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# Lawrence Livermore Laboratory

## APPLICATION OF TIME DOMAIN PARET TO THE MEASURED RESPONSES OF A BUILDING

Darrel L. Lager

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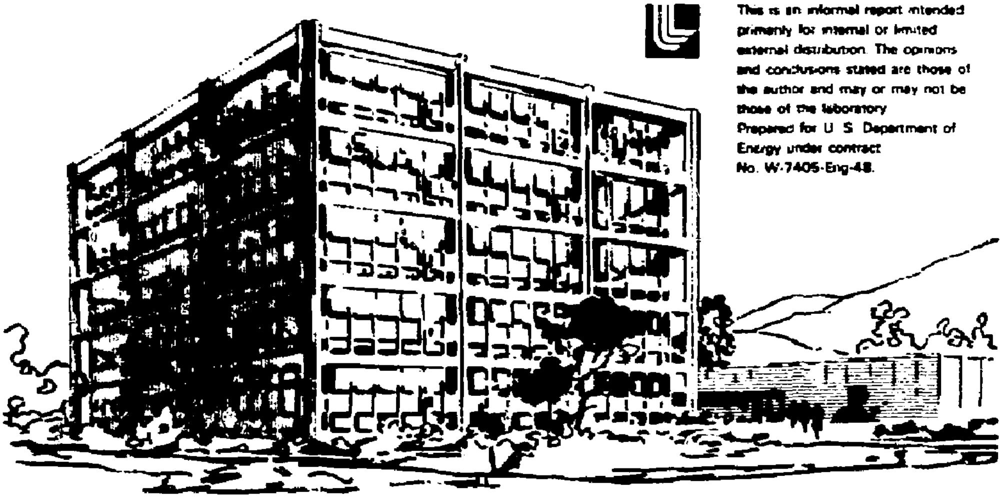

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Title: Application of Time Domain PARET to the Measured Responses of a Building

The work described in this report is a subtask of the project for the Nuclear Regulatory Commission (NRC) entitled Dynamic Testing Methods for Operating Reactors. The subtask is task C - the application of PARET to data from real structures.

In this report I describe the application of the Time Domain PARET (TDP) algorithm to data obtained from the measured responses of a three story reinforced concrete building approximately 465 feet long by 220 feet wide by 40 feet high, with 12 to 18 inch thick walls. The measurements were taken by Agbabian Associates, El Segundo, California. The structure was excited by a device developed at Agbabian that uses a mass sliding down a rod to cut metal disks attached to the rod[1]. The result is a series of impulse forces driving the building at the attachment point of the rod. The responses measured were the accelerations at two locations on the structure. A constraint imposed was that the equipment in the building must remain operating during the time the measurements were made.

A cross section of the building is depicted in Figure 1. The data records given to me for processing were for an input at the point labeled "node 108" and for responses at the points labeled "node 111" and "node 120." The measured waveforms are shown in Figure 2 for three "identical" repeated tests. The only differences between the tests are due to the variability in the cutting of the disks and in the ambient noise. The waveforms for the

