AN ENHANCEMENT OF NASTRAN FOR THE SEISMIC ANALYSIS OF STRUCTURES

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SUMMARY

New modules, bulk data cards and DMAP sequence have been added to NASTRAN to aid in the seismic analysis of structures. These allow input consisting of acceleration time histories and result in the generation of acceleration floor response spectra. The resulting system contains numerous user convenience features, as well as being reasonably efficient.

INTRODUCTION

At ONTARIO HYDRO, the primary analysis tool is NASTRAN. This use began with the purchase of level 15.1 and continued with 15.5 and SPERRY/NASTRAN. Currently MSC/NASTRAN is being implemented as levels 16 and above are not available in CANADA. To perform a seismic analysis of nuclear power plant structures, the NASTRAN normal modes analysis has been utilized in conjunction with two post processors written at ONTARIO HYDRO. The one performs a time history method analysis to generate the desired floor response spectra, the other performs a response spectrum method analysis by utilizing these floor response spectra. While the response spectrum processor has stood the test of time, the time history method processor has not.

The time history analysis post processor was initially conceived to be used with simple stick type lumped mass models. However, as the complexity of the analyses increased, this processor was unable to satisfy all requirements. In addition, the cost of analysis for the more complex structures became excessive. About this time, the need to treat problems which were subjected to multiple-support excitations became a requirement.

Considering the shortcomings of the existing post processor, as well as future requirements, it was decided to develop an entirely new capability and to include it within NASTRAN. This project was then divided into two main development stages. The first, which is described in this paper, is a replacement for the existing post processor and provides the ability to handle any size problem, efficiency, improved output and user convenience features. The second stage, development of which is underway, extends the first stage to allow for the consideration of multiple-support excitation problems.

SYMBOLS

$a(t)$	-	acceleration time history at the ground (g).
b_j	-	structural damping ratio associated with a particular mode j.
$F_i(t)$	-	generated force time history acting at a specific degree of freedom.
g_e	-	structural damping ratio associated with the lth element.
k_j	-	stiffness matrix associated with a specific mode j.
k_l	-	stiffness matrix associated with a particular element l.
m_j	-	modal mass matrix associated with the jth mode.
m_i	-	total structural mass associated with grid point i.
$P_i(t)$	-	absolute acceleration time history used as a load for the response spectra generation.
β	-	equipment damping ratio for which spectra are required.
ξ	-	displacement components in modal co-ordinates.
ϕ_j	-	mode shape associated with the jth mode.
ω_o	-	input and modal frequencies at which the response spectra will be computed.

THEORY

Since the input for seismic activity is usually available as acceleration time histories, and force time histories are required, a conversion must be performed. Several techniques are available, the one chosen here replaces the acceleration time history by a set of force time histories according to the equation

$$F_i(t) = m_i\, a(t) \tag{1}$$

This results in a force time history at each free degree of freedom corresponding in direction to the input acceleration.

Once the force time histories have been created, a modal transient analysis is performed. The resulting relative acceleration time histories are then converted to absolute accelerations prior to the generation of the floor response spectra. This is done by adding the input acceleration to each of the computed acceleration time histories in the corresponding direction.

Floor response spectra are computed by performing a transient analysis for each of a set of one degree of freedom oscillators. The transient analysis performed utilizes the solution of separate second order differential equations of the following form.

$$\ddot{\xi}_i + 2\beta\omega_o \dot{\xi}_i + \omega_o^2 \xi_i = \frac{1}{m_i} P_i(t) \tag{2}$$

$$\omega_o \beta = \frac{b_i}{2m_i} \tag{3}$$

$$\omega_o^2 = \frac{K_i}{m_i} \tag{4}$$

The frequencies ω_o utilized are a combination of user input frequencies and the frequencies determined for the structure. As results are required only in modal coordinates, the value of m_i is arbitrarily set to 1.0. This requires then only the solution of the equation

$$\ddot{\xi}_i + 2\beta\omega_o \dot{\xi}_i + \omega_o^2 \xi_i = P_i(t) \tag{5}$$

