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Studies on the Subsystem Pipe Modeling Technique Using Structural Overlapping

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BACKGROUND

The pipe modeling technique of structural overlapping is a procedure for analyzing the dynamic response of a piping system by performing a separate analysis on subsystems of the complete structure. In the present procedure, two subsystems are used in place of the full system. Since the analysis is based upon a structure that is not the actual system, the results, in general, will not be the same as the results from the analysis of the actual structure. Differences should be expected when a subsystem is analyzed in place of a complete system. Whether the differences are negligible or significant depends upon the structural characteristics of the two systems. This report examines a few cases which show some of the factors that affect the differences that result by using an approximation of the original structure in a subsystem analysis.

A form of subsystem analysis is often used in place of a complete system. It is used, for example, when a continuum is discretized because the physical sizes are greatly different. This occurs in places where the numerical values clearly show that there is a great deal of difference between the characteristics of interacting parts. An example is where a flexible pipe penetrates a substantially more massive wall. For this case, the pipe is assumed to terminate at the massive connection. A standard method used in the nuclear industry is to introduce rigid anchors into the system. These anchors are intended to be rigid enough so that they take up all reactions and do not transmit any force or moment or torsion beyond them. The anchors, in effect, decouple the separate parts of the system and permit independent analysis of each subsystem.

The current procedure under study is a modification of this idea. The overlapping method requires that, for each subsystem, a region be identified which overlaps into the adjacent subsystem such that the piping is restrained in bending and torsion while it is axially unrestrained. The intention is to keep thermal stress low while dynamically uncoupling the subsystem. Each subsystem is investigated as though it alone exists. The eigenvalues and eigenvectors are obtained for the separate subsystems. The excitations are separately imposed on each subsystem. In addition, the proposed method applies a different response spectrum to each subsystem for those cases where the support point response spectra have a wide difference. The stresses are overlayed on each other and the maximum values are retained and are used to represent the stresses that develop in the full system. It is hoped that the maximum stresses that result are equal to or greater than the maximum stresses that would be calculated if the full problem were analyzed as is.

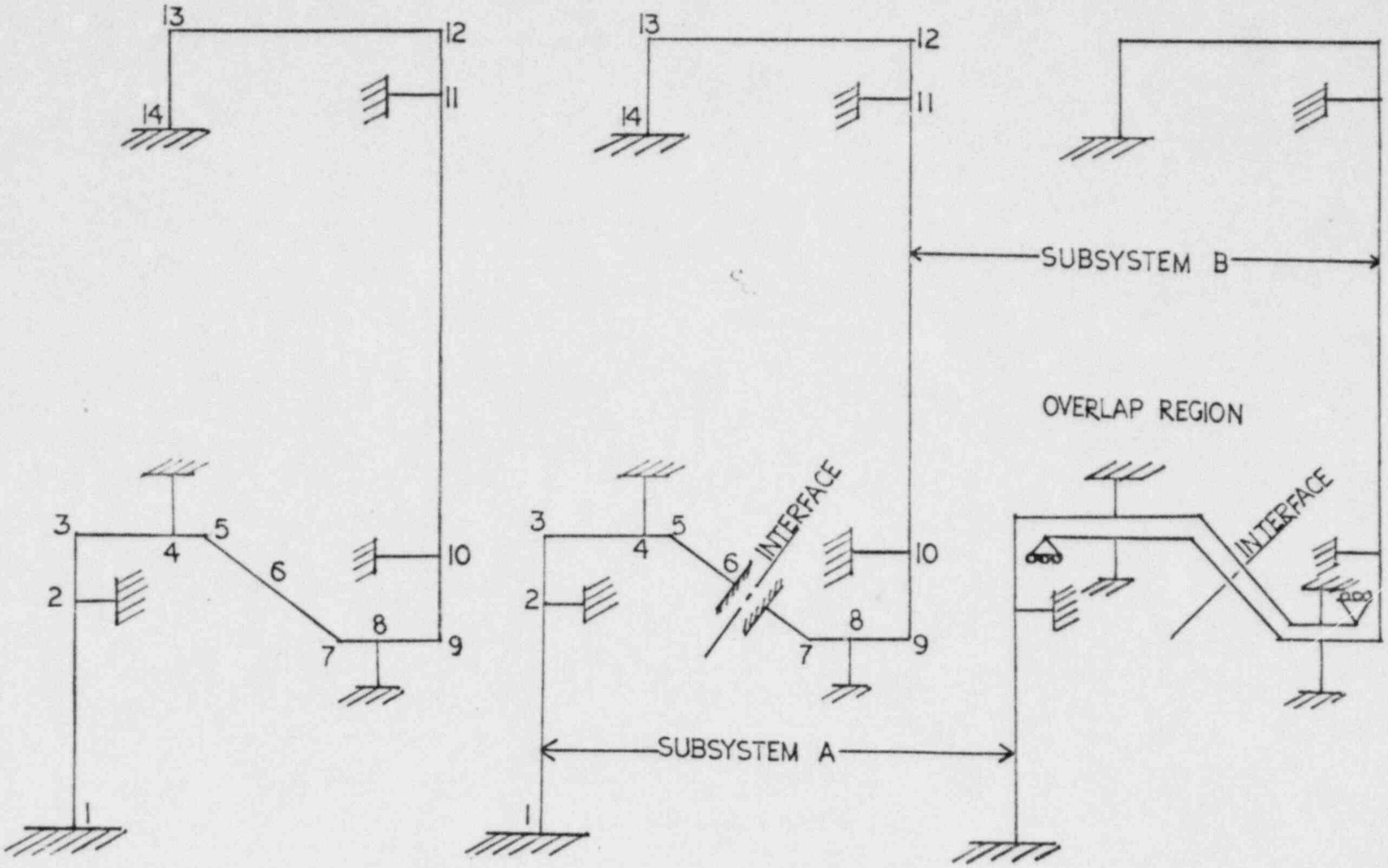
OBJECTIVE

The objective of this study was to show some of the problems and examine some of the limitations associated with the use of the overlap method in piping analysis.

BASIC PROBLEM

The substructure method is intended to investigate the response of a large piping system by dividing it up into two subsections. These are then analyzed separately.

The method requires that a central portion of the original system be identified. The central portion is used as an overlap region which is included in the analysis of each portion of the substructure. The basic problem is shown in Figure 1.



a. ACTUAL SYSTEM   b. ANCHORED SUBSYSTEMS   c. OVERLAPPED SUBSYSTEMS

FIGURE I

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The full system consists of the piping structure from nodes 1 through 14. The interface is selected at point 6, as shown in Figure 1b. The central portion is chosen to extend on either side of point 6, from node 3 to node 9. The full system is divided into two subsystems. Subsystem A extends from node 1 through node 9. Subsystem B extends from node 3 through node 14. These are shown in Figure 1c. The final node in the central portion is taken as a roller type of simple support so that motion is possible along the axis of the last member but not perpendicular to the member.

The input excitation in the full system is applied at all support points. In Figure 1a, this includes nodes 1,?,4,8,10,11 and 14. For the subsystem, the input is also applied at the support points, as before. However, the terminal point in the central section also will have an input. This means that the terminal point, corresponding to node 3, is Subsystem B will have an input excitation as will the terminal point corresponding to node 9 in Subsection A.

SCOPE

No theoretical basis for the method is known and so no analytical estimate of its relative accuracy for the general case can be made. Because of this, specific case studies were selected in order to obtain an initial appraisal of the method and to examine some of the problems associated with its use. The case studies were increased in complexity so as to incorporate more realistic aspects to the problem. Specifically, the following different types of structures were considered:

1) In-line.

2) Three dimensional pipe bend.
   a) Three leg bend.
   b) Four leg bend.

3) An NRC designated piping configuration.

A type 1, in-line piping arrangement has only single plane motion possible. There are no cross coupling effects. Types 2a and 3b are more complex three-dimensional piping system where interaction in different planes is possible. Type 3, is a realistic structure in which some of the problems that were shown to exist for the simplier systems could be examined in an actual structure. The type 3 piping is assumed to extend vertically between two different levels of a building. At the upper end, the piping is at an operations level while at the lower end the piping is at an equipment level. The vibrational environment at these two different levels is different. The use of the subsystem approach was also examined for the case where different spectra were defined for opposite ends of a piping system.

SUMMARY

This report examines some of the problems and limitations associated with the use of the overlap method in piping analysis. The overlap method is a procedure for analyzing the dynamic response of a piping system by performing a separate analysis on subsystems of the complete structure. Specific cases were selected to obtain an initial appraisal of the method. The case studies were increased in complexity in order to examine some of the problems involved in implementing the method. They include in-line pipe systems, three-dimensional pipe bends and an NRC designated piping configuration.

For the in-line piping cases, only a single direction of excitation was used. Only concentrated mass points were defined so that no cross coupling was possible. A total of nine cases were examined. To study some of the characteristics of three dimensional piping systems in terms of complex responses, a three leg piping arrangement was investigated. The same basic proportions of lengths was

maintained with the 3-D system as compared with the in-line system. A total of seven sections was used in the first study. The individual section lengths and piping designations were also the same as was previously used for the in-line systems. The center span was composed of three sections with the outboard portions having two sections each. Three different cases with two different bends were investigated.

Finally, an actual piping system designated by the NRC was used to investigate the application in a realistic situation. A 30 inch diameter piping system with intermediate spring hangers was studied. The piping extends vertically a distance of about 50 feet and connects two points at different elevations. Two different spectrums were used to study the system response using the subsystem method with different areas and degress of overlap. In addition, both a fixed end and a free end and a free end at the terminal point of the broken end were considered.

Conclusions

The essential results and conclusions of the investigation are:

1) The structural overlap method does not work generally and should no generally be substituted for a complete analysis of the full system.

2) If a sufficiently stiff (high natural frequency) property is associated with the central section, acceptable results could be obtained. For seismic excitation, where the excitation band is essentially between 1 to 10 Hz, the central overlap section may be considered to be rigid enough if it has a fundamental natural frequency of at least 33 Hz.

3) The overlap region should have enough anchor points and include enough bends in three directions to prevent the transimission of motion due to modal excitation from one end to the other and to reduce to a negligibie level the

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sensitivity of the structure to direction of excitation. The limited number of cases that have been investigated that there should be no fewer than four restraints in each of three perpendicular directions in the overlap region. In addition, the pipe span between any two restaints should have a natural frequency in bending higher than the highest expected significant forcing frequency. This is 33 Hz, for example, for seismic loading and 120 Hz for SRV loading.

4) There will be differences between an analysis by the subsystem method and by an analysis which uses the full system. The differences could be magnified when periodic excitation is imposed. Appropriate requirements on the overlap region (see Item 3 above) are needed to keep the differences small enough so that, even if magnified, they remain still negligible. This is especially important where time histories of responses are obtained in load combination problems.

5) For cases where multiple spectra are involved at different anchor points, the bounding spectra should be used. This means that the appropriate portion of the bounding spectra that is defined over the region of each of the subsystems should be used as the excitation for each subsystem.

6) When a subsystem natural frequency occurs in the vicinity (within 5%) of a major peak of the exciting spectrum, the peak value of the spectrum should be used in computing the response. This is in addition to the broadening and smoothing of the floor response spectra, as shown by the shaded area in the figure.

IN-LINE SYSTEM

A first look at the problem was done using an in-line arrangement of a piping system. The piping was assumed to extend in a straight line. No unbalanced inertia was assumed to be present. All masses were identified at the centerline of the system. Nine different cases were studied. Only a single direction of excitation was used. For each of the nine cases, separate runs were made of the full section, the left section plus the center section and the right section plus the center. The center section always includes an extra length equal to the shortest span of this section as a terminating point. The results of the analysis were compared. The comparison was based upon the information that was obtained regarding natural frequencies, normal nodes, modal participation factors, response spectrum analysis and pipe stresses. The analysis evaluates the first 20 natural frequencies and normal nodes for the full span and 10 natural frequencies and normal modes for the sub-sections.

Table 1, lists the 9 cases that were examined for the in-line system. In each case, the center section is composed of three spans. The outboard portions have two spans each. There are a total of seven spans for each case.

The numbers in the first column of the table show the proportion of the individual lengths. Row 2, for instance, has a left side of two spans, each four units long, a right side of two spans, each six units long and a three span center section, each two units long.

Each span is divided into pipe elements ten feet long. For Case 2, the first two spans are four units long with eight elements in each unit. The second, third and fourth spans have four elements each. A total of fifty two pipe elements are used to describe the system, as shown in Figure 2. All elements have the same properties. No additional mass, other than the pipe properties, is designated. Longitudinal, circumferential and shear stresses were evaluated when an earthquake excitation was applied. Three separate runs were made, one for the full system, one for the left subsection and one for the right subsection.

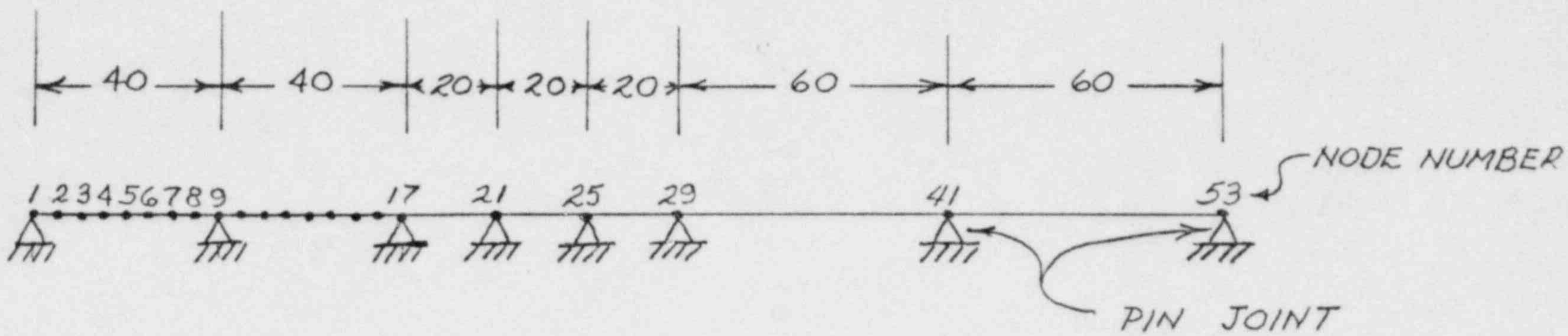
For each of the nine cases, an earthquake excitation was imposed at the support points. The results of the subsection analysis were compared with the results of the full section analysis. The comparison is based upon the maximum stress developed. Those modes with high participation factors were also compared with respect to natural frequencies.

Figures 3 through 11 show the results for those modes with the highest participation factors. In each figure, the major normal modes are plotted for the full section together with their counterparts from the subsection analysis.

Table 1

In-Line Cases

Case No.	Left Section Lengths	Center Section Lengths	Right Section Lengths
1	4-4	2-2-2	4-4
2	4-4	2-2-2	6-6
3	6-6	2-2-2	6-6
4	8-8	2-2-2	8-8
5	6-6	3-2-3	6-6
6	8-8	2-2-3	6-8
7	2-2	2-2-2	6-6
8	2-2	4-4-4	8-8
9	2-2	2-8-8	8-8