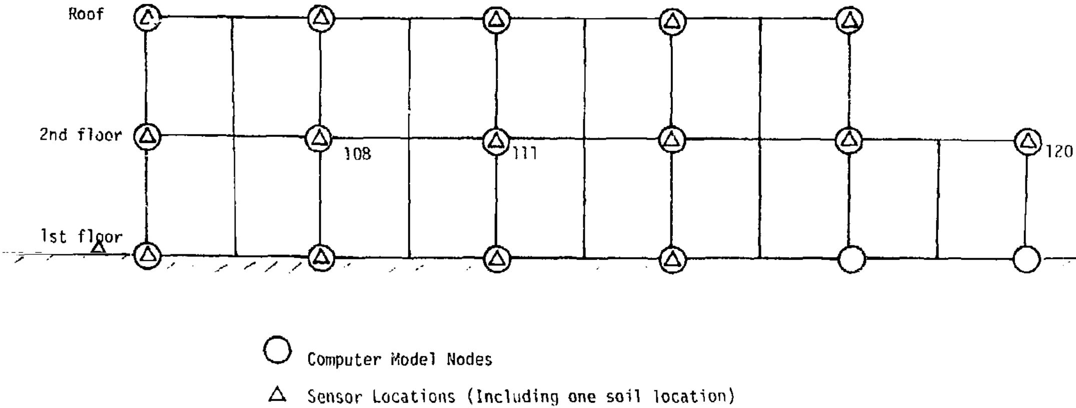
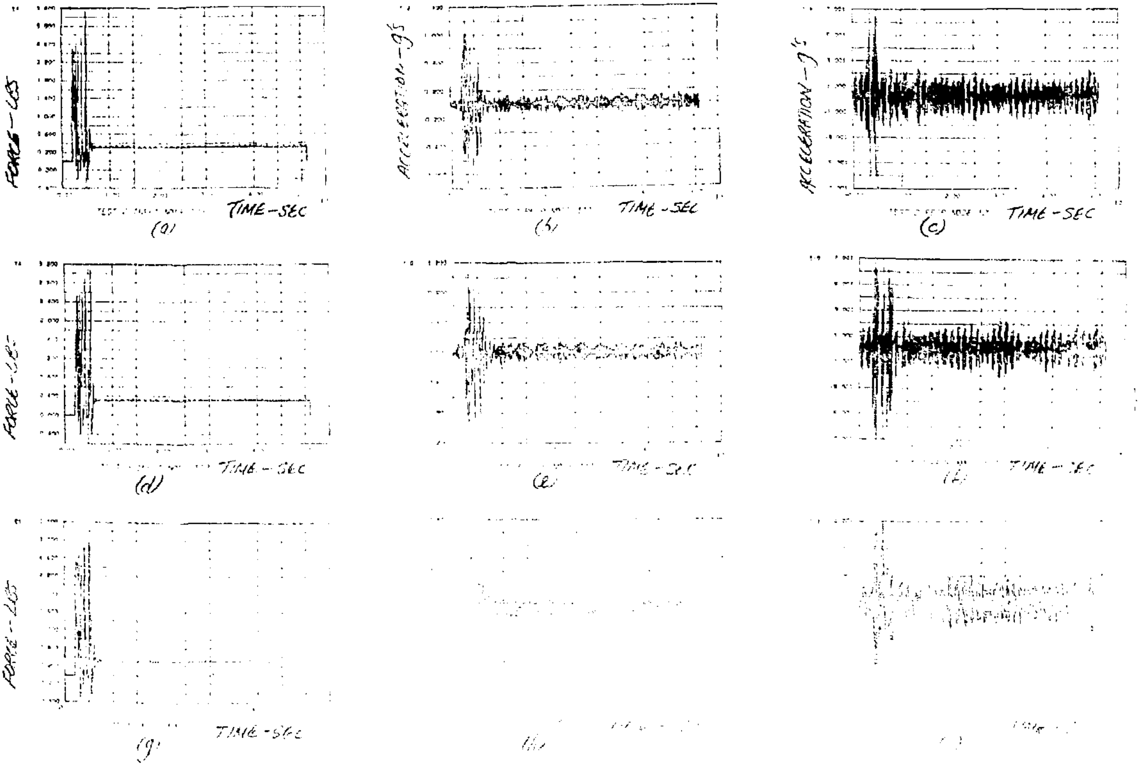



Figure 1: Cross Section of Building Indicating Measurement Locations


FORCE - LBS
TIME - SEC
(a)
ACCELERATION - g's
TIME - SEC
(b)
ACCELERATION - g's
TIME - SEC
(c)
FORCE - LBS
TIME - SEC
(d)
TIME - SEC
(e)
TIME - SEC
FORCE - LBS
TIME - SEC
(g)

experiment [illegible] "test 2" are shown in Figures 2(a), (b) and (c). [illegible] experiment "test 3" are shown in Figures 2(d), (e) and (f). [illegible] "test 4" are shown in Figures 2(g), (h) and (i).

All the figures [illegible] a sampling of [illegible] have [illegible] Figures 2(a), [illegible] Unfortunately, [illegible] about 5 mg, giving [illegible] ratio.

I did two preprocessing [illegible] the data [illegible] late-time offset in the input waveforms due to the [illegible] weight of the mass after it came to rest and the second [illegible] multiplication of all the data by an exponential tapering function [illegible] ambient noise in late time. The tapering function was

$$f_t(t) = e^{(-1.535t)}$$

which tapers to a value of .01 at 3 sec and a value of .464 at 0.5 sec. Therefore, it has little effect on the input waveforms since they only last about .5 sec but substantially reduces the late time noise. The waveforms after preprocessing are shown in Figure 3 corresponding to the same inputs and responses shown in Figure 2.