The equation of motion, therefore, corresponds to that of a single degree of freedom system having the prescribed damping and frequency properties and subjected to the prescribed degree of freedom acceleration. The relative acceleration is obtained at each time step as follows:

$$\ddot{\xi}_{i,n+1} = \frac{P_{i,n+1}}{m_i} - 2\beta\omega_o \dot{\xi}_{i,n+1} - \omega_o^2 \xi_{i,n+1} \tag{6}$$

To obtain the desired absolute accelerations, the computed acceleration is added to the above relative acceleration. The maximum acceleration is then retained over all time steps. This procedure is repeated for each of the designated frequencies and equipment damping input. The resulting table of maximum acceleration versus frequency is the desired floor response spectra.

Damping must be included in the analysis. Here, the user may specify modal damping, uniform structural damping or element structural damping. The preferred technique is to use element structural damping. In this case, the composite modal damping values will be computed. These values are based upon the fraction of the strain energy sustained by each element in the model. The modal damping for the jth mode is computed as follows:

$$b_j = \frac{\sum_{i=1}^{N} \{\Phi_j\}^T K_L \{\Phi_j\} g_L}{K_j} \qquad (7)$$

APPROACH

This facility has been implemented in NASTRAN by means of a DMAP program. This program is a modification of that used for Modal Transient Analysis (Rigid Format 12). The general problem flow is as shown in Figure 1.

To implement this facility, four new modules were written. Two of which precede the transient analysis module (TRD) and two follow. In addition, extensive use is made of existing NASTRAN modules in the solution.

The standard NASTRAN approach is followed for the matrix generation and eigenvalue extraction phase. Following this, the equivalent force time histories are created. The input acceleration time histories may come either from TABLED1 cards, or from a user file where the tables have been prestored. A modal transient analysis is then performed. The output from this stage consists of relative acceleration time histories. An added module will convert these into absolute accelerations. This matrix is subsequently transposed and from it the floor response spectra are generated. Finally, XY plots of the spectra may be produced. All normal NASTRAN output is available, in addition to the output produced by these new modules.

NASTRAN IMPLEMENTATION

To implement this capability in NASTRAN, two bulk data cards, four modules and a complete DMAP sequence have been developed. The new bulk data cards are SDATA and SET1.

The SDATA card, used to define the input loading and optionally to select the data required to generate the floor response spectra, is illustrated in the appendix. The SDATA card is selected by the DLOAD case control card. If the acceleration is to be combined with other acceleration or force time histories, then the DLOAD bulk data card may be used to combine them. Each SDATA card may select acceleration time histories for up to six degrees of freedom at any one grid point. In addition, data may be provided for the generation of floor response spectra. This data includes the equipment damping set and the set of grid points at which spectra are desired. Miscellaneous data for the control of the analysis may also be provided.

The SET1 card is used to define the grid points at which spectra are computed. It is selected by the SDATA card and is required only if floor response spectra are to be generated. The card format is shown in the appendix.

The acceleration time histories required may be supplied either as TABLED1 cards or from prestored tables on a user file. The latter technique is preferred when a standard set of time histories is available.

Four modules were created for this enhancement. They are SCNTL, SAPF, STHGNMX, and SFRG.

SCNTL - This module verifies all data input on SDATA cards and ensures that the required sets and data tables are available before proceeding with the analysis.

SAPF - This module accepts the input acceleration time history and generates the required force time histories. This is done by creating new forms of the DLT and DIT tables.

STHGNMX - This module accepts the relative time histories output from TRD and creates the absolute acceleration time histories. In addition, this module can, at user request, reduce the size of the output matrices prior to subsequent output requests.

SFRG - This module accepts the transposed absolute acceleration matrix and creates the required floor response spectra. This includes the generation of data for XY plots as well as printed output. This information is then passed to the XY PLOT and OFP modules.