INLINE SYSTEM CASE 2 , 4/4-222-6/6

FIGURE 2

4/4-222-4/4

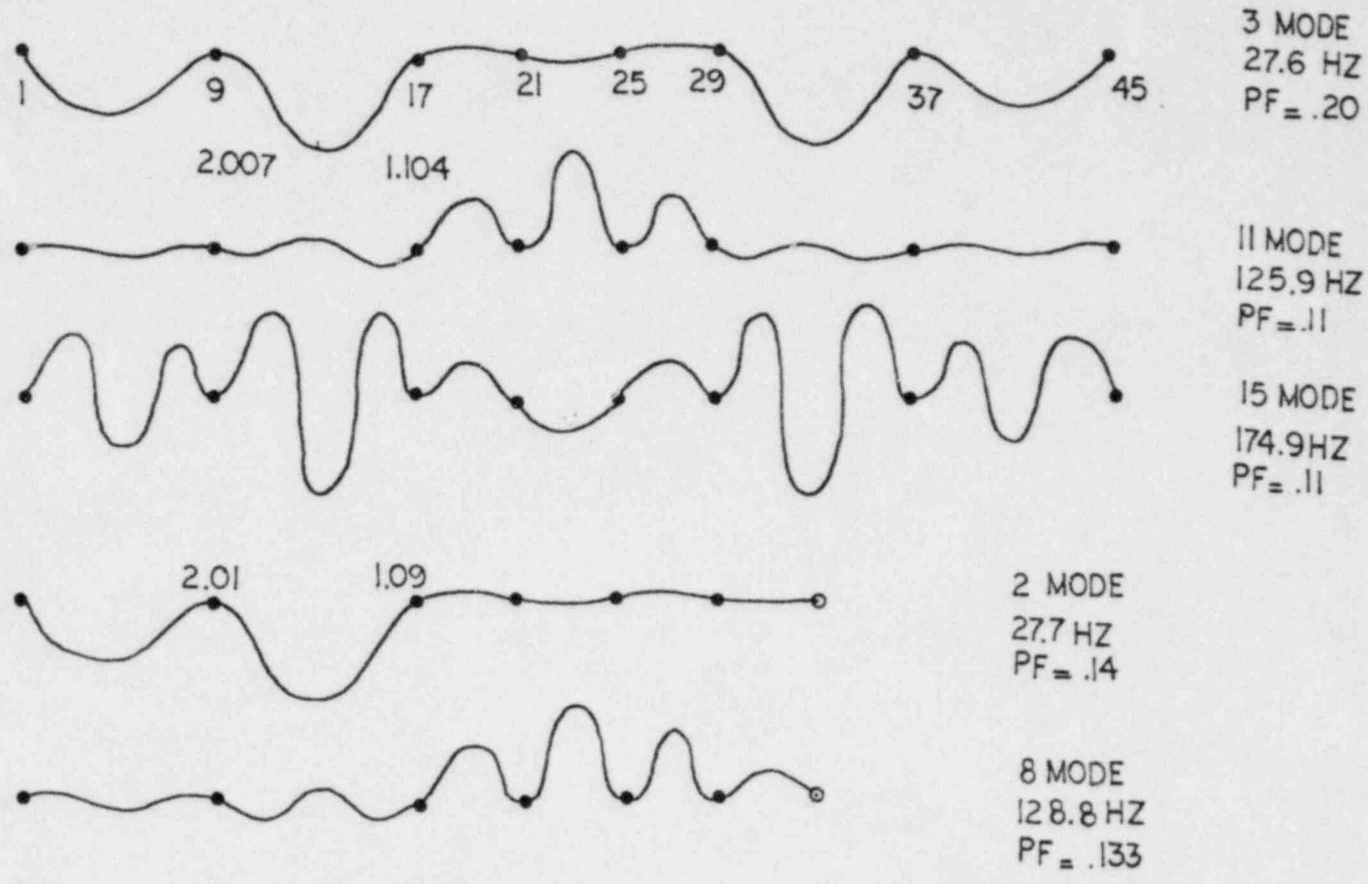


FIGURE 3

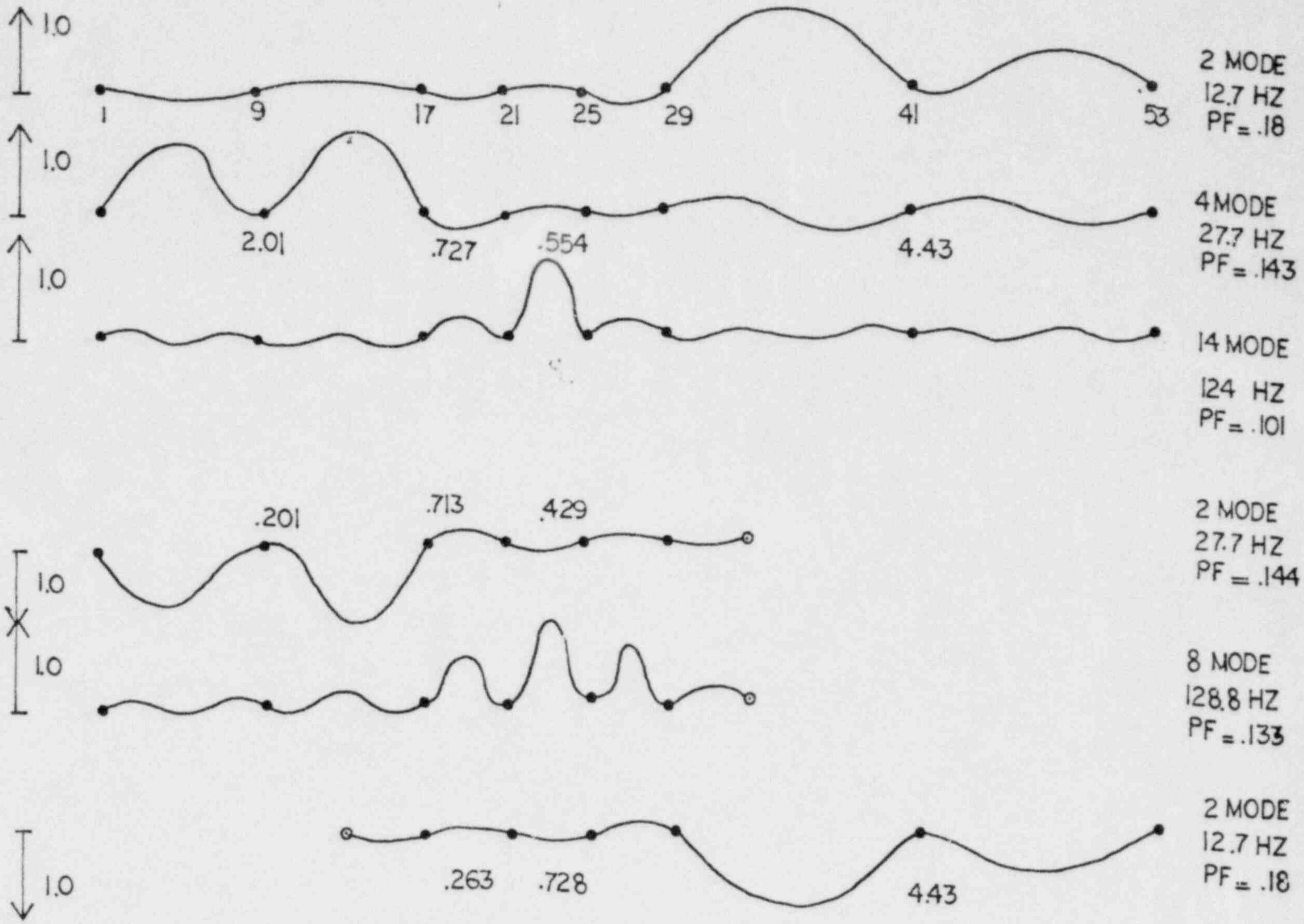


FIGURE 4

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6/6-222-6/6

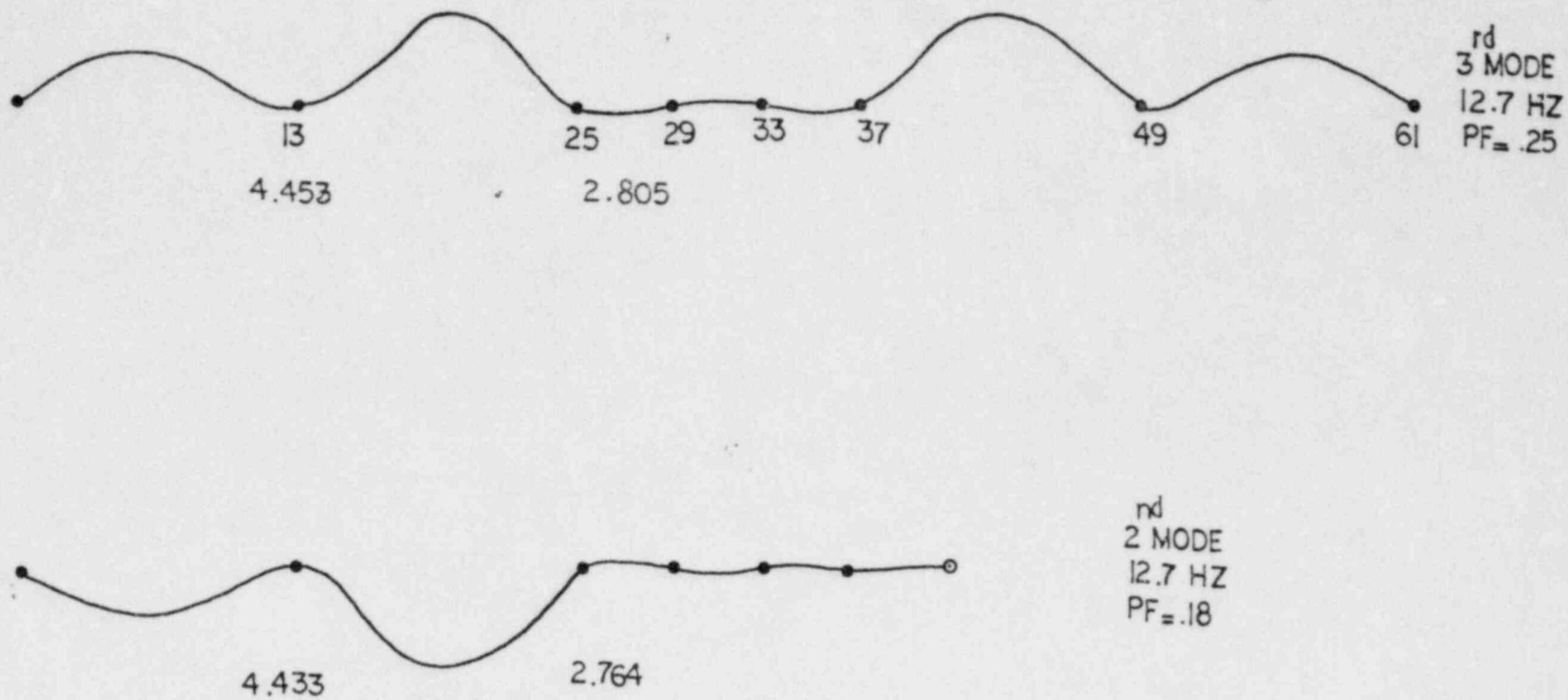

FIGURE 5

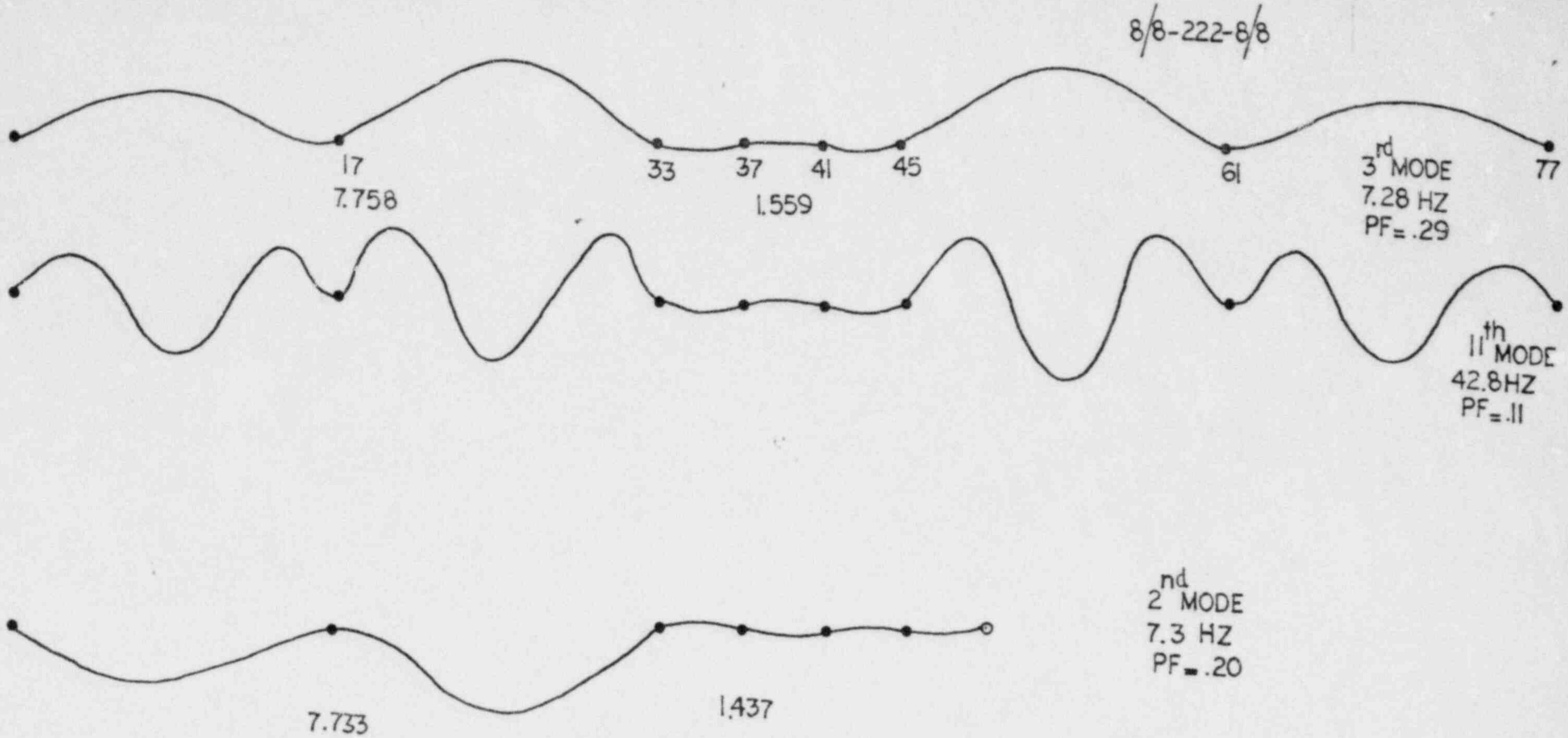
8/8-222-8/8
17
33
37
41
45
61
77
7.758
1.559
3rd MODE
7.28 HZ
PF= .29
11th MODE
42.8HZ
PF= .11
2nd MODE
7.3 HZ
PF= .20
7.733
1.437

FIGURE 6

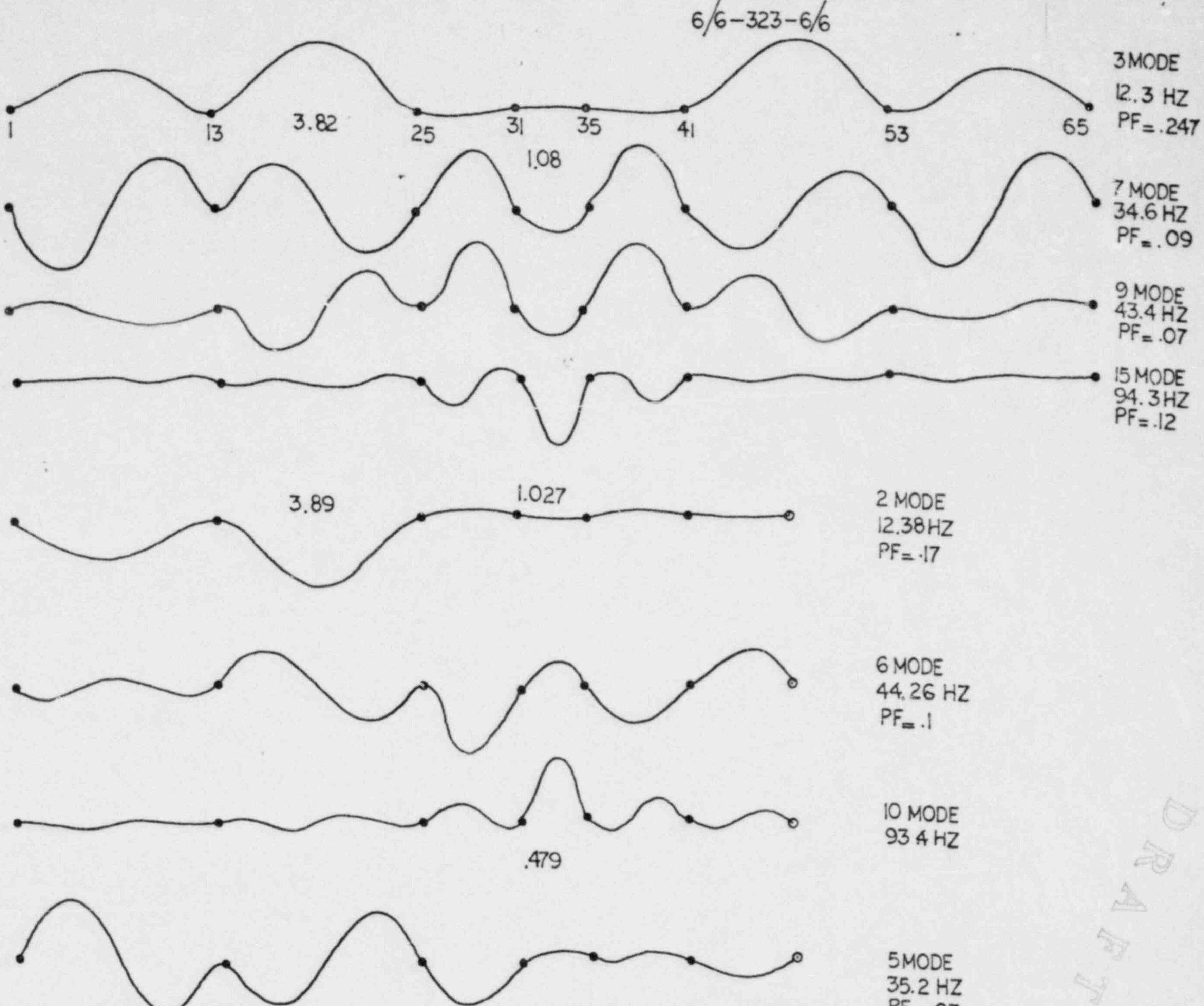
6/6-323-6/6
1
13
3.82
25
31
35
41
53
65
3 MODE
12.3 HZ
PF=.247
1.08
7 MODE
34.6 HZ
PF=.09
9 MODE
43.4 HZ
PF=.07
15 MODE
94.3 HZ
PF=.12
3.89
1.027
2 MODE
12.38 HZ
PF=.17
6 MODE
44.26 HZ
PF=.1
10 MODE
93.4 HZ
.479
5 MODE
35.2 HZ
PF=.07
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FIGURE 7