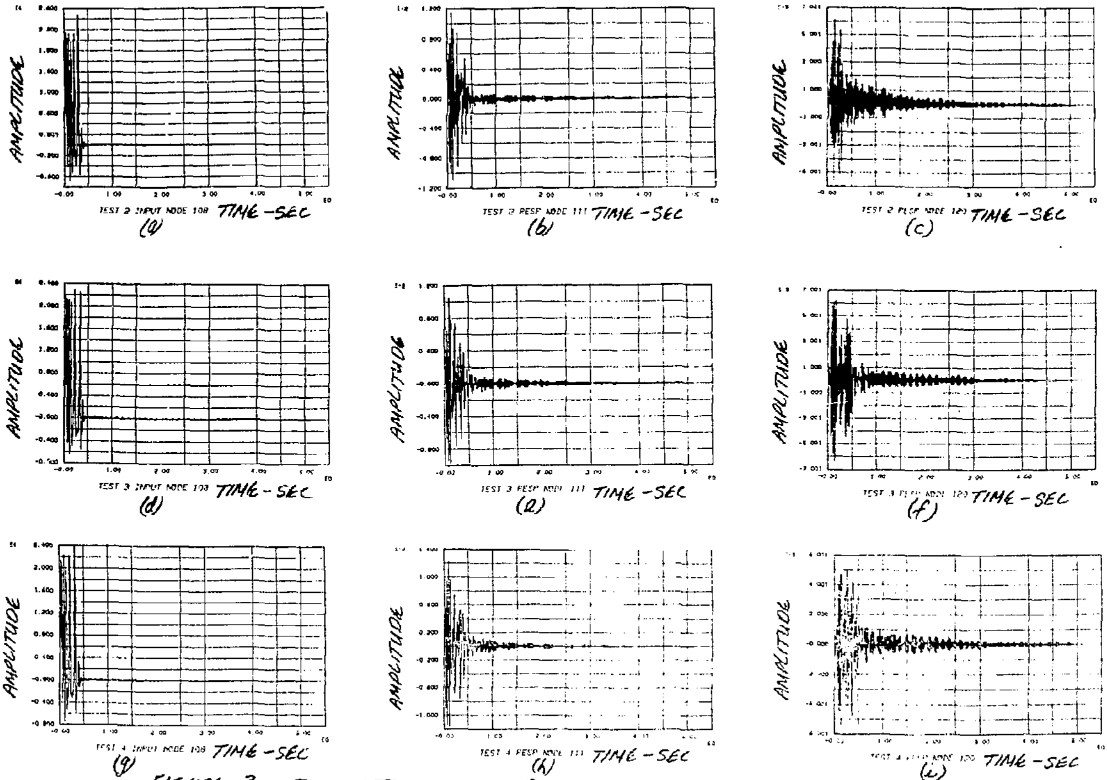


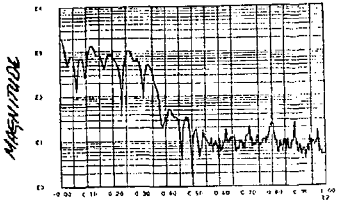

FIGURE 3 — DATA AFTER REMOVING DC OFFSET AND EXPONENTIAL TAPERING

The magnitude of the spectrum of each of the waveforms of Figure 3, as calculated by the Fast Fourier Transform (FFT), is shown in Figure 4. The frequency range plotted is from 0 to 100 Hz. Note the input is fairly wide band (0 to 35 Hz) but does have some significant notching near 10 and 20 Hz.

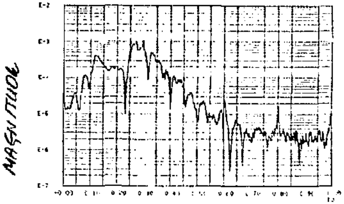
I next used a routine written by Fisher and Posehn[2] to estimate the transfer function and coherence function as an average over the 3 "tests" for the measurements at nodes 111 and 120. The averaged transfer function for node 111 is shown in Figure 5(a) and the corresponding coherence is shown in Figure 5(b). The coherence is used as a test of the quality of the data and the linearity of the system.[3] It is a dimensionless real quantity between 0 and 1. For a linear system with no measurement noise the coherence is unity. An observation of Figure 5(b) yields the conclusion that from approximately 5 to 35 Hz the data is of good quality while outside that range it is poor. The node 111 transfer function and coherence are plotted over the 5 to 35 Hz frequency range in Figures 5(c) and (d) to allow observing more detail. For the TDP parameter estimations I concentrated my efforts to identifying parameters over the 5 to 18.8 Hz range since that is where the data is most coherent and since a convenient notch occurs in the spectrum at 18.8 Hz for truncation filtering.