In addition to these bulk data cards and modules, the DMAP sequence contains a number of parameters which may be used by the engineer to select optional processing paths. In general, the engineer need not use any of these parameters as the default values will select the most appropriate options.

All the normal output from a Modal Transient analysis may be requested. This includes both relative and absolute accelerations. The primary output, and all which is normally required, is the floor response spectra which may be printed or plotted as desired.

SAMPLE PROBLEM

To illustrate the ease with which this enhancement may be used, the structure shown in Figure 3 is analyzed and floor response spectra generated at grid point 6. As a point of comparison, the floor response spectra generated by the previous post processor is shown in Figure 4. That portion of the NASTRAN input data required for this enhancement is shown in Figures 5, 6 and 7 for the Executive control, Case control and Bulk data decks respectively. The plot of the resulting floor response spectra is shown in Figure 8 and a portion of the printed output in Figure 9. A review of this data and the resulting output demonstrates the ease with which floor response spectra may be generated.

EXTENSIONS

Several extensions to this enhancement are either planned or in progress. One will be to implement this facility in the other NASTRAN versions available at ONTARIO HYDRO. Another is the extension to solve multiple-support excitation problems. Upon completion of this last item, the original reason for developing these features will be satisfied. All future work will then add more user convenience features or efficiency improvements.

CONCLUSIONS

As a result of this enhancement of NASTRAN, an easy to use capability for the generation of floor response spectra has been made available. This is an extension of the existing Modal Transient analysis which retains all the original capabilities. In addition, the approach used is relatively efficient in terms of computer resources and user interaction required. It is a vast improvement over the original post processor and removes all of the restrictions inherent in it.

REFERENCES

1. The NASTRAN User's Manual NASA SP-222 (01), May 1973

2. The NASTRAN Theoretical Manual NASA SP-221 (01), December 1972

APPENDIX

Input data card SDATA

Description: Defines an input acceleration time dependent loading and various parameters for the generation of floor response spectra.

Format and example

1	2	3	4	5	6	7	8	9	10
SDATA	SID	RUN	XQT	DTM	SAVE	SOURCE	THN1	DIR1	+abc
SDATA	101	-1	3	2			BRTEQH	2	+SD1

+abc	IDFSP	IDEQ	NSKO	IDUMP	THN2	DIR2	THN3	DIR3	+def
+SD1	10	20							

+def	X	THN4	DIR4	THN5	DIR5	THN6	DIR6	X	

Field	Contents
SID	Set identification number (integer > 0)
RUN	Run type control parameter < 0 - simple structure > 0 - multi excitation
XQT	Erection phase control = 1 generate time histories only = 2 generate floor response spectra only = 3 both 1 and 2
DTM	Identification number of the grid point at which the acceleration time history is applied (integer > 0)

SAVE	A flag indicating that the output time histories are to be saved for subsequent use (integer $>$ 0 or blank)
SOURCE	Identifier of the file on which the input time history is stored (integer $\geq$ 0, default = 0)
THNi	Name of the acceleration time history if on a file, or the id of a TABLED1 card.
DIRi	Direction associated with this time history (1 $\leq$ integer $\leq$ 6)
IDFSP	Set id of a SET1 card on which the points at which floor spectra as desired are listed (integer $>$ 0 or blank)
IDEQ	Set id of FREQ, FREQ1 or FREQ2 cards on which the equipment dampings are defined (integer $>$ 0 or blank)
NSKO	Alternate skip factor to reduce the output time histories by (integer $>$ 0 or blank)
IDUMP	Intermediate output flag (integer $>$ 0 or blank) = 1 print input tables = 2 print generated tables

Remarks:

1. The SDATA card must be selected by the DLOAD Case Control card.

2. This loading may be combined with other loadings by means of the DLOAD bulk data card.

3. The items SAVE and SOURCE refer to the NASTRAN GINO file INPT, INP1 thru INP9. INPT is denoted by zero, INP1 - INP9 by the integers 1 to 9.