8/8-223-6/8

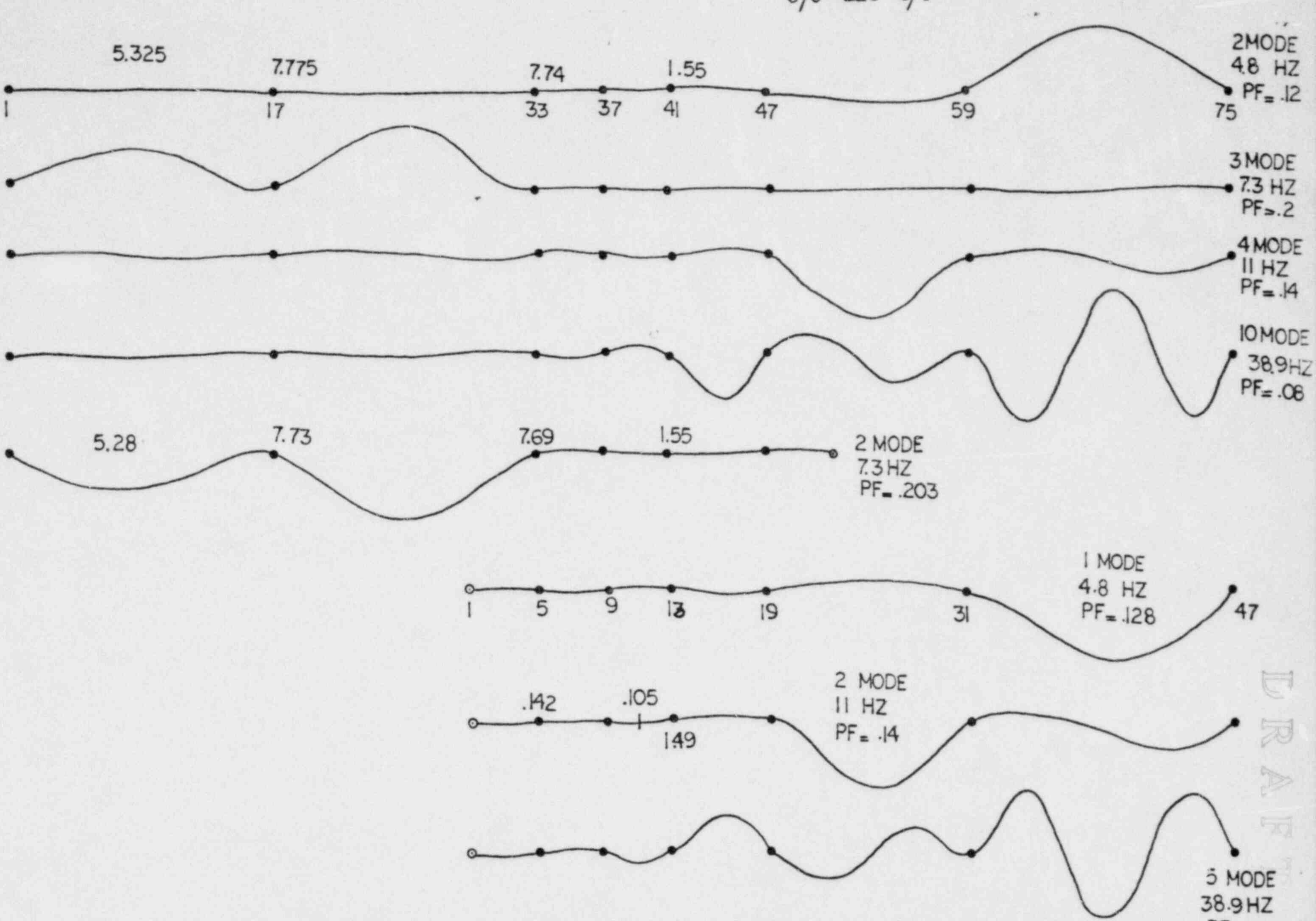
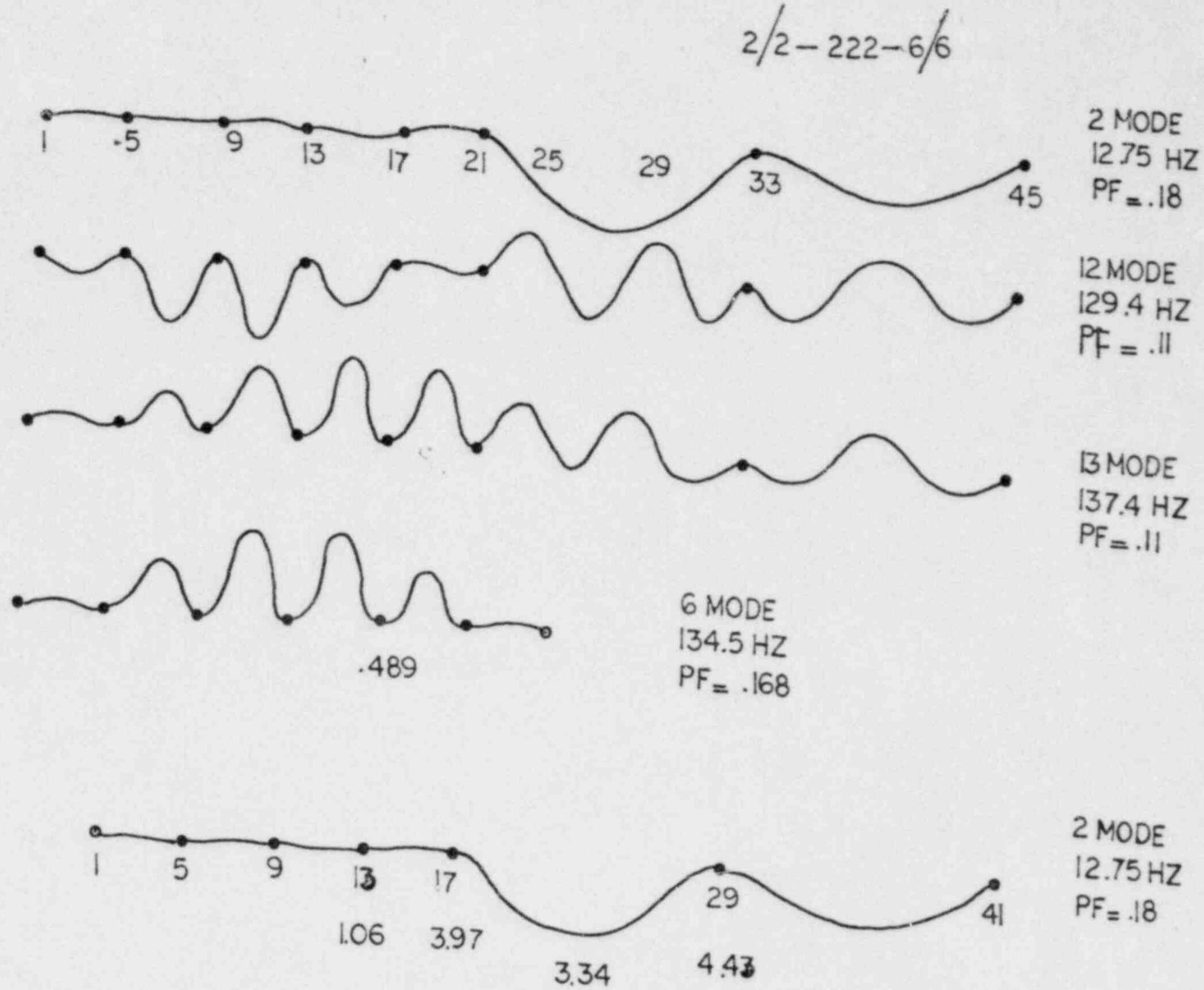


FIGURE 8



2/2 – 222 – 6/6
1
5
9
13
17
21
25
29
33
45
2 MODE
12.75 HZ
PF = .18
12 MODE
129.4 HZ
PF = .11
13 MODE
137.4 HZ
PF = .11
.489
6 MODE
134.5 HZ
PF = .168
1
5
9
13
17
29
41
1.06
3.97
3.34
4.43
2 MODE
12.75 HZ
PF = .18

FIGURE 9

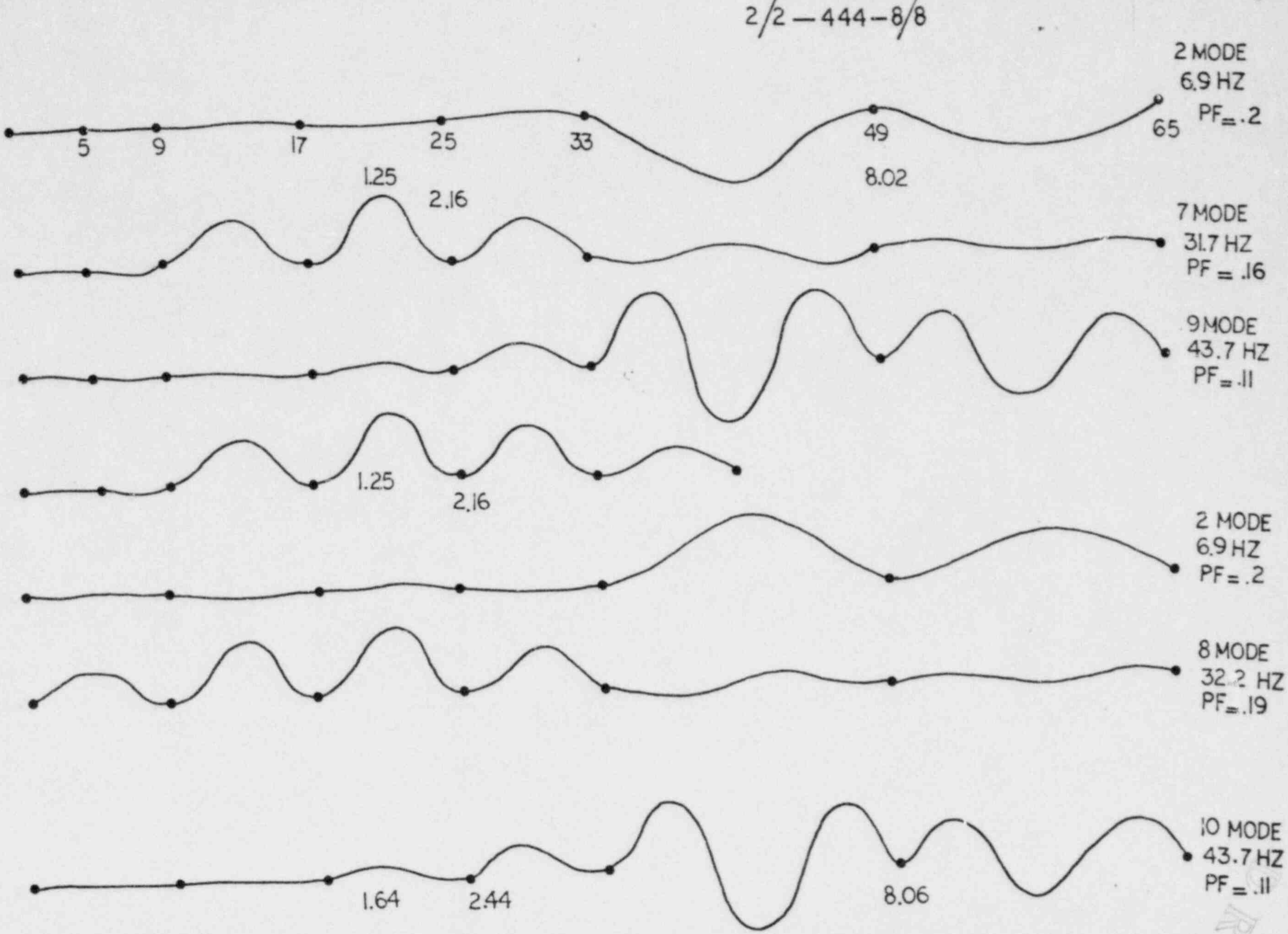

2/2—444—8/8
2 MODE
6.9 HZ
PF = .2
5
9
17
25
33
49
65
1.25
2.16
8.02
7 MODE
31.7 HZ
PF = .16
9 MODE
43.7 HZ
PF = .11
1.25
2.16
2 MODE
6.9 HZ
PF = .2
8 MODE
32.2 HZ
PF = .19
10 MODE
43.7 HZ
PF = .11
1.64
2.44
8.06

FIGURE 10

2/2 — 288 — 8/8

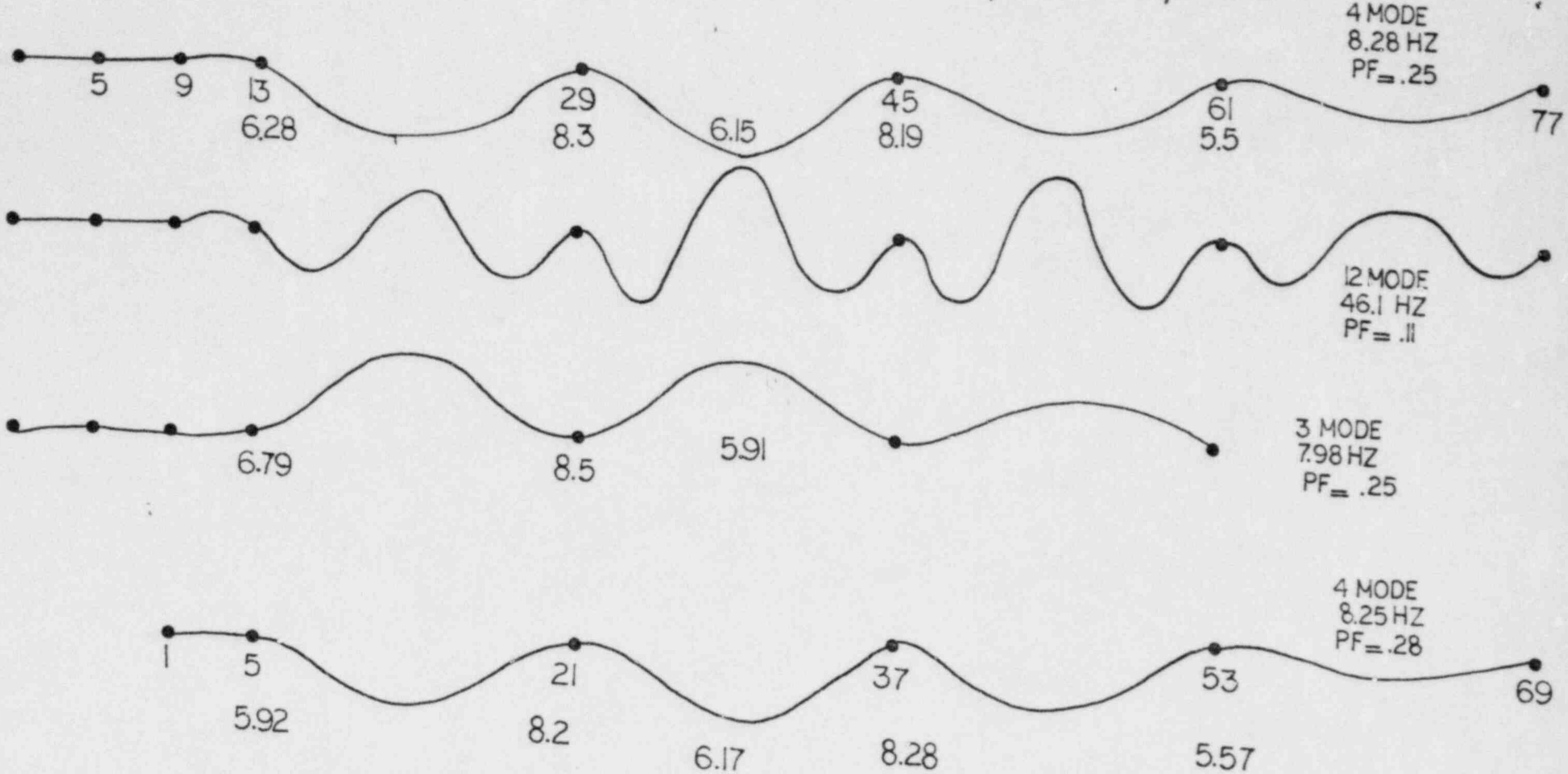


FIGURE 11

Table 2 shows the results of the analysis for the dynamic characteristics of each of the 9 systems. Four major columns are listed in the table. The first column identifies each of the cases. The next three major columns are the results of the full system, the left hand subsystem (Subsystem 1) and the right hand subsystem (Subsystem 2). Each of the three major columns lists the normal mode, the corresponding natural frequency and the modal participation factor. Only those modes with the higher participation factors are entered in the table. The table lists subsystem dynamic characteristics along side the corresponding full system property. When the dynamic characteristic is missing in the subsection, it means that the property is not a characteristic of the subsystem, and so no numbers are entered. For example, for Case 2, three full system normal modes and corresponding natural frequencies and modal participation factors are listed. These include modes 2, 4 and 14, which are the modes with the highest participation factors. For Subsystem 1, the first line is left blank, since there is no mode which corresponds to mode 2 in the full system. However, mode 2 in Subsystem 1 corresponds to mode 4 in the full system, and so is entered. Similarly, only one entry is made for Subsystem 2. All other entries in Table 1 follow this procedure. The only exception is in Case 6, where no entry is made either for Subsystem 1 or Subsystem 2 corresponding to Mode 12 for the full system. This is because the frequency of 129.4 is above the 10 frequencies that were recorded for Subsystem 2. However, nothing else is changed because of space left open in Case 6.

Table 3 is a comparison of the data in Table 2. An evaluation is made of the largest percent difference for each of the nine cases in terms of natural frequencies and modal participation factors. The percent difference in the maximum stress that was developed as a result of earthquake excitation and is listed in the final column.

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Table 2

Results for 10 In-Line Cases

Case No.*	Full			Sub_1			Sub_2		
	Normal mode	Nature Freq.	Part. Factor	Normal mode	Nature Freq.	Part. Factor	Normal mode	Nature Freq.	Part. Factor
1	7	34.1	0.26	6	33.7	0.24	6	33.7	0.24
2	2	12.7	0.18				2	12.7	0.18
	4	27.7	0.143	2	27.7	0.144			
	14	124	0.101	8	129	0.133			
3	3	27.6	0.20	2	27.7	0.14	2	27.7	0.14
	11	125.9	0.11						
4	3	12.7	0.20	2	12.7	0.18	2	12.7	0.18
5	3	7.28	0.29	2	7.20	0.21	2	7.20	0.21
	11	42.8	0.11	6	43.0	0.08	6	43.0	0.08
6	2	12.75	0.18				2	12.75	0.18
	12	129.4	0.11						
	13	137.4	0.11	6	134.5	0.168			
7	3	12.3	0.24	2	12.4	0.17			
	7	34.6	0.09	5	35.2	0.07	5	35.2	0.07
	9	43.4	0.07	6	44.26	0.10			
	15	94.3	0.12	10	93.4	0.11			
8	2	4.85	0.12		4.84		1	4.84	0.13
	3	7.3	0.20	2	7.3	0.20			
	4	11.0	0.14				2	11.0	0.14
	10	38.9	0.0875				5	38.9	0.0919
9	2	6.9	0.20				2	6.9	0.20
	7	31.7	0.16	4	32.5	0.20	8	32.2	0.19
	9	43.7	0.11				10	43.7	0.11
10	4	8.28	0.25	3	7.98	0.25	4	8.25	0.28
	12	46.1	0.11	9	45.1	0.10			

*Case No. refers to system described in Table 3.