The averaged transfer function and coherence function for node 120 are shown in Figures 5(e) and (f), respectively. The data for this node were so incoherent I did not process them any further.

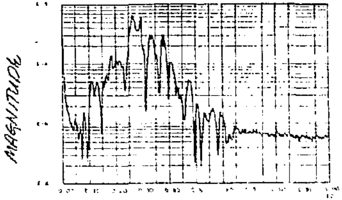
I truncation filtered the averaged transfer function for node 111 with a



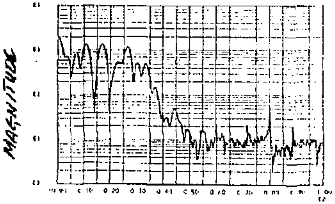

TEST 2 INPUT NODE 108 FREQ - Hz



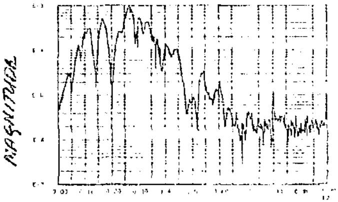

FREQ - Hz



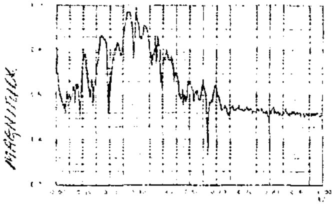

FREQ - Hz



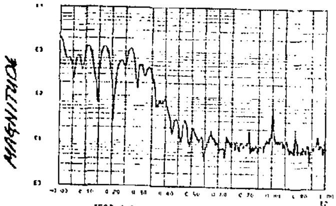

TEST 3 INPUT NODE 103 FREQ - Hz



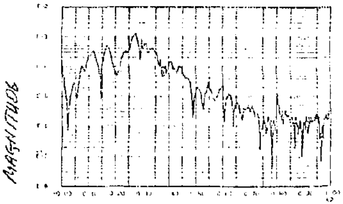

FREQ - Hz



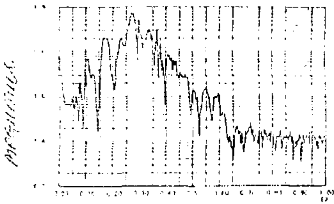

FREQ - Hz




TEST 4 INPUT NODE FREQ - Hz




FREQ - Hz



FREQ - Hz

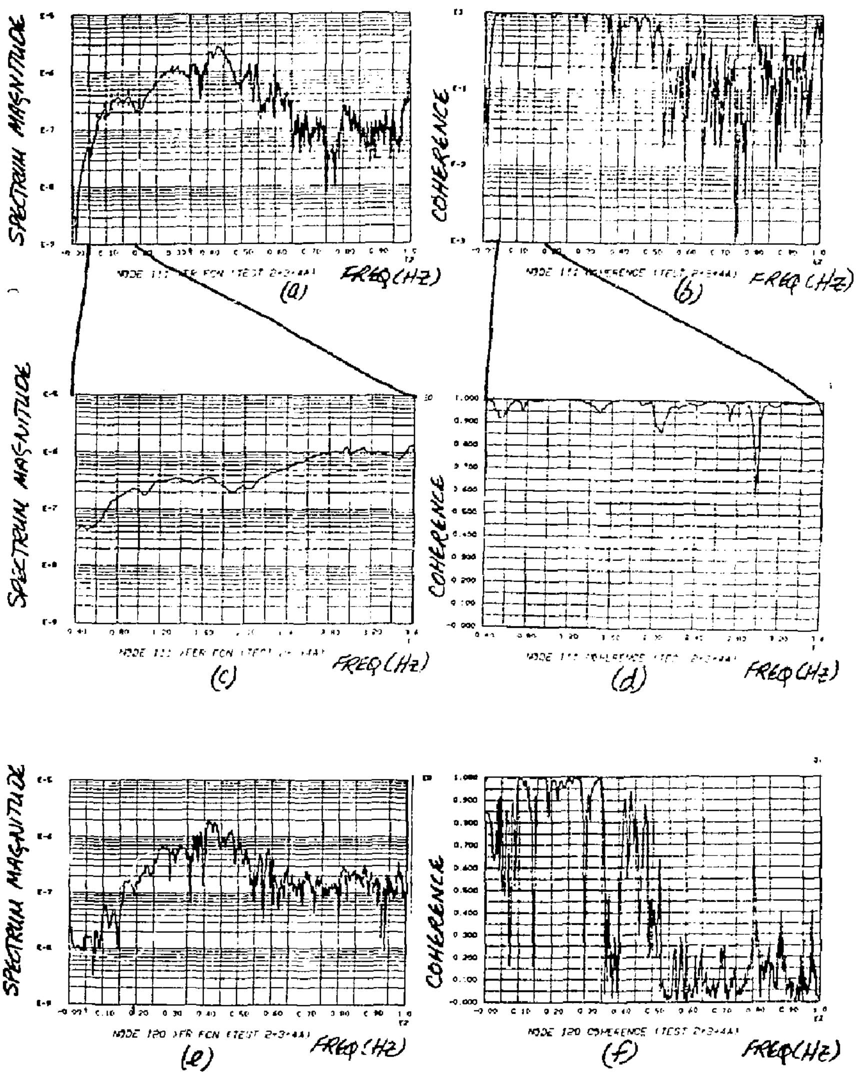
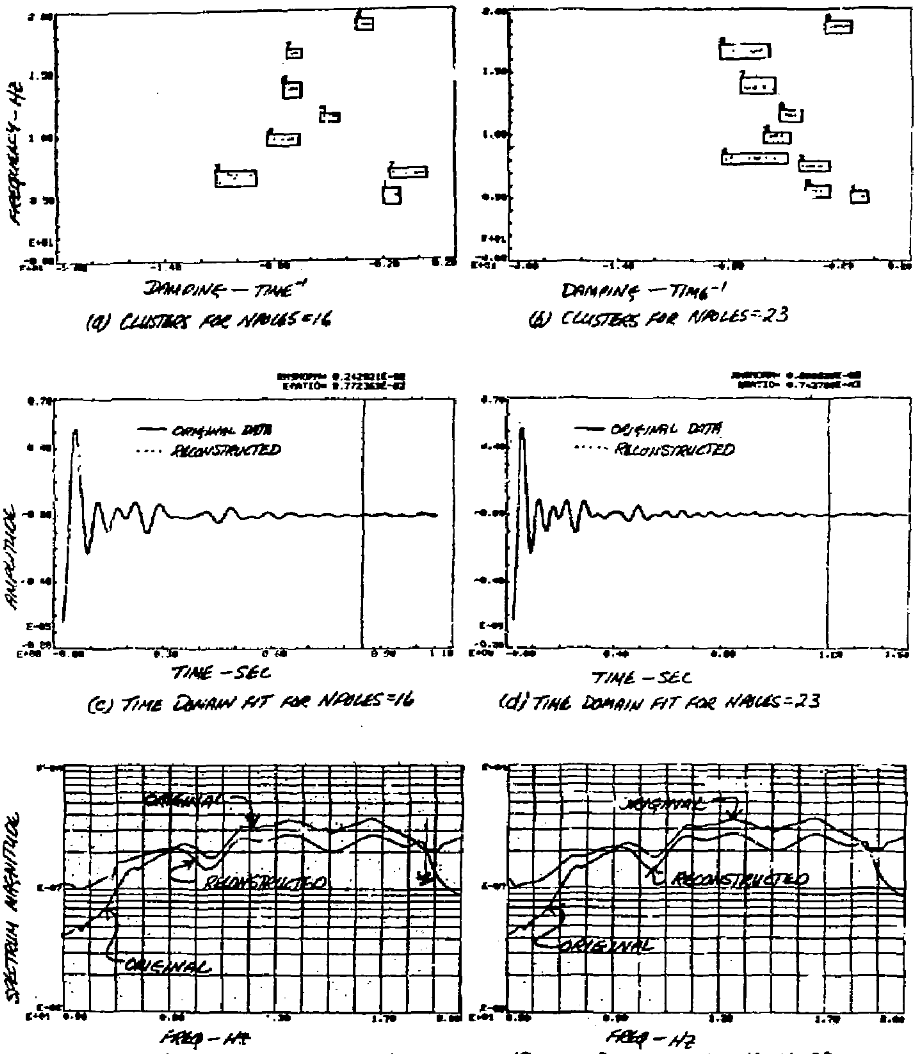



