
PBAR    1       1       .56     63.
MAT1    1       10.0+6          .3      2.591-4
ENDDATA
&

NASTRAN FILES = UMF $ CDC AND IBM
ID      DEM2032,NASTRAN
APP DISP,SUBS
SOL 3,0
TIME 10
CEND
SUBSTRUCTURE PHASE2
PASSWORD = MDLSYN
SOF(1) = FT17,500 $ CDC AND IBM
EQUIV ABASIC,BBASIC
PREFIX B
EQUIV ABASIC,CBASIC
PREFIX C
EQUIV ABASIC,DBASIC
PREFIX D
EQUIV ABASIC,EBASIC
PREFIX E
EQUIV ABASIC,FBASIC
PREFIX F
EQUIV ABASIC,GBASIC
PREFIX G
MREDUCE ABASIC
```

```
NAME MA
BOUNDARY 20
FIXED 20
METHOD 1
MREDUCE BBASIC
NAME MB
BOUNDARY 2
FIXED 2
METHOD 2
MREDUCE CBASIC
NAME MC
BOUNDARY 7
FIXED 7
METHOD 2
MREDUCE DBASIC
NAME MD
BOUNDARY 8
FIXED 8
METHOD 2
MREDUCE EBASIC
NAME ME
BOUNDARY 9
FIXED 9
METHOD 2
MREDUCE FBASIC
NAME MF
BOUNDARY 11
FIXED 11
METHOD 2
MREDUCE GBASIC
NAME MG
BOUNDARY 3
FIXED 3
METHOD 3
COMBINE MA,MB
NAME AB
TOLERANCE 0.01
OUTPUT 2,7,12
COMPONENT MB
TRANSFORM 2
MREDUCE AB
NAME MAB
BOUNDARY 10
FIXED 10
METHOD 22
COMBINE MC,MD
NAME CD
TOLERANCE 0.01
OUTPUT 2,7,12
COMPONENT MD
TRANSFORM 2
MREDUCE CD
NAME MCD
BOUNDARY 15
FIXED 15
METHOD 22
COMBINE ME,MF
NAME EF
TOLERANCE 0.01
OUTPUT 2,7,12
COMPONENT MF
TRANSFORM 2
MREDUCE EF
NAME MEF
BOUNDARY 25
FIXED 25
METHOD 22
COMBINE MAB,MCD
```

```
NAME ABCD
TOLERANCE 0.01
OUTPUT 2,7,12
COMPONENT MCD
TRANSFORM 3
MREDUCE ABCD
NAME MABCD
BOUNDARY 30
FIXED 30
METHOD 25
COMBINE MEF,MG
NAME EFG
TOLERANCE 0.01
OUTPUT 2,7,12
COMPONENT MG
TRANSFORM 3
MREDUCE EFG
NAME MEFG
BOUNDARY 35
FIXED 35
METHOD 25
COMBINE MABCD,MEFG
NAME ABCDEFG
TOLERANCE 0.01
OUTPUT 2,7,12
COMPONET MEFG
TRANSFORM 5
MREDUCE ABCDEFG
NAME BEAM
BOUNDARY 20
METHOD 25
OUTPUT 1,5,6,9,10
SOFPRINT TOC
ENDSUBS
TITLE=BEAM DYNAMIC ANALYSIS USING AUTOMATED MODAL SYNTHESIS
SUBTITLE=NASTRAN DEMONSTRATION PROBLEM NO. 2-3-2
LABEL=MODAL REDUCE,COMBINE,MODAL,RECOVERY,RUN2,PHASE2
BEGIN BULK
BDYC    30      DBASIC  30
BDYC    35      EBASIC  40
BDYC    7       CBASIC  50
BDYC    9       EBASIC  50
BDYC    11      FBASIC  50
BDYC    25      EBASIC  40      FBASIC  30
BDYC    8       DBASIC  50
BDYC    10      BBASIC  30
BDYC    15      CBASIC  40      DBASIC  30
BDYC    2       BBASIC  50
BDYC    3       GBASIC  40
BDYC    20      ABASIC  30
BDYS1   30      126     11
BDYS1   40      126     1
BDYS1   50      126     1       11
TRANS   2               100.    0.      0.      100.    0.      1.      +T2
+T2     150.    0.      0.
TRANS   3               200.    0.      0.      200.    0.      1.      +T3
+T3     250.    0.      0.
TRANS   5               400.    0.      0.      400.    0.      1.      +T5
+T5     450.    0.      0.
TRANS   7               600.    0.      0.      600.    0.      1.      +T7
+T7     650.    0.      0.
EIGR    1       INV     .0      3000.00 10      10                      +E1
+E1     MAX
EIGR    2       INV     .0      3000.00 10      10                      +E2
```

APPENDIX D. (concluded)

```
+E2     MAX
EIGR    3       INV     .0      3000.00 10      10                      +E3
+E3     MAX
EIGR    25      INV     0.0     1000.0  40      40                      +E25
+E25    MAX
EIGR    22      INV     .0      2000.0  40      40                      +E22
+E22    MAX
ENDDATA
#
```

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15. Supplementary Notes

Langley Technical Monitor: Joseph E. Walz

16. Abstract

This report compares the accuracy between **NASTRAN®** modal synthesis, full structure **NASTRAN®** and several other modal synthesis results (truss only). The results are based on a truss or beam having redundant or point interface connections. Each component substructure is reduced to modal and boundary degrees of freedom prior to the substructure combine operation. The combination structure, formulated in terms of the component modes, is also reduced to modal degrees of freedom for solution by the transient analysis rigid format.

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