Table 3

Case No./ Fig. No.	In-Line System	Natural Freq.	Participation Factor	Max Stress $ST_{Sub} - ST_{Full}$
1	4/4-444-4/4	1.2	7.5	+0.6
2	4/4-222-6/6	2.4	28.1	0%
3	4/4-222-4/4	2.3	20.9	+0.4
4	6/6-222-6/6	0.5	10.0	-0.4
5	8/8-222-8/8	1.1	27.2	-0.3
6	2/2-222-6/6	2.1	52.7	-0.3
7	6/6-323-6/6	1.7	29.2	+1.8
8	8/8-223-6/8	0.2	5.0	-0.5
9	2/2-444-8/8	1.6	18.8	+0.5
10	2/2-288-8/8	3.6	12.0	+2.7

Percent Differences in Natural Frequency , Participation Factor and Maximum Stress.

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Table 3 shows that all of the natural frequencies of the subsystems, as compared to the corresponding frequencies of the full system, are less than 4 percent different. The maximum stresses are within 3 percent. However, the modal participation factors are as much at 50 percent different. This is especially significant for steady state loading.

LOAD COMBINATIONS -SINE LOADING

Piping for nuclear power plant facilities etc., are designed for all types of load combinations that may be expected during their lifetime. These load combinations include both multiple dynamic loads as well as static loads. Specifically, the piping systems will be subjected to dynamic loads from various sources, such as earthquakes, loss-of-coolant accidents, safety relief valve actuations and vent chugging loads.

For some loading phenomena, the dynamic analysis provides a definitive time history response thus allowing for a straightforward addition of responses where more than one load is acting simultaneously. In other cases, no specified time phasing relationship exists, either because the loads are random in nature or because the loads have simply been postulated to occur together without a known or defined coupling.

Where the time phase relationship is lacking, design engineers have utilized different methods to combine the dynamic responses. One method is called the Absolute Sum Method (ABS) by which the peak responses are added absolutely. Another method is called the Square Root of the Sum of the Squares (SRSS) by which the combined result is equal to the square root of the sum of the squares of the individual response peaks.

It is obvious that ABS represents the maximum possible combination result and may lead to overly conservative design requirments. On the other hand, the other approaches are mainly based on heuristic reasoning, and are not supported by a rigorous mathematical proof.

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There is no general closed form mathematical solution that could be used for guidance in determining the degree of conservatism regarding the combination of randomly occurring signals by the absolute sum method. The absolute sum is a bounding case. This is all that is known. The degree to which departures in the absolute sum procedure may be used safely, and the restricting conditions that should be imposed, is not known quantitatively.

When combining two signals that are known temporally, the individualistic shapes are crucial to how they combine. Whether SRSS is an acceptable substitute for ABS depends upon wave shape.

The earthquake loading introduces transient responses. The stress is computed by the superposition of the stress of many modes. In this summation process, the maximum stress is the result of many component contributions. The transient nature of the loading together with the summing procedure de-emphasizes some of the differences that occur because of the subsection approximation. Other types of loading may result in accentuating the differences between the full system and the subsystem approximation.

An SRV type of load, for example is a short term, somewhat sinusoidal type of excitation which could show a greater disparity between the full system and subsystem analysis. This type of load should emphasize the differences between the full and subsystem characteristics.

To investigate this, a sinusoidal time signal was imposed upon the full 2/2-222-6/6 in-line piping system. This system was selected because of the high disparity in the modal participation factors between the full and subsystems. The response at the point of maximum stress was recorded. This occurs at node 13. The subsystem which contained this node was also excited by the same signal and the response recorded. A two second sinusoidal signal was used as a forcing motion at each of the support points. This was intended to represent an SRV type of excitation.

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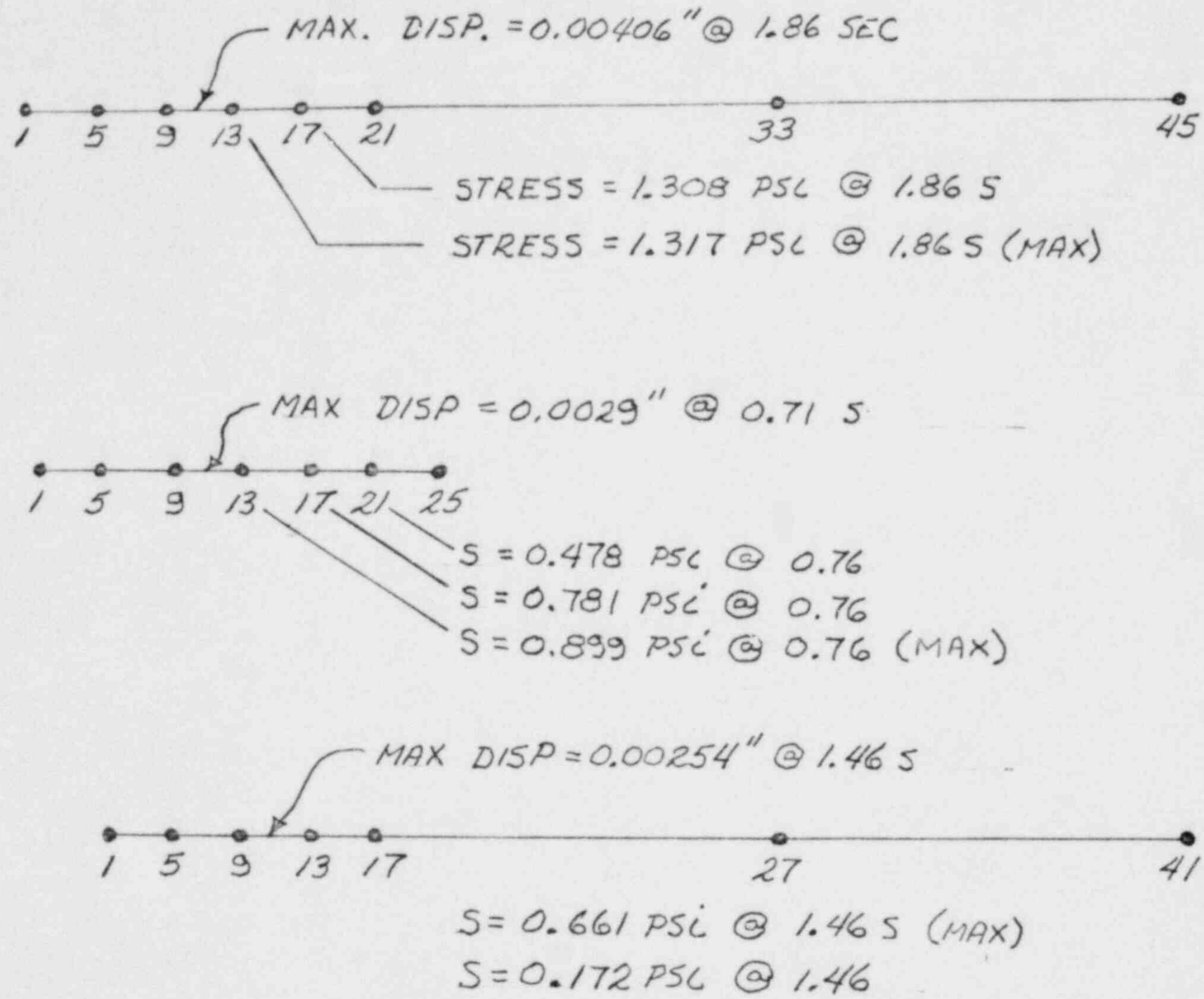
Figure 12 shows the maximum displacements and stresses that were recorded for the full system as well as from the two subsystems. The times at which the maximums are developed are also noted. Table 4 shows the percent difference in maximum stresses and maximum deflection that were developed at the same point in the structure. From the table, there is 49.8 percent difference between the Subsystem 2 and full system maximum stress. The maximum stress predicted by the subsystem is lower than the maximum stress developed in the full system. Furthermore, the times of occurrences are different, and so combinations of multiple loads on a time basis would give different results.

SYSTEM 2/2-222-6/6, STRESS AT NODE 13



SINUSOIDAL FORCING FREQUENCY (20 Hz)

2 SECOND DURATION, COMP. RESULTS

FIGURE 12

COMPARISON OF MAXIMUM DEFLECTIONS AND MAXIMUM STRESSES FOR SHORT DURATION SINUSOIDAL EXCITATION

Table 4

	Max. Disp.	% Diff.	Max. Stress	% Diff.
Full System	0.00406		1.317	
Sub. 1	0.0029	28.6	0.899	31.7
Sub. 2	0.00254	37.4	0.661	49.8

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For short duration signals that are essentially sinusoidal, large differences in the response could be obtained both qualitatively as well as quantitatively. Figures 13a and 13b show a quantitative difference in the response. A sinusoidal loading at a frequency of 19.5 Hz was imposed to obtain the responses shown in Figs. 13a and 13b. The type of response motion obtained is essentially the same, but the amplitudes are in the ratio of 2 to 1. For this case, the subsystem gives the greatest displacement. If the forcing frequency is increased to 20 Hz, a change of only 0.5 Hz, the responses obtained are shown in Figures 14a and 14b. This time, both a qualitative as well as a quantitative difference in the responses is seen and this time the full system deflection is greater by about a ratio of 3 to 2.

The previous results were obtained for Case 7 of Table 1. The central portion for this case had dynamic characteristics similar to one end. On the other hand, Case 6 has a central portion which is stiffer than either end. As an indication of the differences that should result when the central overlap portion is relatively stiff compared to the remainder of the system, a forcing function was imposed on the system in Case 6, as in the previous case. A sinusoidal excitation was imposed with a forcing frequency near a natural frequency with a high participation factor. Mode 10, as shown in Figure 8, was used in this case. The time response for a 2.0 second run was recorded at an antinode. The results are shown in Figures 15a and 15b for the full system and for the subsection which contain the same node. It is seen that the displacement results are essentially the same both on a qualitative as well as a quantitative basis. For this case, the subsystem approach gives the same response as the full system. In effect, the natural frequency of the central portion is high compared with the ends. At this frequency, the two ends are essentially isolated by the central portion, and so the separate results are the same as the full system results.