FIGURE 5 — AVERAGE TRANSFER AND COHERENCE FUNCTIONS

passband from 5 to 18.8 Hz, performed an inverse FFT and used the TDP algorithm to process the resulting time waveform. The TDP control parameters which I held constant throughout the processing were:

| | |
|---|---|
| NBEGIN = 6 | (the first peak) |
| NWINDOW = 10 | (number of sliding windows) |
| IWINDOW = 1 | (increment between successive windows) |
| FMAX = 20 | (data sampling rate in Hz) |

I varied the number of poles from 8 to 28 and observed the fit the extracted parameters made to the time waveform. A pattern emerged where up to NPOLES = 15 the fit was consistently poor; at NPOLES = 16 a very good fit was realized; then from NPOLES = 17 to 22 slightly poorer fits were achieved; finally at NPOLES = 23 the best fit was realized degrading slightly up to NPOLES = 28. At the lower values of NPOLES the algorithm appeared to be matching multiple "bumps" in the spectrum with just one mode. Then as NPOLES was increased the single mode would "split" and become two, thus improving the fit. Unfortunately, I feel this process could continue until the algorithm had matched every "bump" in the spectrum even though most were due to noise rather than any physical property of the structure. The splitting phenomenon occurred for the weak lower frequency modes however, while the estimates for the parameters for the stronger modes stayed stable over a wide range of NPOLES. In Figure 6 I show a comparison between the parameters extracted for the two optimum values of NPOLES. The pole clusters for NPOLES = 16 and NPOLES = 23 are shown in Figures 6(a) and (b), respectively. The frequency and damping values are in Table 1 (after correcting for the exponential




(a) CLUSTERS FOR NPOLES=16

(b) CLUSTERS FOR NPOLES=23

(c) TIME DOMAIN FIT FOR NPOLES=16

(d) TIME DOMAIN FIT FOR NPOLES=23

(e) FREQ DOMAIN FIT FOR NPOLES=16

(f) FREQ DOMAIN FIT FOR NPOLES=23

FIGURE 6 - TDP PROCESSING OF AVERAGE TRANSFER FUNCTIONS

TABLE I

NPOLES = 16

| Mode No. | Freq. (Hz) | Damping (% Critical) |
|---|---|---|
| 1 | 5.14 | Artifact - Filter Pole |
| 2 | 6.88 | Artifact |
| 3 | 6.97 | 21.3 |
| 4 | 9.70 | 9.05 |
| 5 | 11.5 | 4.30 |
| 6 | 13.7 | 6.45 |
| 7 | 16.6 | 5.24 |
| 8 | 18.6 | Artifact - Filter Pole |

NPOLES = 23

| | | |
|---|---|---|
| 1 | 5.08 | Artifact - Filter Pole |
| 2 | 5.56 | 4.90 |
| 3 | 7.58 | 3.99 |
| 4 | 8.14 | 9.90 |
| 5 | 9.91 | 6.35 |
| 6 | 11.6 | 4.33 |
| 7 | 13.7 | 5.91 |
| 8 | 16.6 | 5.18 |
| 9 | 18.6 | Artifact - Filter Pole |

tapering function used in the preprocessing). The fits to the time domain waveforms are shown in Figures 6(c) and (d), respectively. The measure of fit is the ERATIO, the ratio of the sum of the squares of the errors to the sum of the squares of the waveform values (i.e., the energy in the errors to the energy in the waveform). Note that for Figures 6(c) and (d) the ERATIO is less than 1 percent. The vertical bar at about .85 sec indicates the time at which the values computed from the parameters are extrapolated beyond the data "window" used by the algorithm to estimate the parameters.

A comparison of the magnitude spectrum of the waveform and a spectrum calculated from the estimated parameters is given in Figures 6(e) and (f). Note that there is little difference in the fit from 9 to 18 Hz when NPOLES is changed from 16 to 23.

As a check on the stability of the parameter estimates I also processed the individual transfer functions from each "test" (rather than the average of all three). There is a great deal of variability from test to test as evidenced in Figure 7 where all three transfer functions are superimposed over the frequency range of 5 to 20 Hz.

As expected, there is a large variability in the estimates returned by the TDP algorithm as shown in Figures 8 and 9. Figure 8 shows the clusters and fits for NPOLES = 16 and Figure 9 is for NPOLES = 23. A comparison of the ERATIO for both shows that neither value of NPOLES is consistently better than the other. An observation of the clusters shows a large variability in the estimate of the damping for the modes.