4. If SAVE is blank, the output time histories will not be saved.

5. If any DIRi or THNi is left blank, then the scan of these items is terminated.

6. Up to 6 acceleration time histories at a single grid point may be defined on one logical card.

Input data card SET1

Description: Defines a set of grid points at which output is desired.

Format and example

1	2	3	4	5	6	7	8	9	10
SET1	SID	G1	G2	G3	G4	G5	G6	G7	+abc
SET1	10	6							

+abc	G8	-etc-							

Field	Contents
SID	Set identification number (integer > 0)
G1, G2 etc	List of structural grid points (integer > 0 or "THRU")

Remarks:

1. These cards are referenced by the SDATA card.
2. If "THRU" is used if must appear in field 4. Fields 6 to 10 will then be blank.
3. All points referenced within a THRU list must exist.

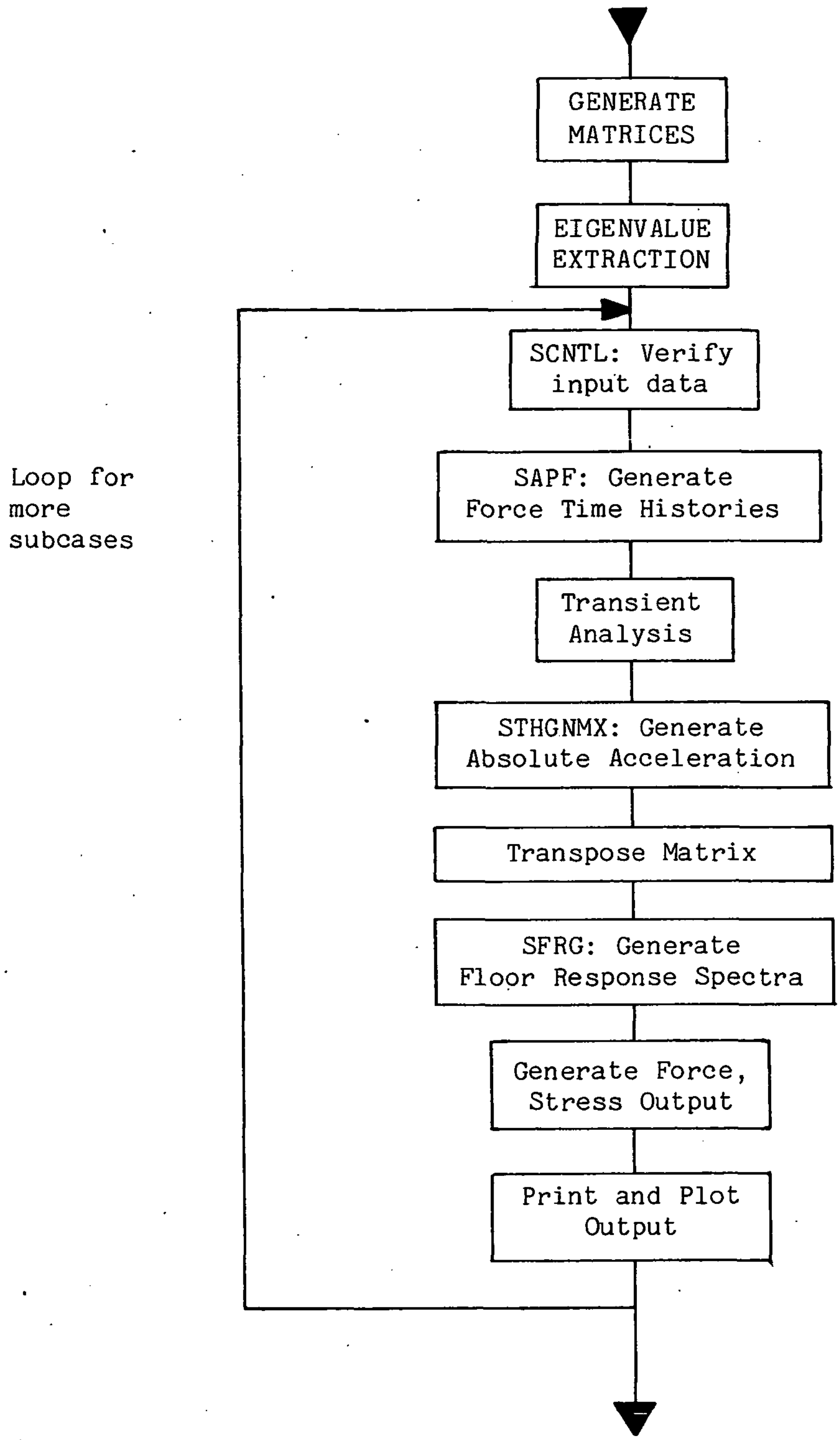

Figure 1: Generation of Floor Spectra Problem Flow

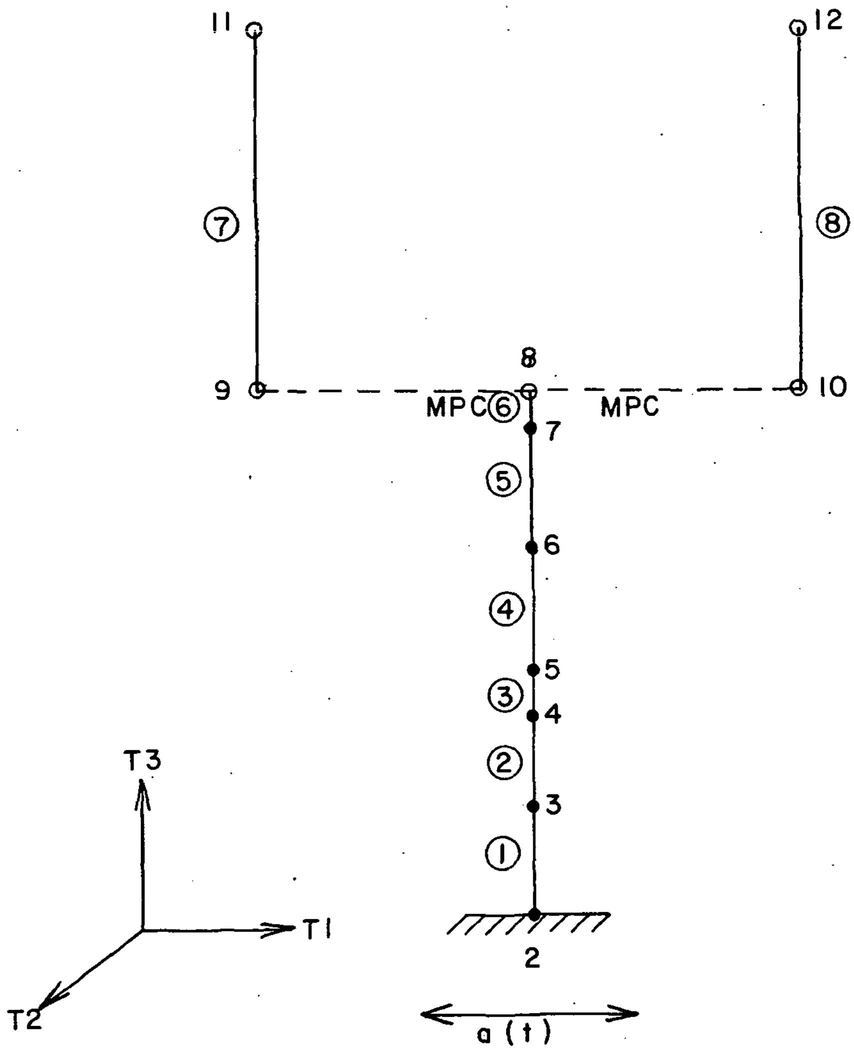

Figure 3: Sample Problem Geometry

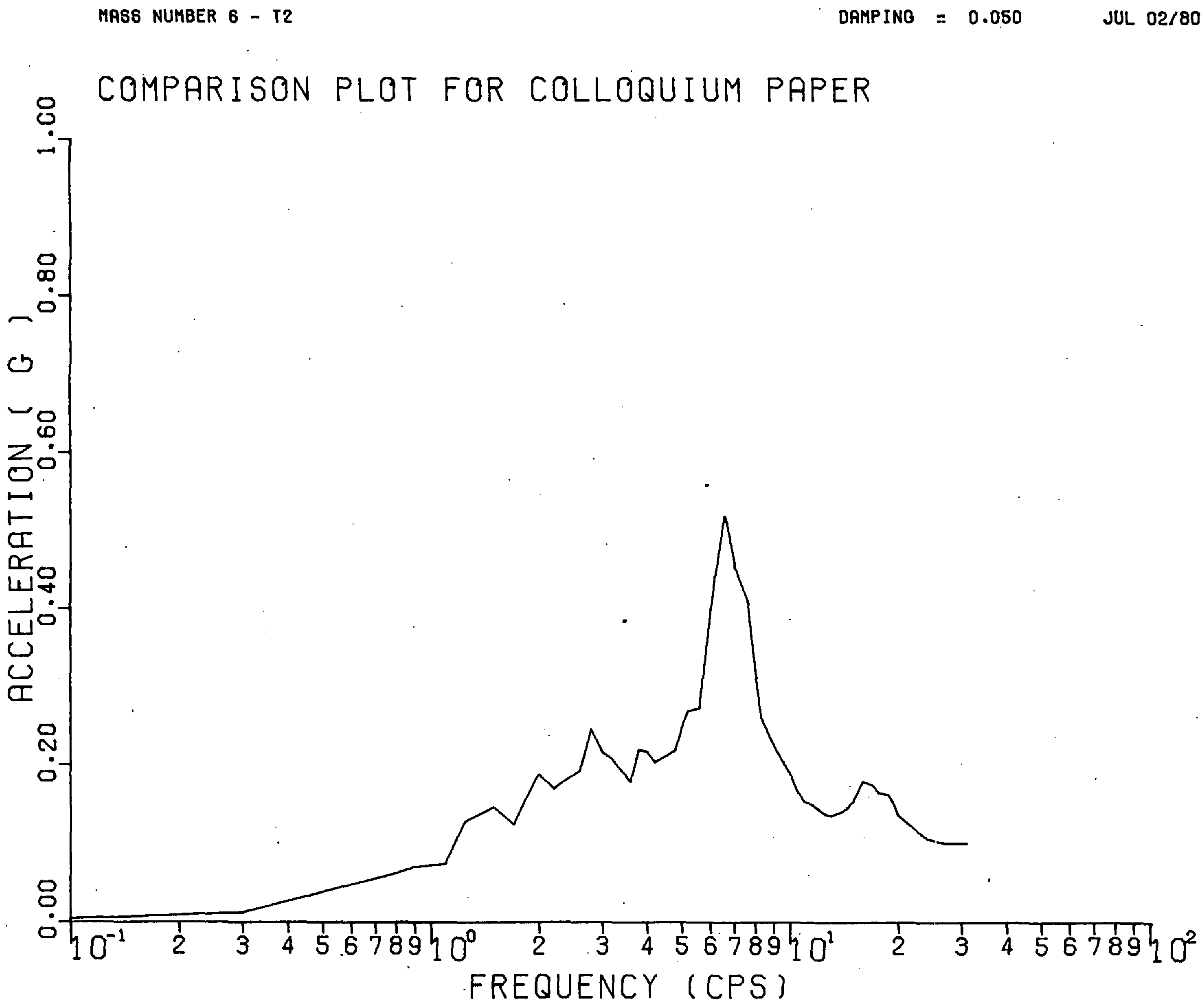

Figure 4: Comparison Floor Response Spectra

```
ID      A,B

APP     DMAP

TIME    10

BEGIN  $
$INSERT DMAP SEQUENCE HERE

END     $

CEND
```