f = 19.5 Hz
Full System

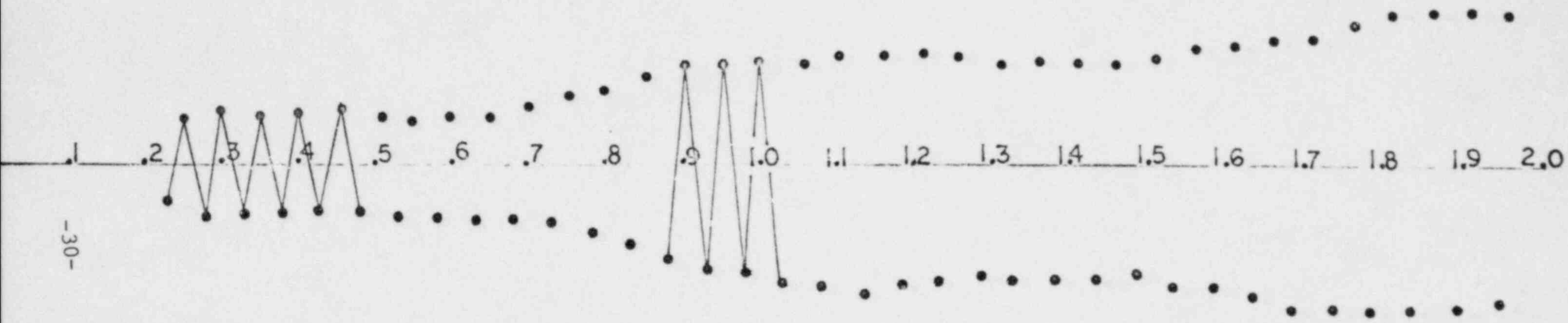


FIGURE 13a

Displacement at Node 11 Full System

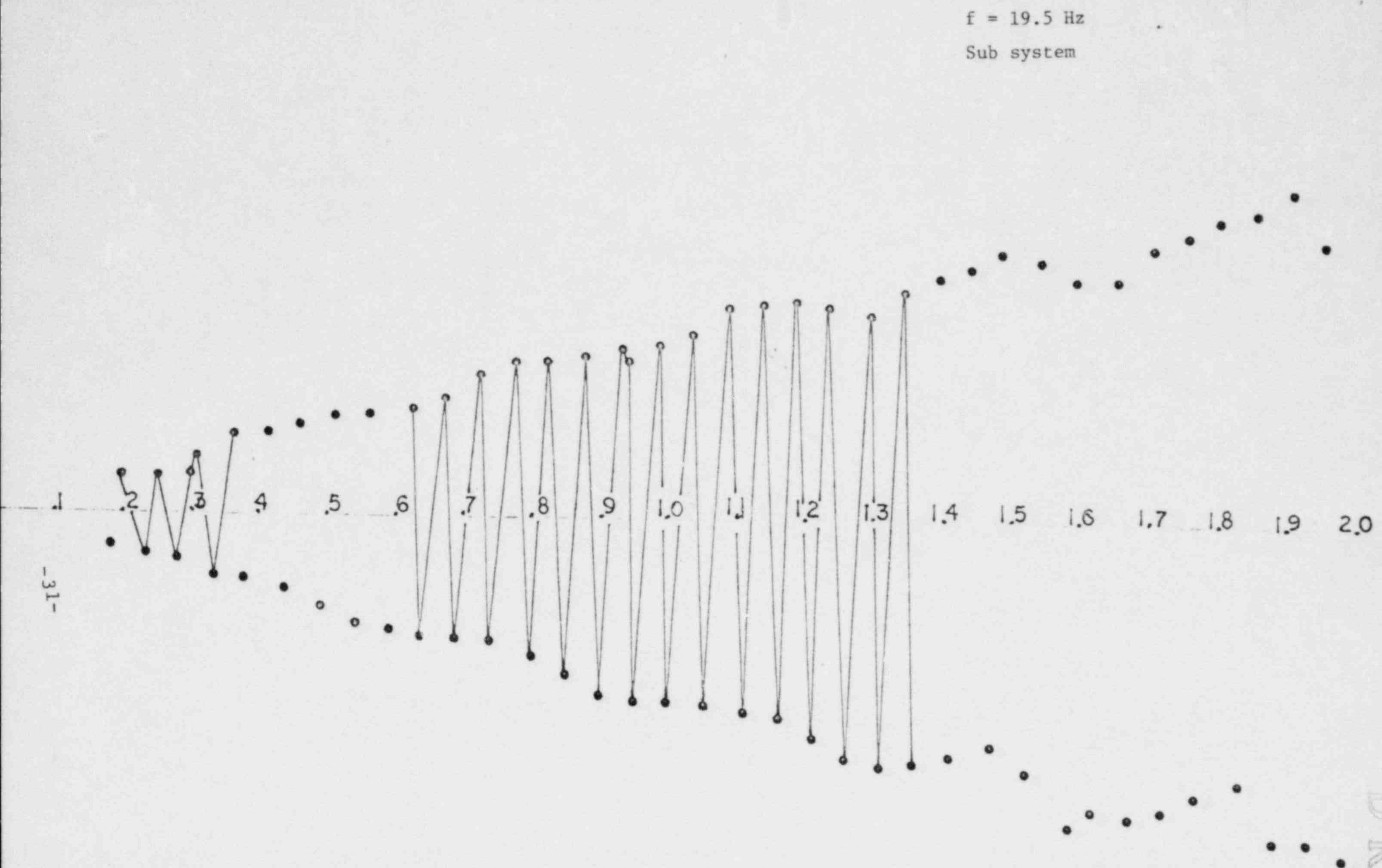


FIGURE 13b

Displacement at Node 11 Subsystem

2/2–2/2/2–6/6

DISPLACEMENT AT 11-6a FULL SYSTEM

f = 20 Hz

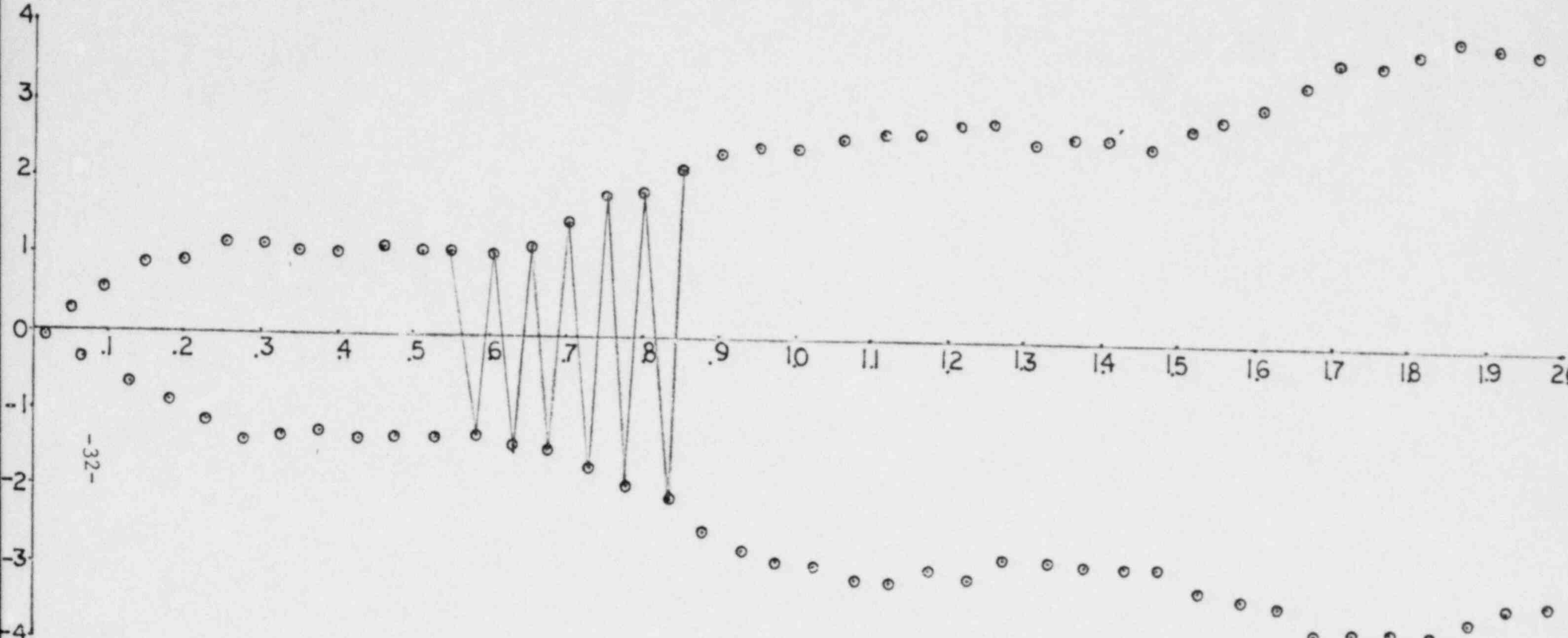


FIGURE 14a

2/2 – 2/2/2/2

DISPLACEMENT AT 11-6b SUBSYSTEM

f = 20 Hz

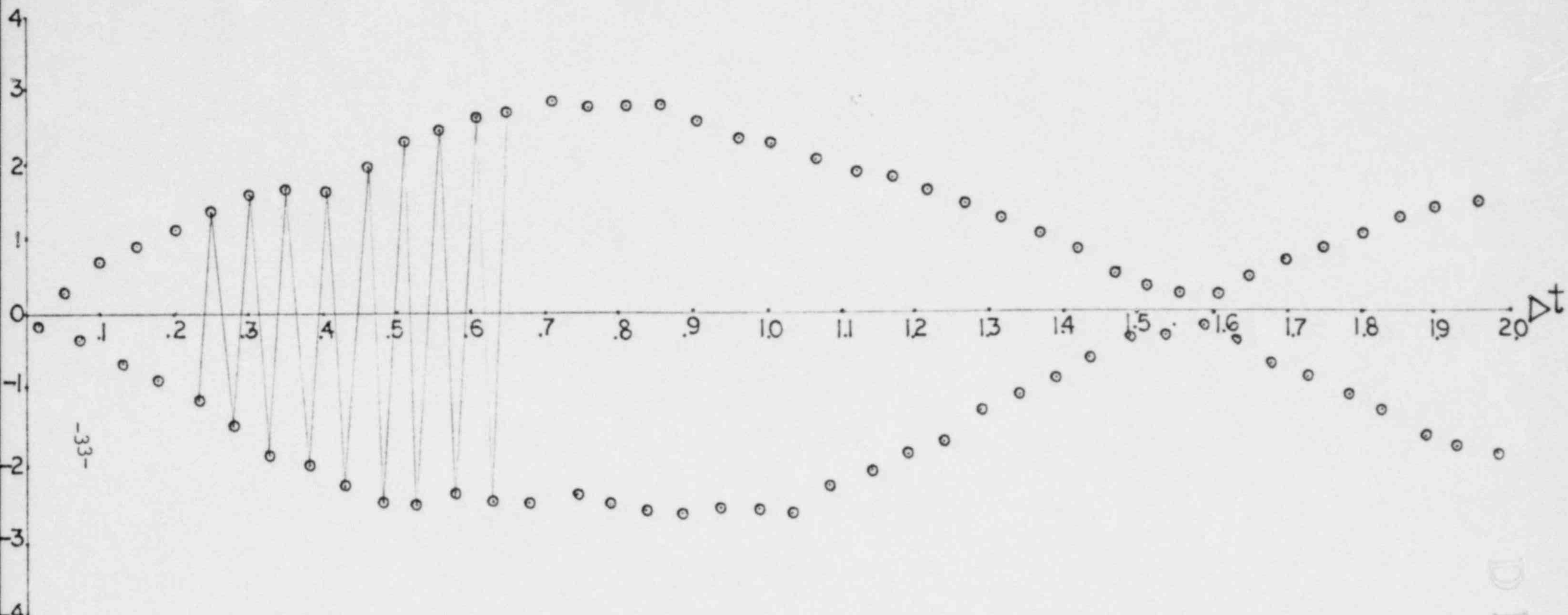


FIGURE 14 b

Of course, this is a single case result. Only qualitative conclusions are drawn from these results. These cases show that:

a) The structural overlap method does not work in general.

b) However, if a sufficiently stiff (a high natural frequency) property is associated with the central section, acceptable results could be obtained. For seismic excitation, where the excitation band is essentially between 1 to 10 Hz, the central section may be considered to be rigid enough if it has a fundamental natural frequency of at least 33 Hz.

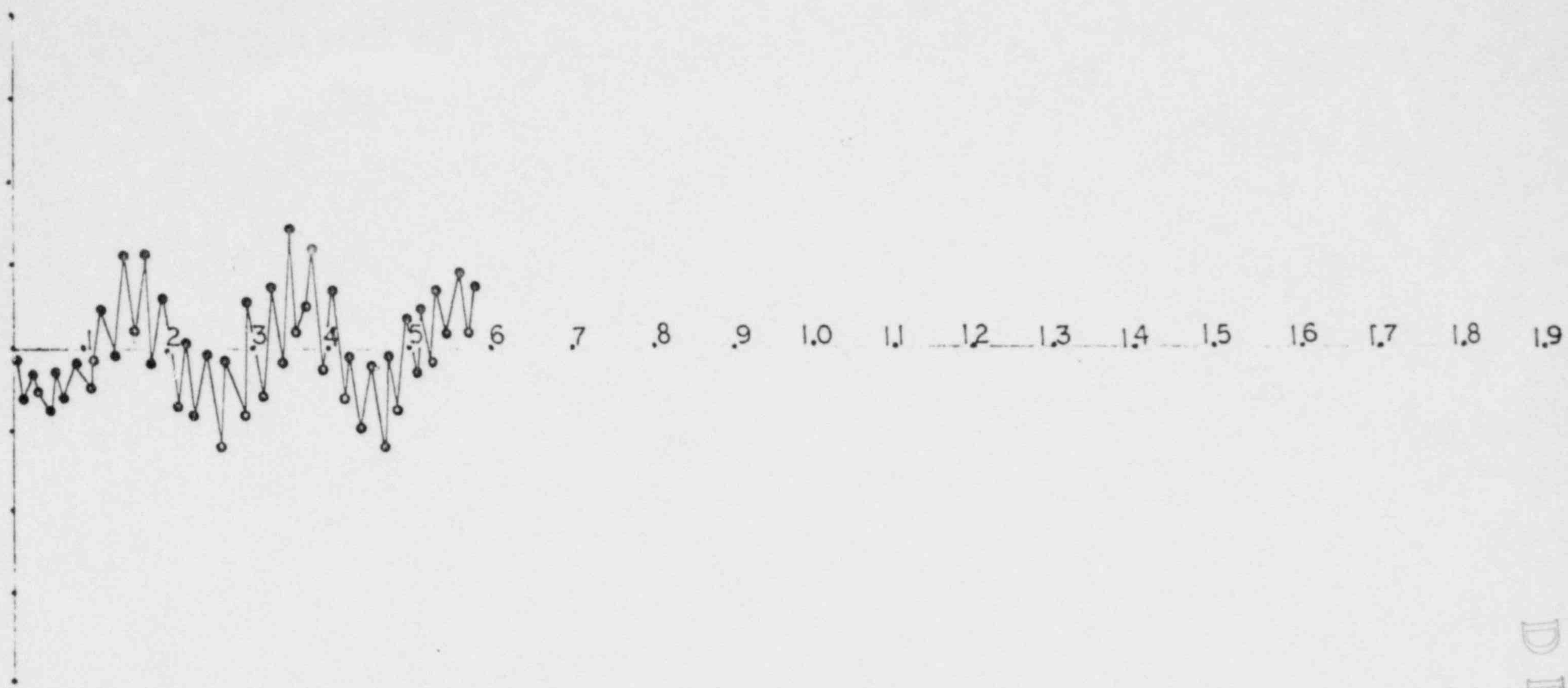


FIGURE 15a

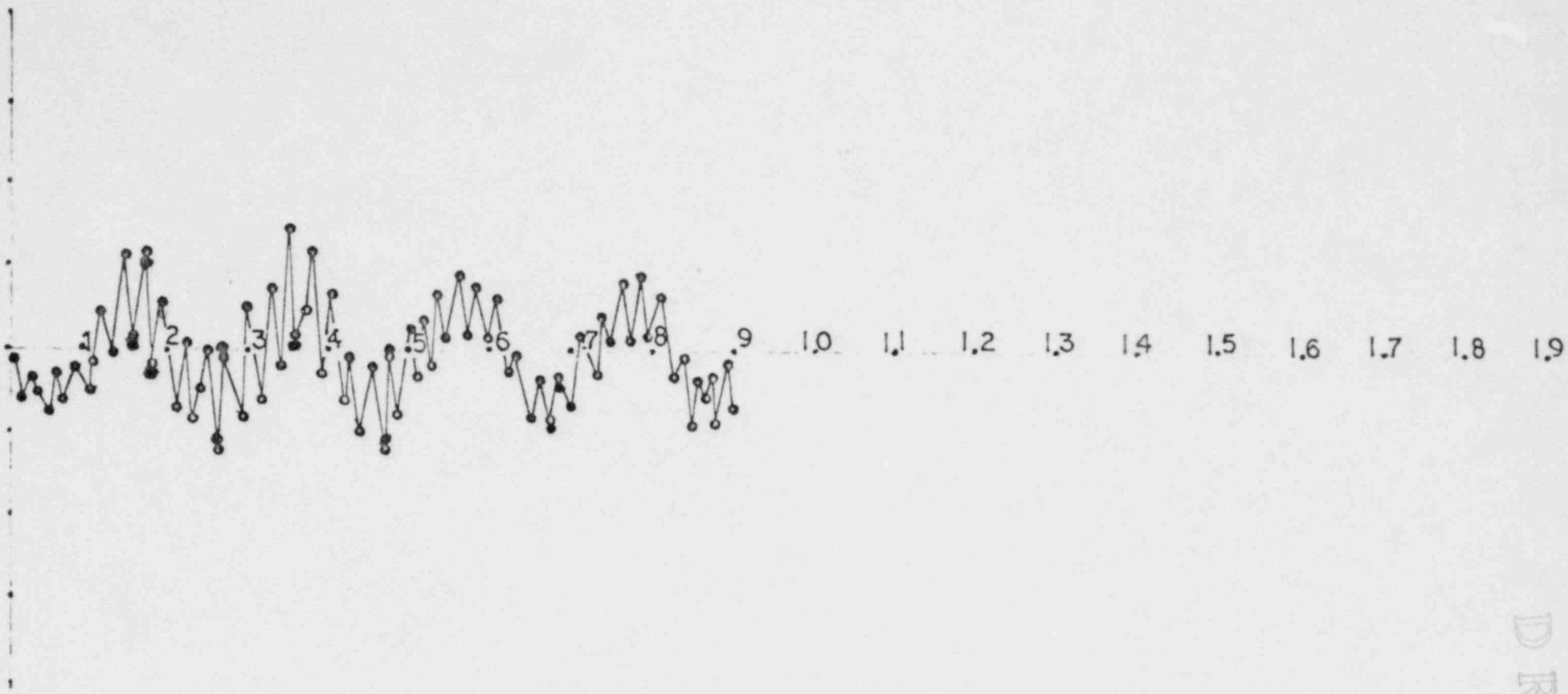


FIGURE 15b

Three Leg Pipe Bend

The in-line case considers only the bending response to a one directional loading situation, there is no structural compling in different directions. Real systems are actually three dimensional and combine bending, torsion and axial response to any one excitaticn. To study some of the characteristics of three dimensional piping systems in terms of complex responses, a three leg piping arrangement was investigated. The same basic proportions of lengths was maintained with the 3-D system as compared with the in-line system. A total of seven sections was used in the first study. The individual section lengths and piping designations were also the same as was previously used for the in-line systems. The center span was composed of three sections with the outboard portions having two sections each.

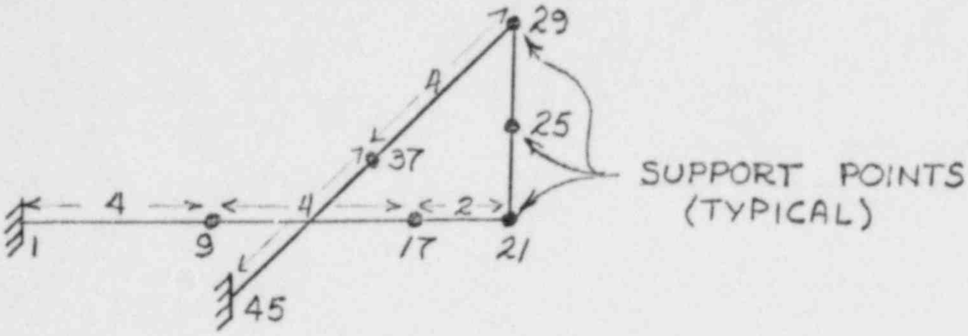
Two different cases were examined, the ratio between the outboard ends to the overlapping span lengths was changed for the two cases. Figure 16a shows the piping arrangment for a full 4/4-222-4/4 system. Figures 16b and 16c shows the corresponding subsystems. The overlap region includes the three sections between nodes 17 to 29. Figure 17 shows the arrangement for the second system. This has span lengths of 6/6-222-6/6.

Table 5 shows a comparison of the maximum stress that was calculated for an earthquake input. Two maxima are listed for the full section. This is because the point of maximum stress does not occur at a point that is common to both subsections. Accordingly, a maximum is selected so that reference could be made for the corresponding point in each subsection. For these two cases, the maximum difference in the stresses between the subsystem and full system analysis was 3.5%. These results are similar to those for the in-line arrangement. However, for each of these cases, the stress in the full section is greater than the stress in the subsection. As before, the

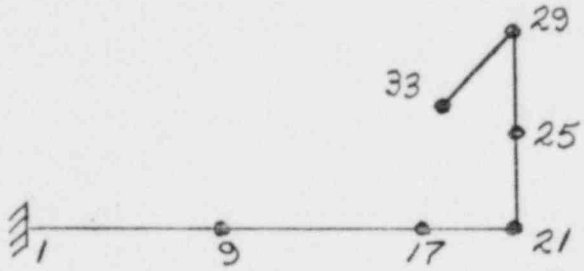
Table 5

3-D Piping, 3 Span Center Section, 2 Bends in One Plane

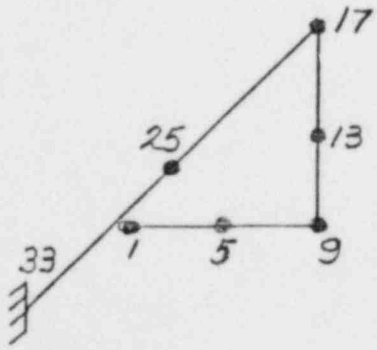
Case	Span Lengths	Stress Full	Stress Sub_1	Stress Sub_2	Max % $\frac{S+_{sub} - ST_{full}}{ST_{full}}$
1	4/4-222-4/4	3.41	3.31		-2.9%
		3.10		2.99	-3.5%
2	6/6-222-6/6	7.43	7.21		-2.9%
		6.80		6.60	-2.9%



(a) FULL SYSTEM



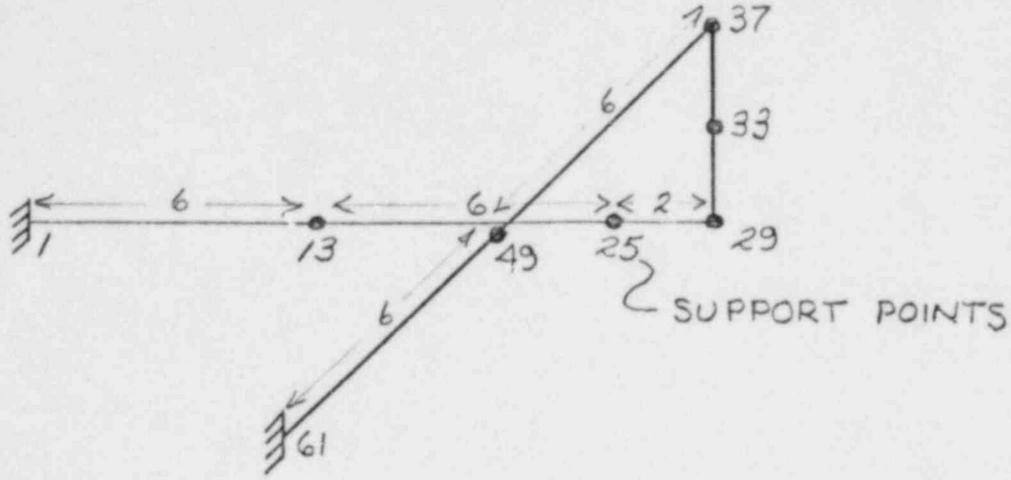
(b) SUBSYSTEM 1



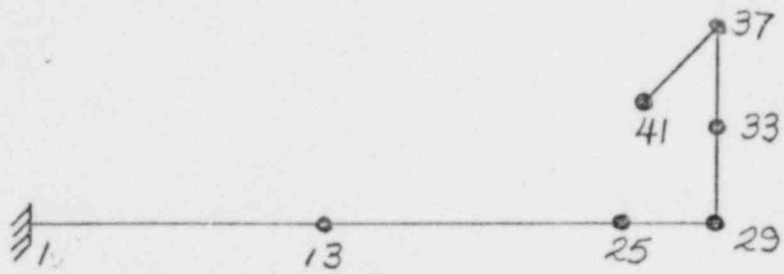
(C) SUBSYSTEM 2

4/4-222-4/4 3 D SYSTEM

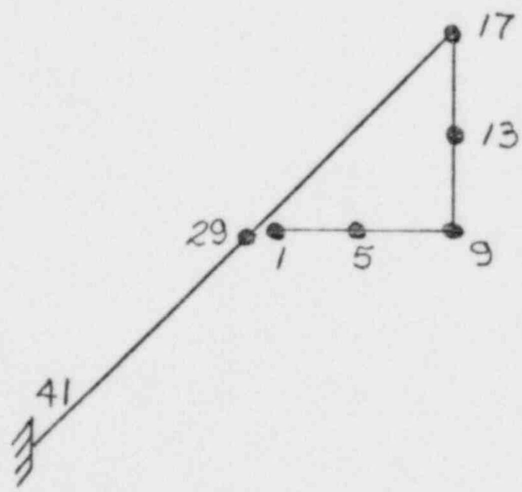
FIGURE 16



(a) FULL SYSTEM



(b) SUBSYSTEM 1



(C) SUBSYSTEM 2

6/6 - 222 - 6/6 3D SYSTEM

FIGURE 17

second case, with a span ratio of 3 to 1, showed somewhat more isolation than the 2 to 1 ratio.