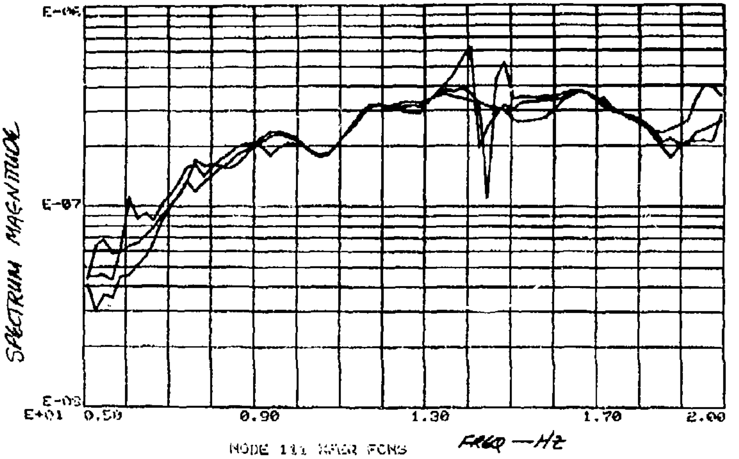



FIGURE 7 – INDIVIDUAL TRANSFER FUNCTIONS SUPERIMPOSED

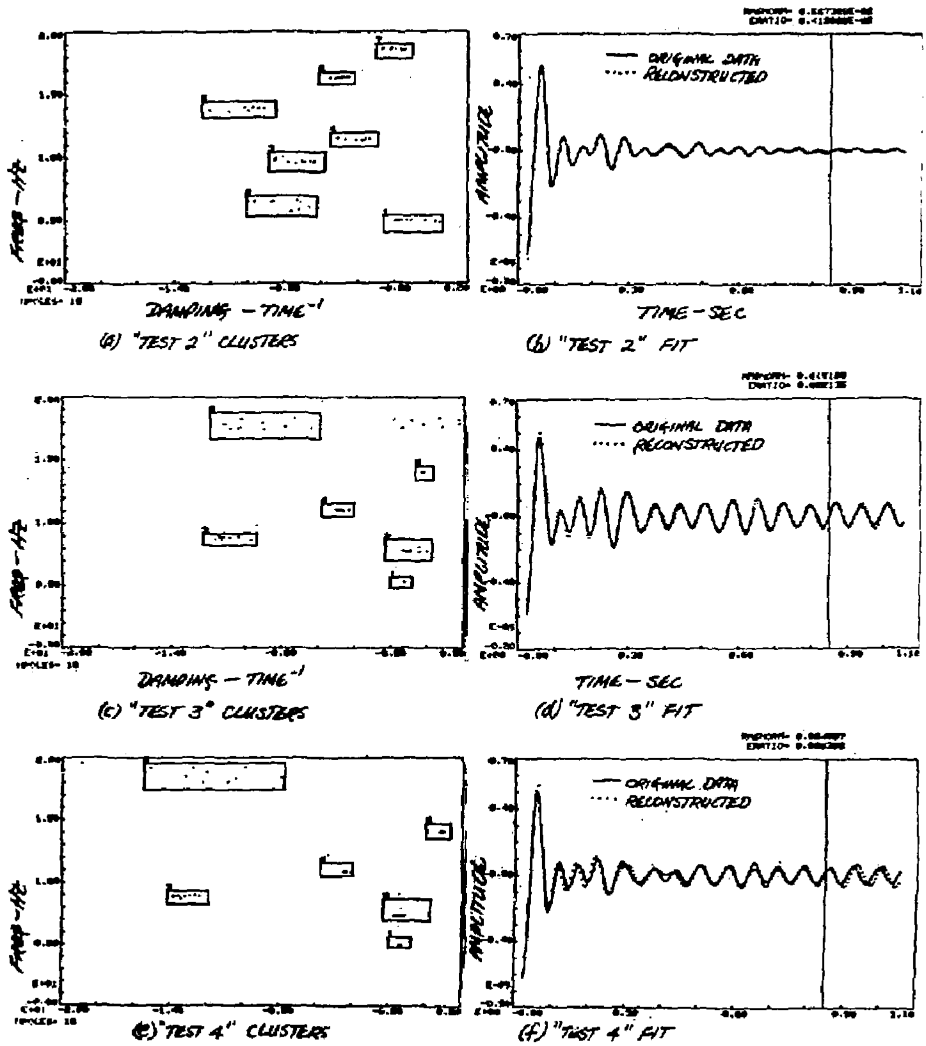



FIGURE 8 — TDP PROCESSING INDIVIDUAL XFER FCNS AT NPOLES=16

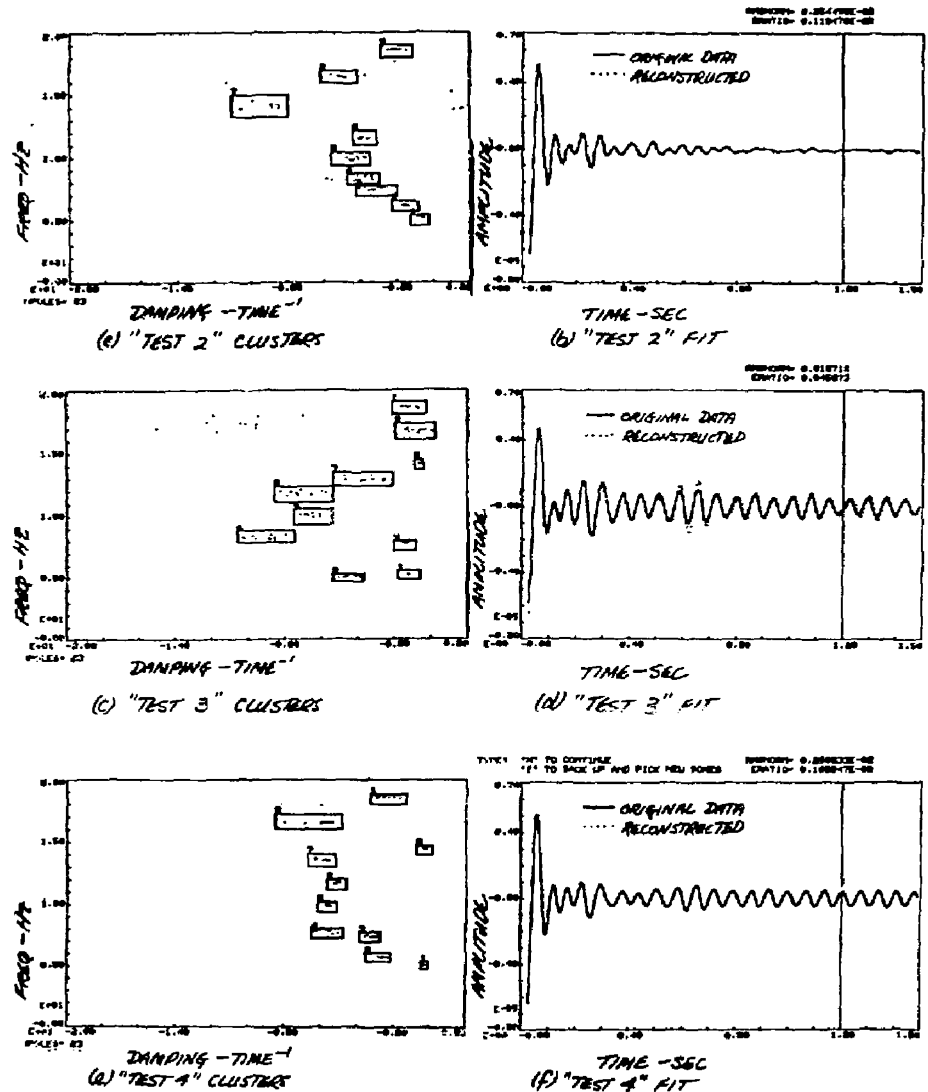



FIGURE 9 – TDP PROCESSING INDIVIDUAL XFER FCNS AT NPOLES=23

SUMMARY AND CONCLUSION

The data obained from measurements of a reinforced concrete building were processed by the time domain PARET algorithm. Three sets of data were processed for excitations at node 108 and responses at node 111. Due to the poor signal to noise ratio data was not processed for responses at node 120. The TDP algorithm was used to estimate the modal frequency and damping for modes over a frequency range of 5 to 18.8 Hz in the averaged transfer function. The algorithm produced goods fits to the waveform at several values of NPOLES. Data will have to be obtained at more locations on the structure and with better signal-to-noise ratio in order to determine the value of NPOLES which gives parameter values which are most physically meaningful. For example, data at more locations would allow determining the mode shapes and would serve as another check on the extracted parameter values.

## REFERENCES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2. M. R. Posehn, D. K. Fisher, J. G. Katz, E. L. Luebke, "User's Guide to GPDAP," UCID 18057, February 1979.

3. J. Bendat and A. Piersol, "Measurement and Analysis of Random Data," Wiley and Sons, New York, 1966.