Figure 5: Sample Executive Control Deck

```
TITLE      =     GENERATE FLOOR RESPONSE SPECTRA
TSTEP      =     50
METHOD     =     10
SPC        =     100
DLOAD      =     200
FREQ       =     201
OUTPUT (XYPLOT)
PLOTTER    =     NASTPLT MODEL D,0
```

Figure 6: Sample Case Control Deck

BEGIN BULK

1	2	3	4	5	6	7	8	9	10
FREQ	2	.01	.05						
FREQ	201	.1	.5	.9	1.2	1.7	2.0	2.5	+F1
+F1	3.0	3.5	4.0	4.5	5.0	6.0	7.0	8.0	+F2
+F2	10.0	12.0	14.0	20.0	28.0	30.0	35.0		
SDATA	200	-1	3	2	-1		BRTEH	2	+SD1
+SD1	1	2							
SET1	1	6							
TSTEP	50	3000	.005	2					
$									
$	ALL OTHER GEOMETRIC DATA								
$									
ENDDATA									

Figure 7: Sample Bulk Data Deck

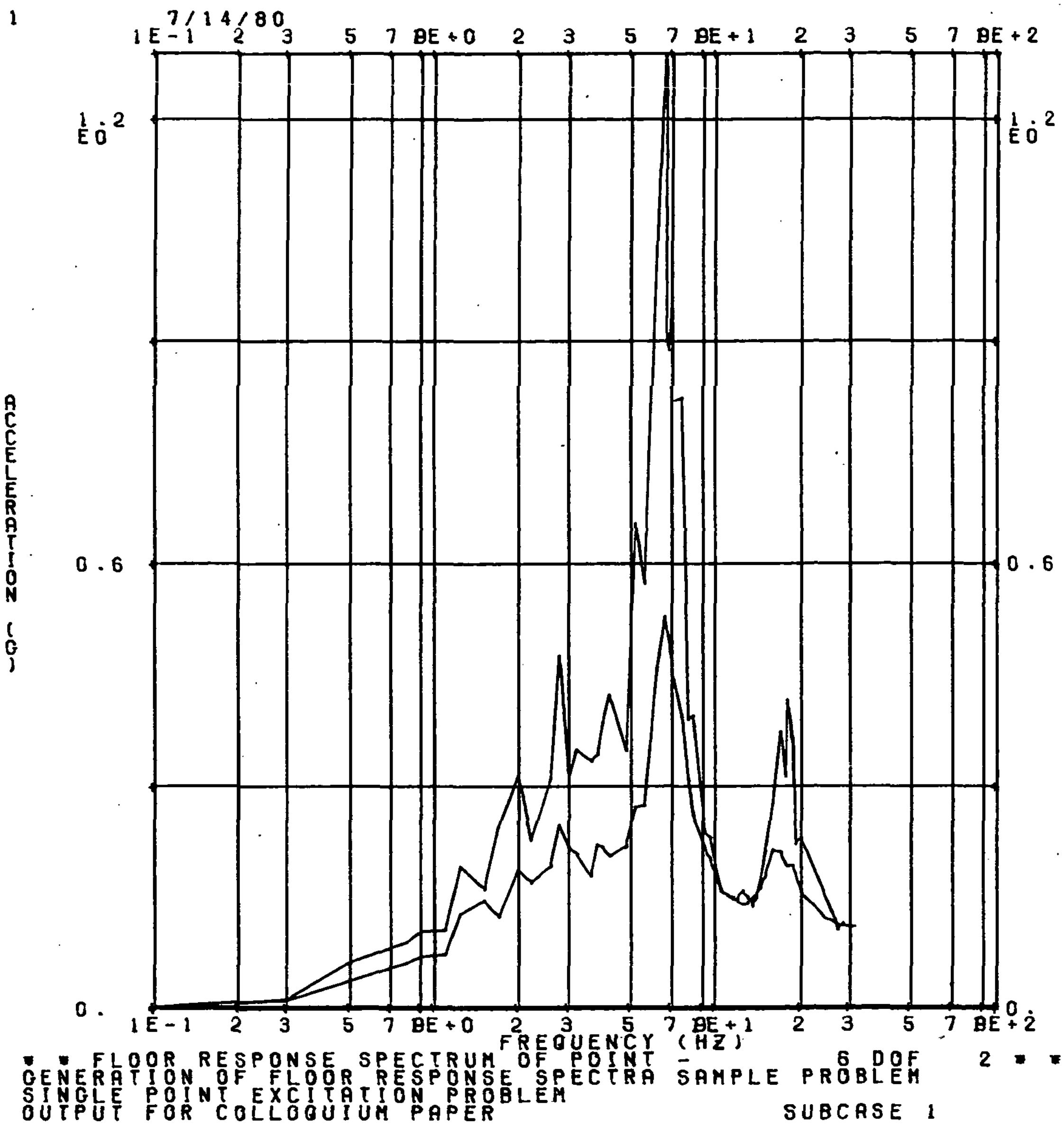

Figure 8: Generated Floor Response Spectra Plot

OUTPUT FOR COLLOQUIUM PAPER SUBCASE 1
POINT-ID = 6 DIRECTION = 2

F L O O R R E S P O N S E S P E C T R A

FREQUENCY	TYPE	EQUIPMENT DAMPINGS .010	.050				
3.200000+00	G	3.499337-01	2.088033-01	.0	.0	.0	.0
		.0	.0	.0	.0	.0	.0
3.600000+00	G	3.340834-01	1.794977-01	.0	.0	.0	.0