Four Bend System

The previous study of a 3-D pipe bend had a central section with only two bends. Table 5 compares the maximum stress in a full system vs. subsystem analysis for the two cases of increasing ratio between the overlap portion and the remainder of the full system. The effect of adding an additional section to the central portion while, at the same time, adding an additional bend is now considered. The central portion for this case has three section and the overall system has a total of four bends. The system is shown in Figure 18.

Table 6 shows the maximum stress due to the same excitation that was previously used. For the same 3 to 1 ratio between the outer spans and the central span lenghts, the maximum stress results as compared to the 2.9 percent listed in Table 5. This is Case 1 in Table 6. For this case an investigation of the mode shapes for the full system indicated that torsional coupling occurs across some of the spans of the overlap region. This occurs for excitation in the X-Z plane only and does not occur for the excitation in the X-Y plane. In other words, horizontal excitation produces bending in both of the outermost spans through torsional coupling.

Reversal of the direction of the loading changes the sign of the bending response in the full structure. The subsystems are not similarly affected. For other modes, and for other directions of excitation, this sign reversal does not occur. Since the maximum stress is the superposition of many modes, the maximum magnitude of the stress is affected by directional sensitivity for some cases. This occurs in this instance even though the span length of the overlap region is short compared to the outboard spans.

Case 2, Table 6 shows the effect of reversing the direction of the earthquake excitation in the X-Z plane. For this case, the directional change of the input increases the difference between the subsection and full system analysis from 0.6 (Case 1) to 3.0 percent, (Case 2).

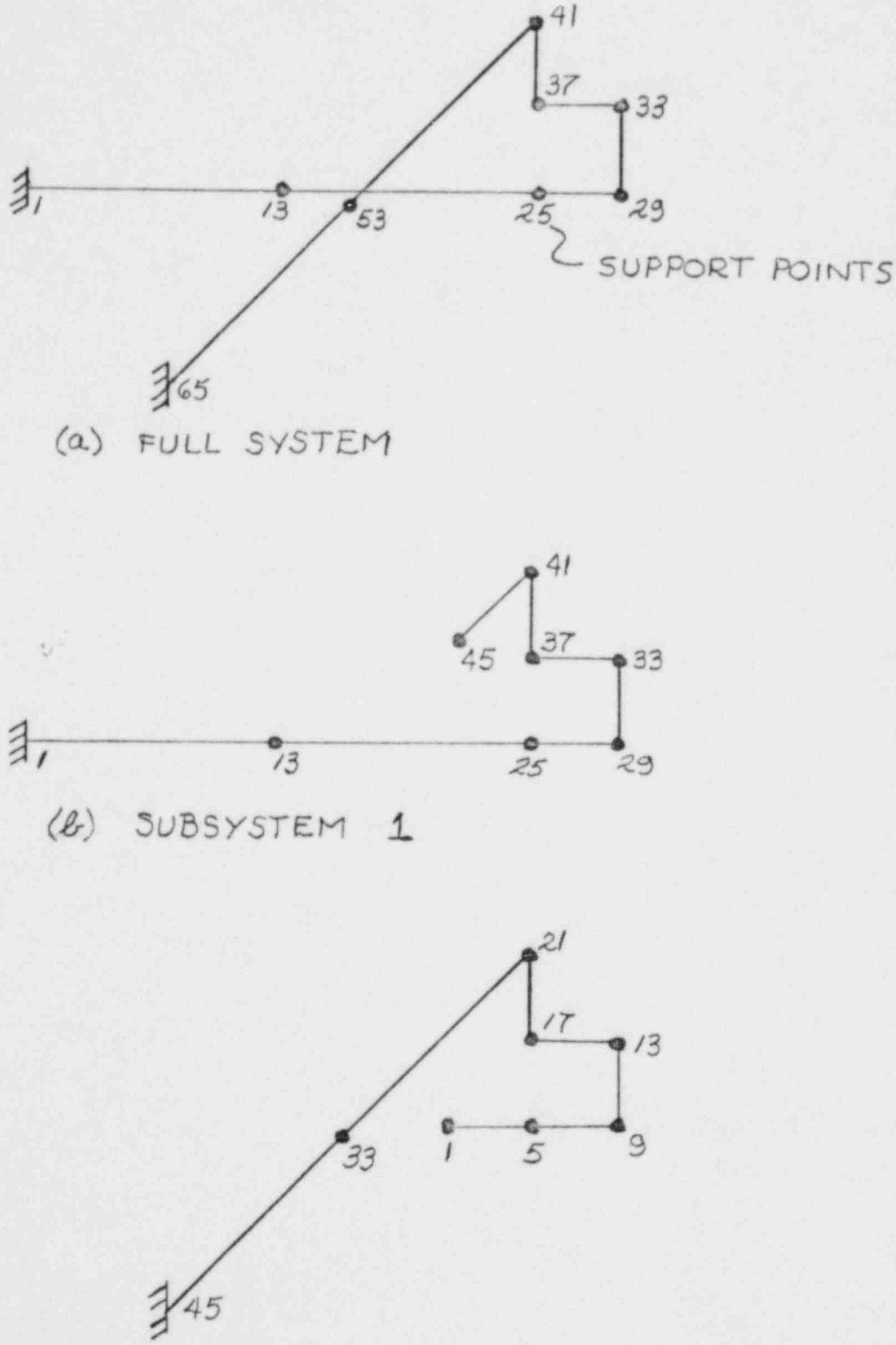
COMPARISON OF MAXIMUM STRESSES FOR SEISMIC EXCITATION

Table 6

3-D Piping, 4 Span Center Section, 3 Bends in one Plane

Case	Direct of Input	Span Length	Stress			% Diff.
			Full	Sub_1	Sub_2	
1	Z axis	6/6-2222-6/6	6.625	6.597		- .4
			7.202		7.244	+ .6
2	-Z axis	6/6-2222-6/0	6.541	6.597		+ .8
			7.024	7.244		+3.0

Coupling Z and X



6/6/2 -222- 6/6 3D SYSTEM

FIGURE 18

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NRC Designated Piping Configuration

The in-line and the simple pipe bend systems were used to obtain insight into the basic features of the subsystem method. Some of the problems, limitations and areas of difficulty that might be encountered when using the method were discussed in previous sections.

This section uses an actual piping system that was designated by the NRC to investigate the application in a realistic situation. The 30 inch diameter piping system is shown in Figure 19. A total of 36 nodes are used. Intermediate spring hangers are located at nodes 7,14,20,26 and 28. The piping extends vertically a distance of about 50 feet and connects two points at different elevations.

Two different spectrums were used to study the system response using the subsystem method. One of these is called SuperSpectrum and is listed in Table 7. The other is shown in Table 8. For this study, two different overlap regions were used. In addition, both a fixed end and a free end at the terminal point of the broken end were considered.

The results of the investigation are shown in the plots of Figures 20 through 24. The solid line is the response of the total system while the dashed line is the response obtained from the subsystem investigation. The results shown in Figures 20, 21, and 22 are all for the case with an overlap region extending from node 14 to node 20. Figure 23 is a case where the overlap region is between node 28 and node 20 while Figure 24 extends the overlap region from node 28 to node 7.

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Table 7

SPECTRUM TABLE (SUPER SPECTRUM...NRC MODIFIED.....

NUMBER OF POINTS = 38
SCALE FACTOR = .10000E+01

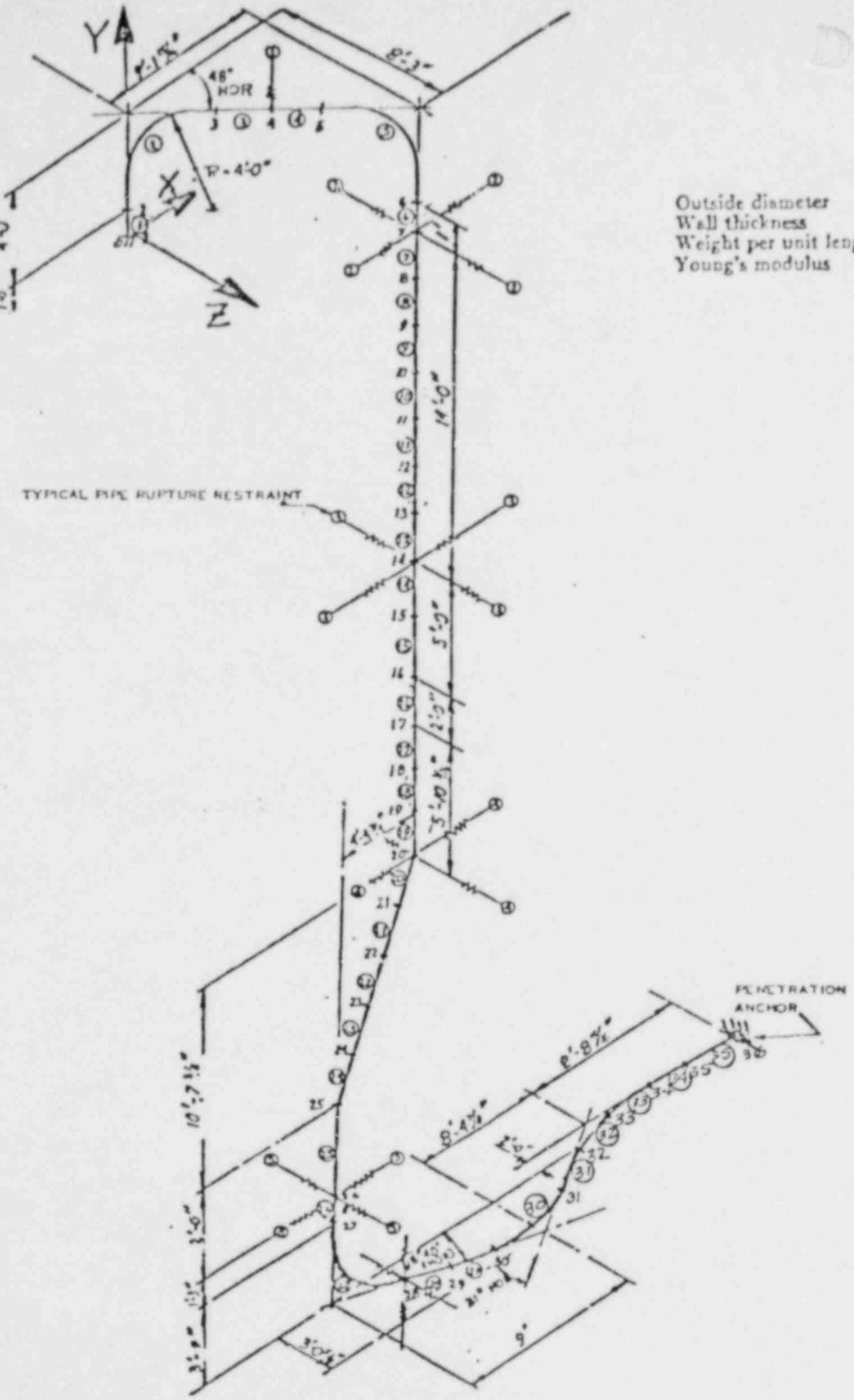
INPUT POINT	PERIOD	SPECTRUM VALUE
1	.5000E-02	.1600E+03
2	.1020E-01	.1600E+03
3	.1391E-01	.2430E+03
4	.1700E-01	.2430E+03
5	.1923E-01	.1700E+03
6	.2164E-01	.2550E+03
7	.2439E-01	.2550E+03
8	.2667E-01	.4070E+03
9	.4202E-01	.4750E+03
10	.4609E-01	.5550E+03
11	.5528E-01	.6520E+03
12	.5882E-01	.7550E+03
13	.6711E-01	.7550E+03
14	.7110E-01	.8650E+03
15	.1000E+00	.8650E+03
16	.1156E+00	.1222E+04
17	.1413E+00	.1222E+04
18	.1482E+00	.1150E+04
19	.1534E+00	.1399E+04
20	.1676E+00	.1399E+04
21	.1923E+00	.1140E+04
22	.2268E+00	.1140E+04
23	.2392E+00	.1057E+04
24	.2924E+00	.1057E+04
25	.3049E+00	.1023E+04
26	.3175E+00	.8550E+03
27	.3460E+00	.8550E+03
28	.3571E+00	.8120E+03
29	.3922E+00	.8120E+03
30	.4167E+00	.9140E+03
31	.5208E+00	.9140E+03
32	.5263E+00	.8650E+03
33	.6173E+00	.8650E+03
34	.6250E+00	.9050E+03
35	.7813E+00	.9050E+03
36	.8696E+00	.6620E+03
37	.9524E+00	.6620E+03
38	.1000E+01	.6000E+03

Table 8

SPECTRUM TABLE (SMALL SPECTRUM.......

NUMBER OF POINTS = 6
SCALE FACTOR = .10000E+01

INPUT POINT	PERIOD	SPECTRUM VALUE
1	.1000E-02	.7720E+02
2	.2900E-01	.7720E+02
3	.1250E+00	.1930E+03
4	.6670E+00	.1930E+03
5	.3700E+01	.3090E+02
6	.1000E+02	.5020E+01



Outside diameter	= 30 in.
Wall thickness	= 1 in.
Weight per unit length	= 32 lb/in.
Young's modulus	= 25,800,000 psi

NRC DESIGNATED PIPING SYSTEM

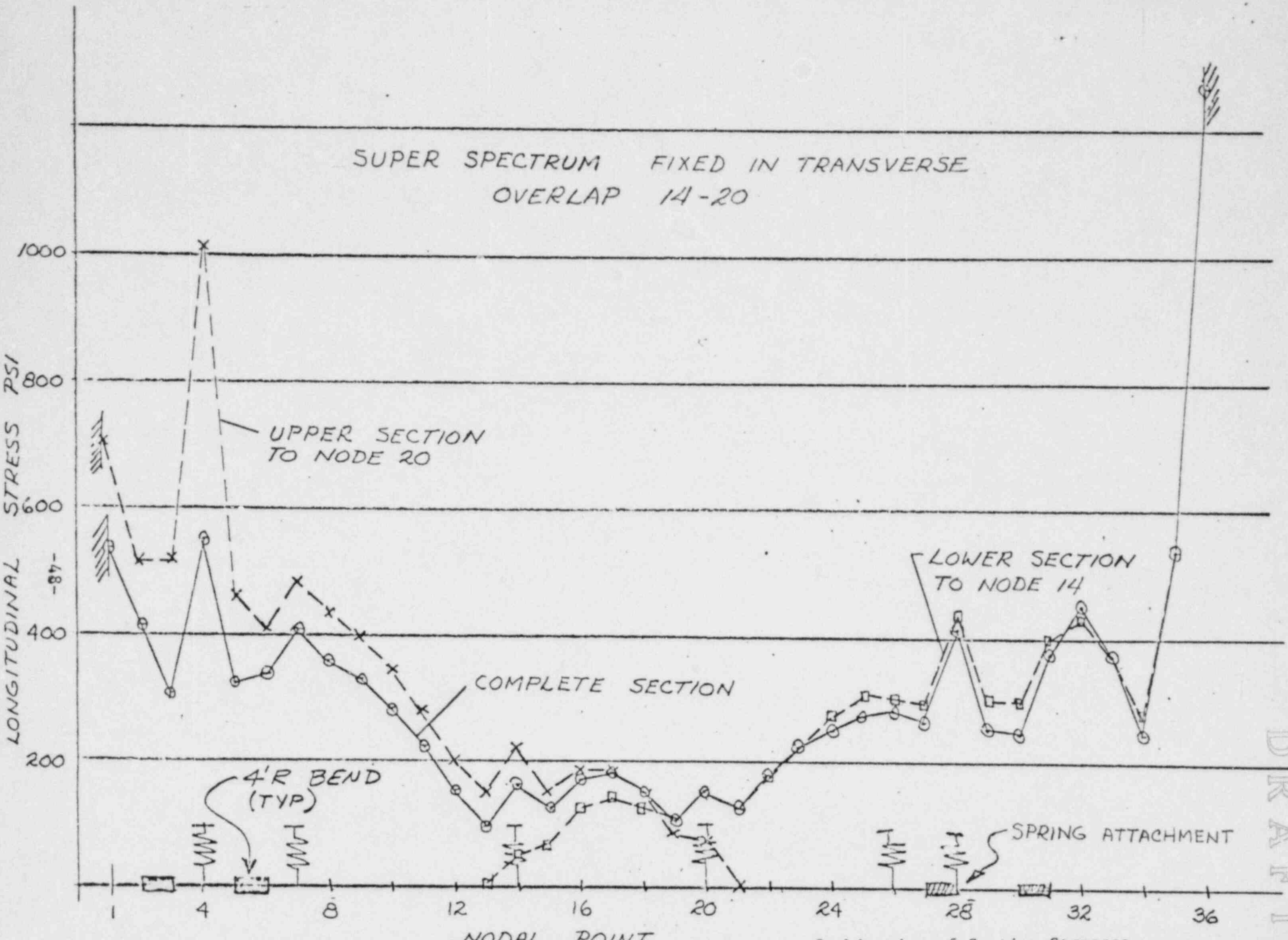
FIGURE 19

Figure 20 shows that the subsystem stresses are equal to or greater than the full section stresses. There are one or two points where the full section stress is slightly higher than the subsection stress, but essentially the curves show that the subsection analysis looks conservative.

The broken ends of the subsections are free in Figure 21 and again the same conclusion is shown in the plot. Only the local stress is affected by the boundary condition and this happens to be a point where the stress is not great anyway.

The small spectrum is applied to the structure in Figure 22. The small spectrum has a value up to a period of 10 seconds as compared to the large spectrum which terminates at one second. Nevertheless, the responses in Figure 22 show that the stresses in the subsections are essentially equal to or greater than the stresses for the full system.

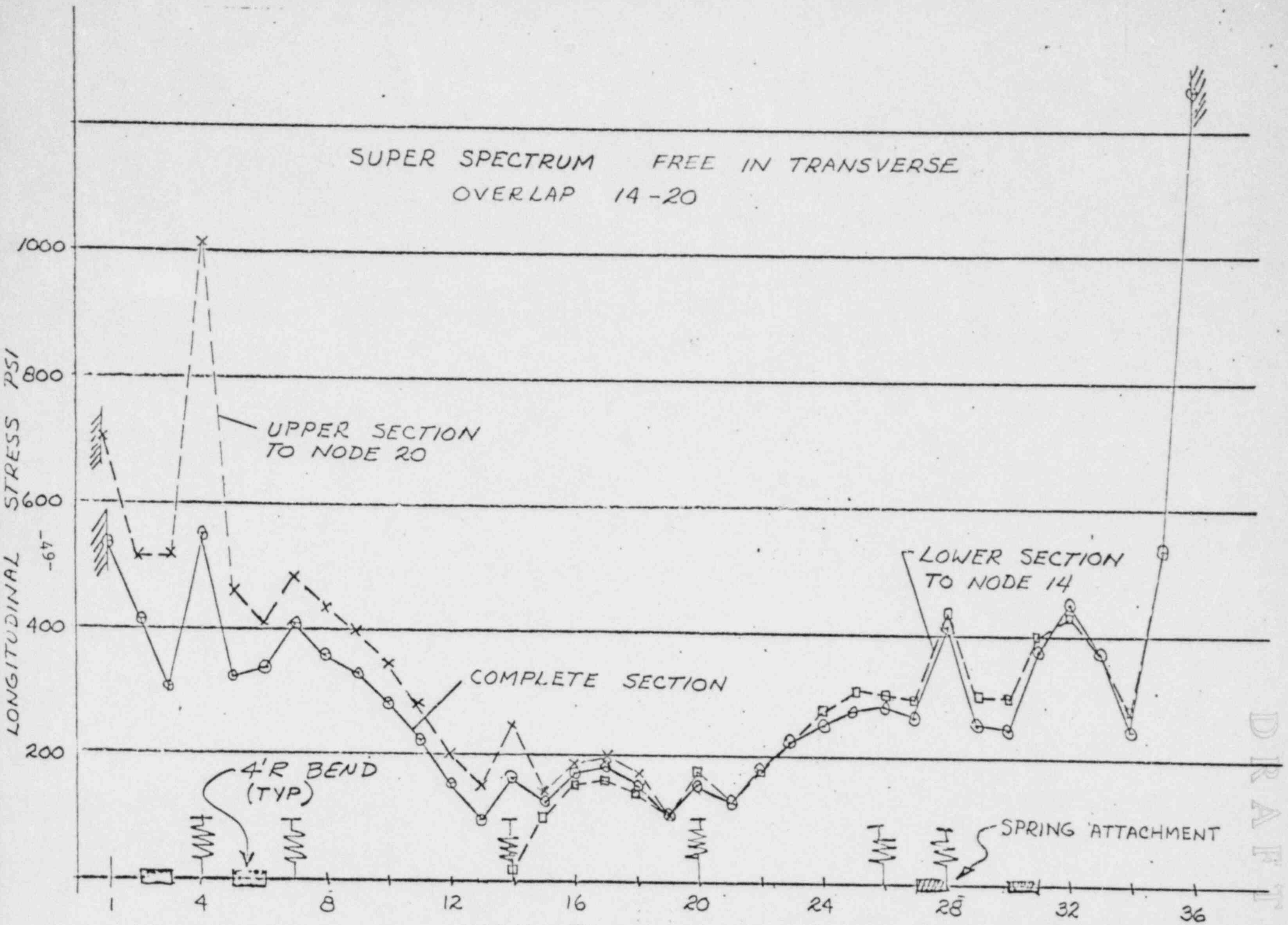
However, a closer examination of Figures 20 and 22 reveal some subtle differences. In both of these cases there are a few points at which the stresses in the full system exceed the stresses in the subsection. These differences are small, and so essential compliance has been accorded to the subsystem calculation for this case. These differences occur at nodes 32 and 36 for the Super Spectrum and at nodes 21 to 24 for the Small Spectrum. These differences may be due to the somewhat different frequency characteristics and the more substantial differences in the modal participation factors that result from the use of the subsystem method. The next section will consider this further.



-87-

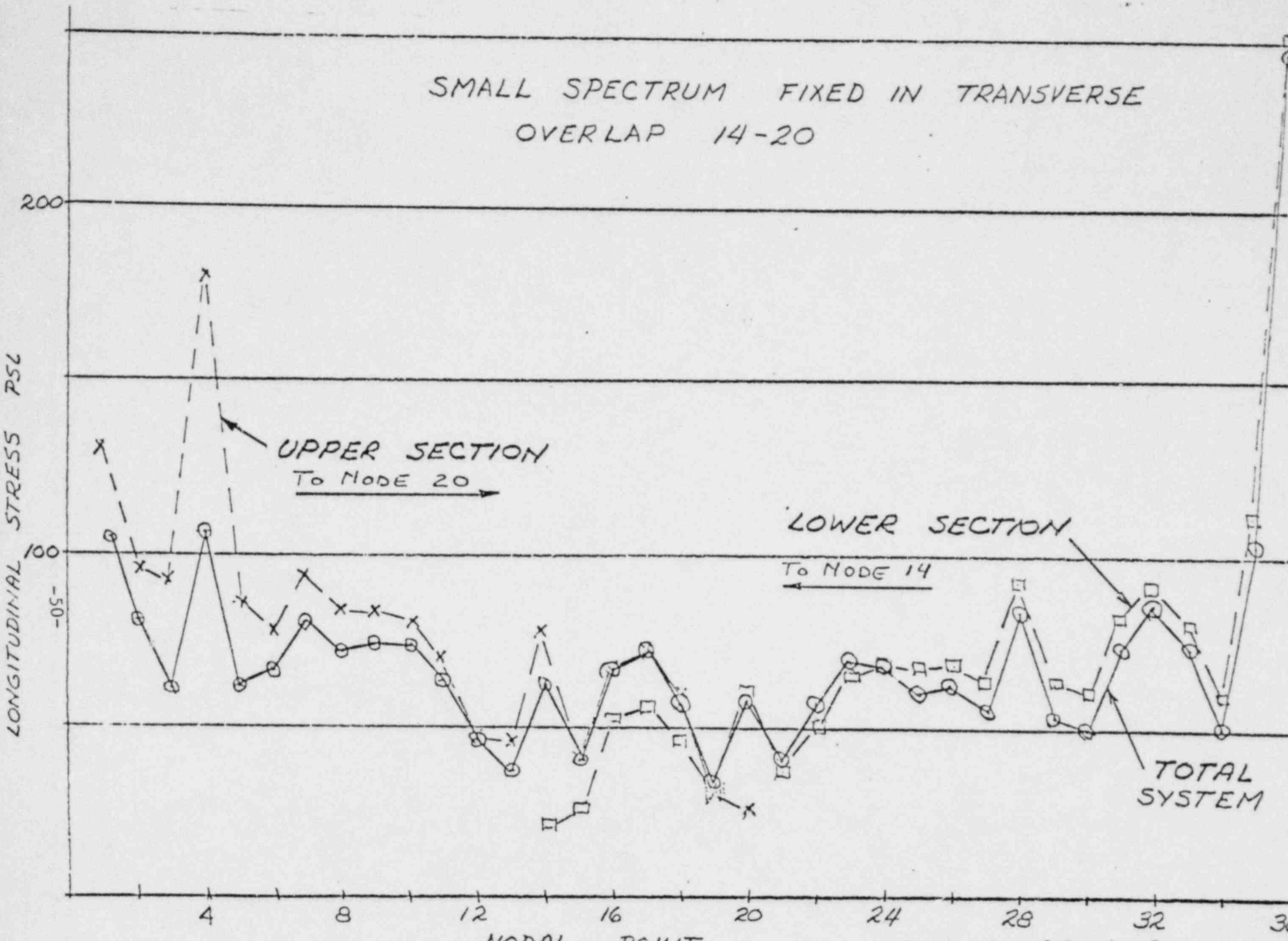
Combination of Section Stresses

FIGURE 20



Combination of Section Stresses

FIGURE 21



Combination of Section Stresses

FIGURE 22

These first three cases examined so far had the overlap region between nodes 14 and 20. This is a straight portion of the pipe. An additional case was taken for which the overlap region occurs between the supports at nodes 20 and 28. This includes a considerably bent portion which is three-dimensional. For this case, the analysis shows that the full section has a maximum stress that is now significantly greater that the corresponding stress in the subsystem. In fact, the entire portion of the pipe system between nodes 28 and 36 have the stress in the full section higher than for the subsection. Moving the overlap region in this case has resulted in the conclusion that the subsystem analysis is not conservative. For two different choices of the overlap region, the method has been shown to be either acceptable or not acceptable. Generically, stringent limitations should be imposed on the selection of the overlap region in those cases where the procedures is accepted.

The extent of the overlap region for the right hand portion was then increased. The overlap section was taken between the supports at node 7 to node 28. The results are shown in Figure 24. With the more extensive overlap region, the stresses in the subsection analysis are now greater than the stresses for the full system. This is in accordance with the results that were obtained from the three dimensional pipe bend in the last section.

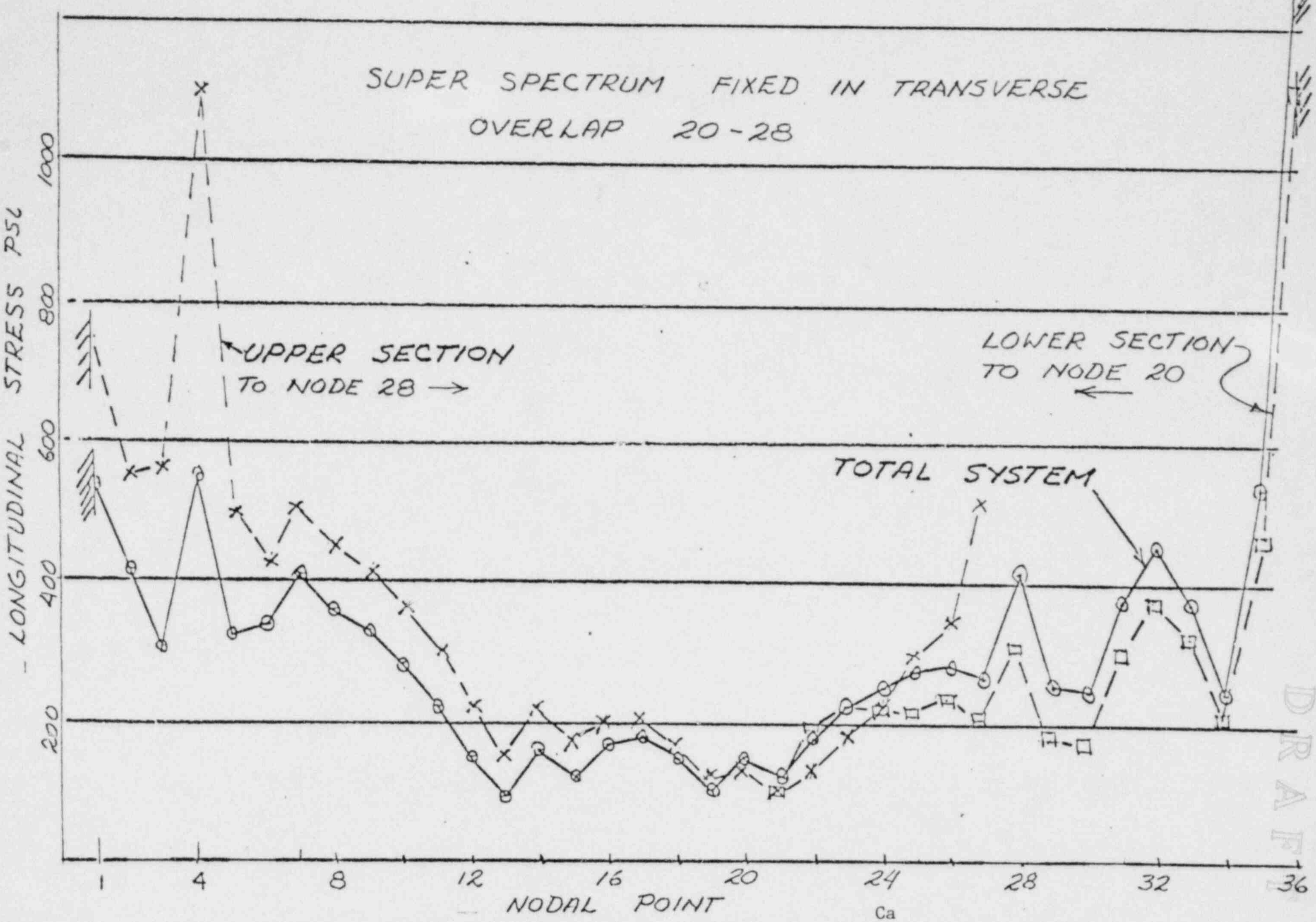

SUPER SPECTRUM FIXED IN TRANSVERSE
OVERLAP 20-28
- LONGITUDINAL STRESS PSI
1000
800
600
400
200
UPPER SECTION
TO NODE 28 →
LOWER SECTION
TO NODE 20 ←
TOTAL SYSTEM
1
4
8
12
16
20
24
28
32
36
NODAL POINT

FIGURE 23

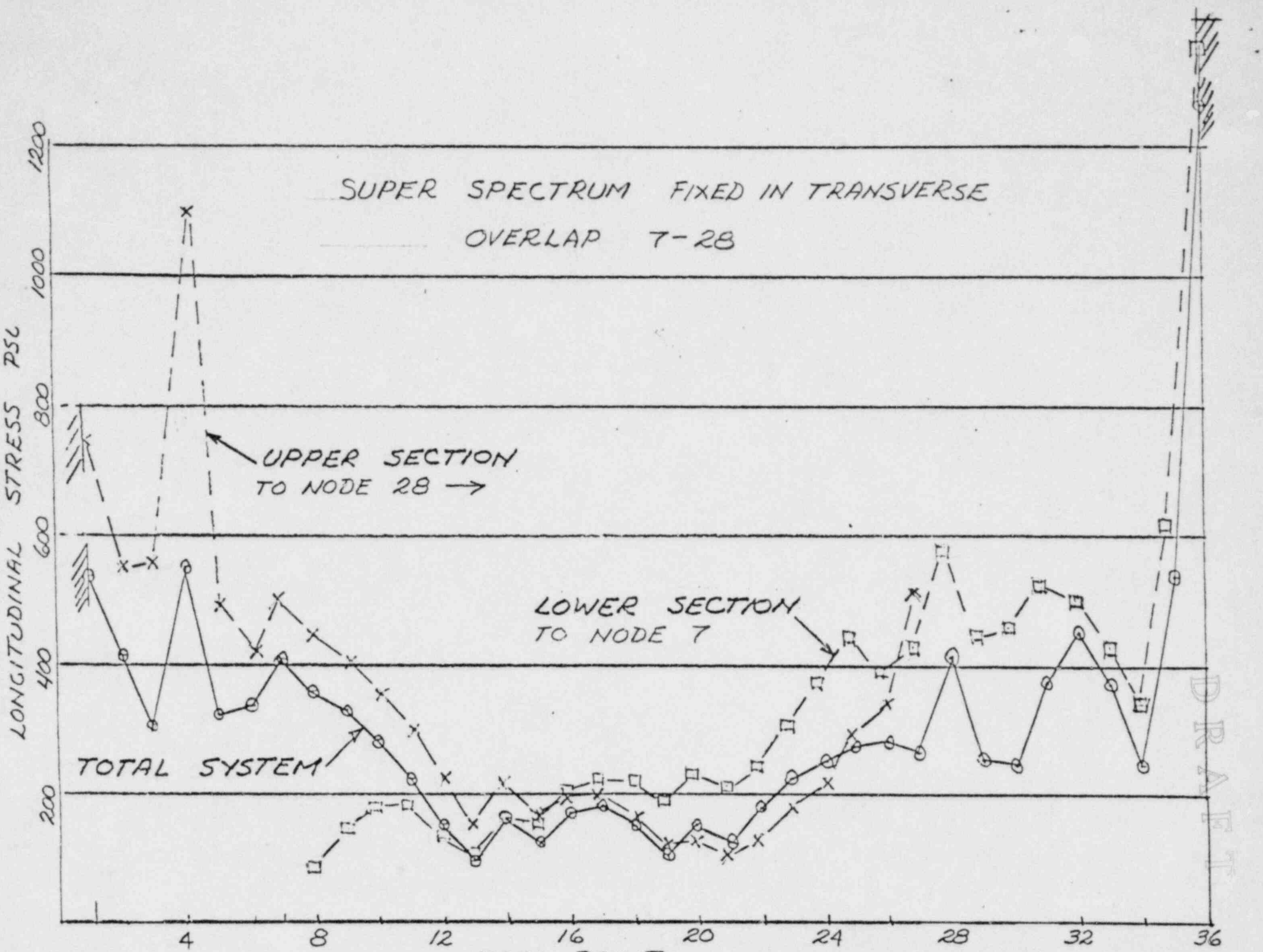

SUPER SPECTRUM FIXED IN TRANSVERSE
OVERLAP 7-28
UPPER SECTION
TO NODE 28 →
LOWER SECTION
TO NODE 7
TOTAL SYSTEM
LONGITUDINAL STRESS PSI
200
400
600
800
1000
1200
4
8
12
16
20
24
28
32
36
NODAL POINT
DRAFT

FIGURE 24

Different Spectra at Different Levels of Pipe

The previous section uses an actual piping run which extends vertically to join portions of a system at two different elevations. The spectra at these different levels are generally not the same. At the lower end (equipment level) the spectrum is frequently lower then at the upper and (operations level). This is because of the excitation of the structure which supports both ends of the pipe.