		.0	.0	.0	.0	.0	.0
3.800000+00	G	3.436410-01	2.215128-01	.0	.0	.0	.0
		.0	.0	.0	.0	.0	.0
4.000000+00	G	3.850916-01	2.188926-01	.0	.0	.0	.0
		.0	.0	.0	.0	.0	.0
4.200000+00	G	4.236383-01	2.059928-01	.0	.0	.0	.0
		.0	.0	.0	.0	.0	.0
4.800000+00	G	3.487423-01	2.203638-01	.0	.0	.0	.0
		.0	.0	.0	.0	.0	.0
5.200000+00	G	6.550089-01	2.713436-01	.0	.0	.0	.0
		.0	.0	.0	.0	.0	.0
5.600000+00	G	5.732045-01	2.750139-01	.0	.0	.0	.0
		.0	.0	.0	.0	.0	.0
6.200000+00	G	1.040017+00	4.595057-01	.0	.0	.0	.0
		.0	.0	.0	.0	.0	.0
6.600000+00	G	1.287466+00	5.287637-01	.0	.0	.0	.0
		.0	.0	.0	.0	.0	.0
6.680144+00	G	9.027770-01	5.140159-01	.0	.0	.0	.0
		.0	.0	.0	.0	.0	.0
6.800000+00	G	8.883788-01	4.994127-01	.0	.0	.0	.0
		.0	.0	.0	.0	.0	.0
6.971636+00	G	9.545243-01	4.633139-01	.0	.0	.0	.0
		.0	.0	.0	.0	.0	.0
7.000000+00	G	8.189829-01	4.544786-01	.0	.0	.0	.0
		.0	.0	.0	.0	.0	.0
7.600000+00	G	8.235375-01	3.937230-01	.0	.0	.0	.0
		.0	.0	.0	.0	.0	.0

Figure 9: Generated Floor Response Spectra - Printed