This section uses an equipment level spectrum and an operations level spectrum applied to the piping run shown in Figure 19. A comparison is made of the results that are obtained by using the different spectra in a subsystem analysis.

Tables 9 and 10 list the spectra that were used at the equipment level and at the operations level. These are plotted in Figures 25 and 26. A response output was obtained for the full system if each of these spectra were applied to the entire system.

The pipe system was divided up so that the overlap region extends between nodes 14 to 20. The previous section showed that the subsection method would give essentially acceptable results for this choice of the overlap region. The equipment level spectrum was applied to the lower section (between nodes 14-36). The results are plotted in Figure 27 together with the results for the total system excited by the same spectrum. For this case, the subsystem is consistently somewhat lower than the results for the total system.

The operations level spectrum was applied to the upper portion of the piping. Figure 28 shows a comparison of the results. For this plot, the operations level spectrum is used for the upper section as well as for the full system while the equipment level spectrum is used for the lower section.

Table 9

SPECTRUM TABLE (MODIFIED HFBR EQUIPMENT LEVEL SPECTRUM

NUMBER OF POINTS = 50
SCALE FACTOR = .38600E+03

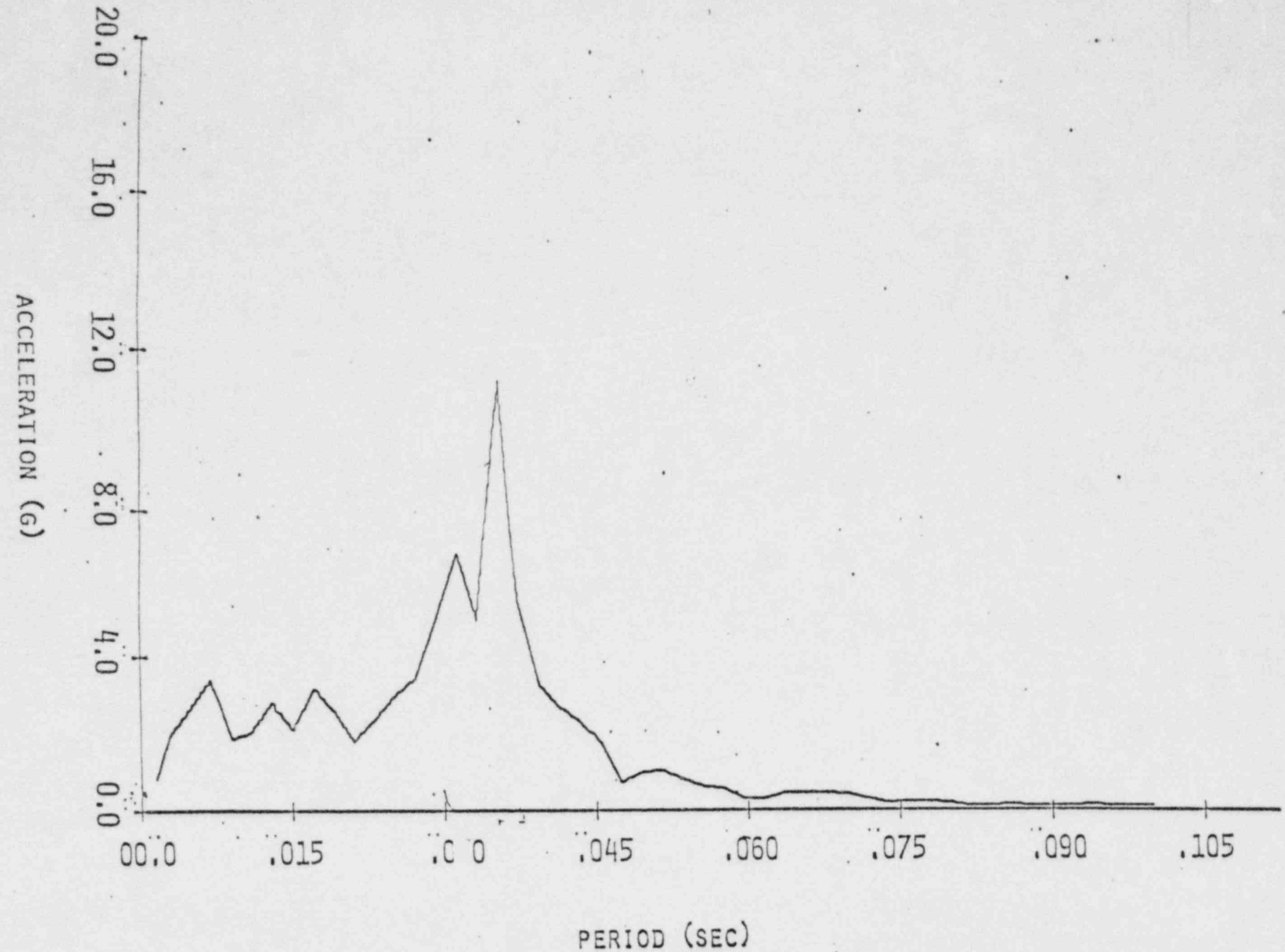
INPUT POINT	PERIOD	SPECTRUM VALUE
1	.1000E-02	.5260E+00
2	.3000E-02	.2005E+01
3	.5000E-02	.2624E+01
4	.7100E-02	.3381E+01
5	.9100E-02	.1866E+01
6	.1110E-01	.2087E+01
7	.1310E-01	.2783E+01
8	.1510E-01	.2121E+01
9	.1720E-01	.3166E+01
10	.1920E-01	.2615E+01
11	.2120E-01	.1838E+01
12	.2320E-01	.2413E+01
13	.2520E-01	.3009E+01
14	.2730E-01	.3462E+01
15	.2930E-01	.4991E+01
16	.3130E-01	.6858E+01
17	.3330E-01	.5048E+01
18	.3530E-01	.1138E+02
19	.3740E-01	.5568E+01
20	.3940E-01	.3285E+01
21	.4140E-01	.2719E+01
22	.4340E-01	.2371E+01
23	.4540E-01	.1833E+01
24	.4750E-01	.7730E+00
25	.4950E-01	.1049E+01
26	.5150E-01	.1099E+01
27	.5350E-01	.8380E+00
28	.5560E-01	.6370E+00
29	.5760E-01	.5900E+00
30	.5960E-01	.3270E+00
31	.6160E-01	.3340E+00
32	.6360E-01	.4660E+00
33	.6570E-01	.4670E+00
34	.6770E-01	.4830E+00
35	.6970E-01	.4230E+00
36	.7170E-01	.3030E+00
37	.7370E-01	.2030E+00
38	.7580E-01	.2420E+00
39	.7780E-01	.2230E+00
40	.7980E-01	.1900E+00
41	.8180E-01	.1320E+00
42	.8380E-01	.1270E+00
43	.8590E-01	.1420E+00
44	.8790E-01	.1390E+00
45	.8990E-01	.1190E+00
46	.9190E-01	.1280E+00
47	.9392E-01	.1430E+00
48	.9600E-01	.1160E+00
49	.9800E-01	.1170E+00
50	.1000E+00	.1240E+00

Table 10

SPECTRUM TABLE (MODIFIED HFER OPERATIONS LEVEL SPECTRUM

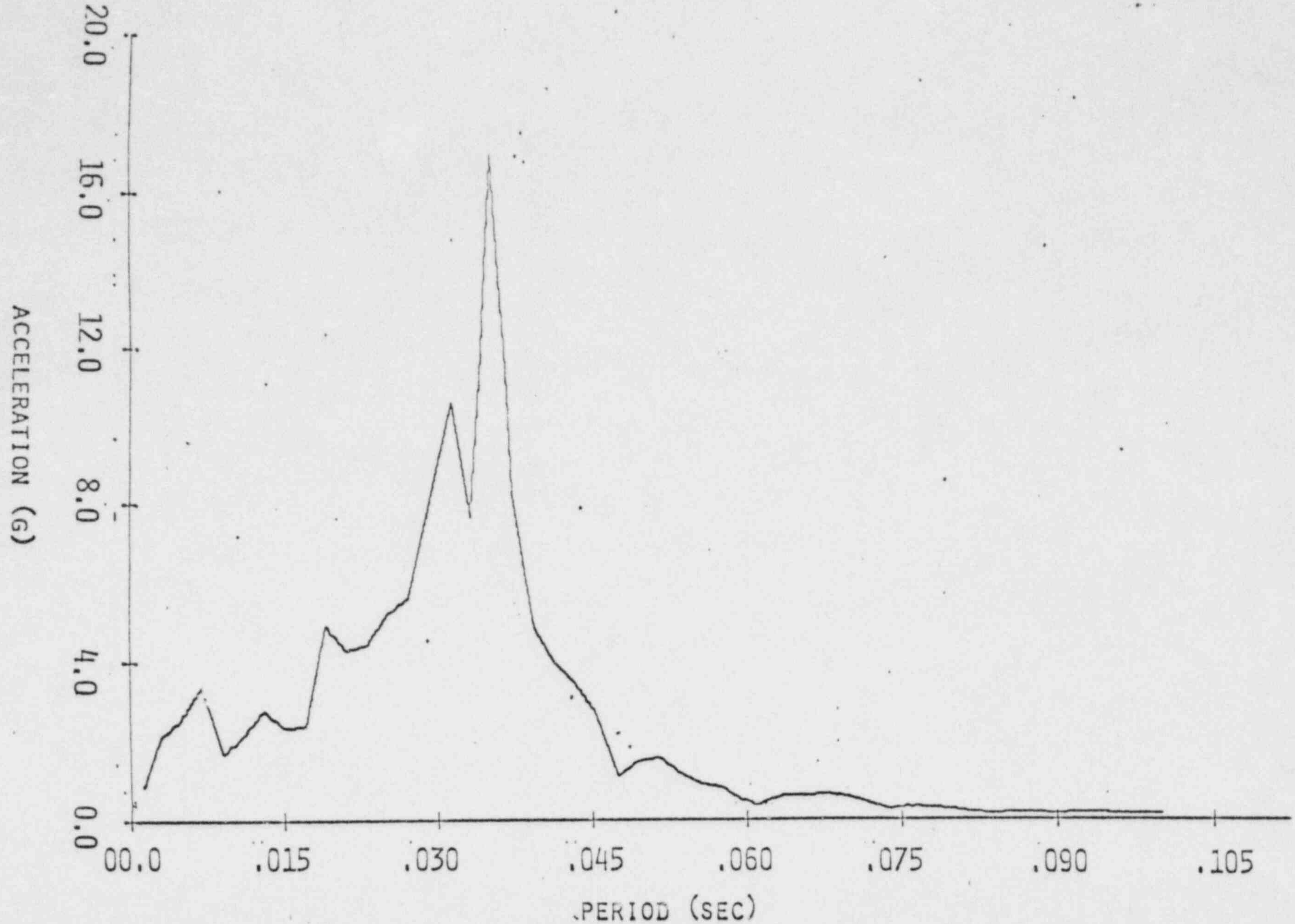
NUMBER OF POINTS = 50
SCALE FACTOR = .38600E+03

INPUT POINT	PERIOD	SPECTRUM VALUE
1	.1000E-02	.7370E+00
2	.3000E-02	.2107E+01
3	.5000E-02	.2561E+01
4	.7100E-02	.3356E+01
5	.9100E-02	.1689E+01
6	.1110E-01	.2174E+01
7	.1310E-01	.2762E+01
8	.1510E-01	.2372E+01
9	.1720E-01	.2400E+01
10	.1920E-01	.4923E+01
11	.2120E-01	.4286E+01
12	.2320E-01	.4458E+01
13	.2520E-01	.5193E+01
14	.2730E-01	.5658E+01
15	.2930E-01	.7902E+01
16	.3130E-01	.1059E+02
17	.3330E-01	.7667E+01
18	.3530E-01	.1708E+02
19	.3740E-01	.8264E+01
20	.3940E-01	.4847E+01
21	.4140E-01	.3952E+01
22	.4340E-01	.3426E+01
23	.4540E-01	.2665E+01
24	.4750E-01	.1139E+01
25	.4950E-01	.1500E+01
26	.5150E-01	.1584E+01
27	.5350E-01	.1208E+01
28	.5560E-01	.9140E+00
29	.5760E-01	.8300E+00
30	.5960E-01	.4830E+00
31	.6160E-01	.4930E+00
32	.6360E-01	.6590E+00
33	.6570E-01	.6460E+00
34	.6770E-01	.6860E+00
35	.6970E-01	.6000E+00
36	.7170E-01	.4370E+00
37	.7370E-01	.2990E+00
38	.7580E-01	.3440E+00
39	.7780E-01	.3110E+00
40	.7980E-01	.2640E+00
41	.8180E-01	.1830E+00
42	.8380E-01	.1760E+00
43	.8590E-01	.1970E+00
44	.8790E-01	.1990E+00
45	.8990E-01	.1780E+00
46	.9190E-01	.1890E+00
47	.9390E-01	.2080E+00
48	.9600E-01	.1660E+00
49	.9800E-01	.1670E+00
50	.1000E+00	.1760E+00



MODIFIED HFBR SPECTRUM, EQUIPMENT LEVEL

FIGURE 25



MODIFIED HFBR SPECTRUM, OPERATIONS LEVEL

FIGURE 26

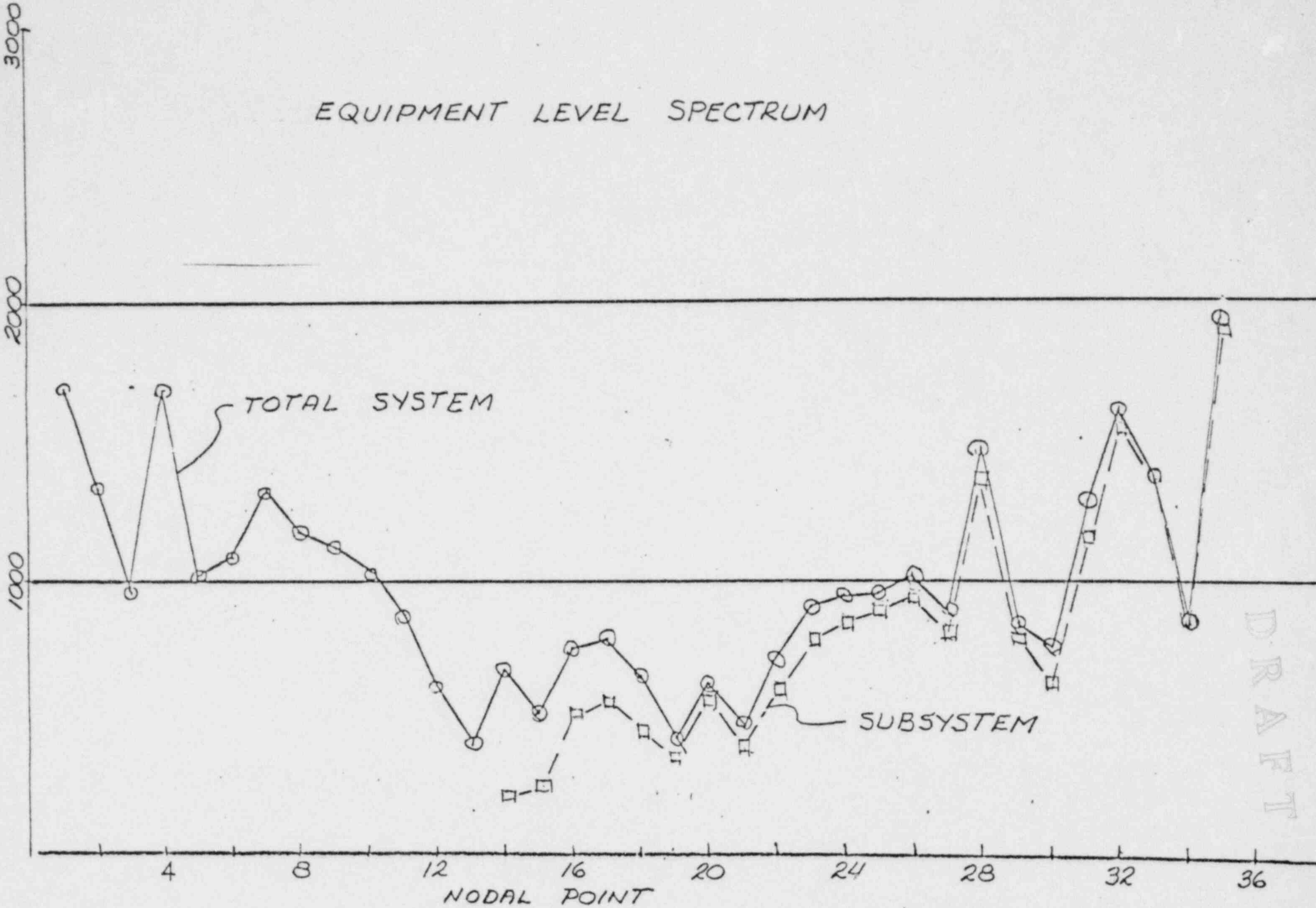

EQUIPMENT LEVEL SPECTRUM
3000
2000
1000
TOTAL SYSTEM
SUBSYSTEM
4
8
12
16
20
24
28
32
36
NODAL POINT

FIGURE 27

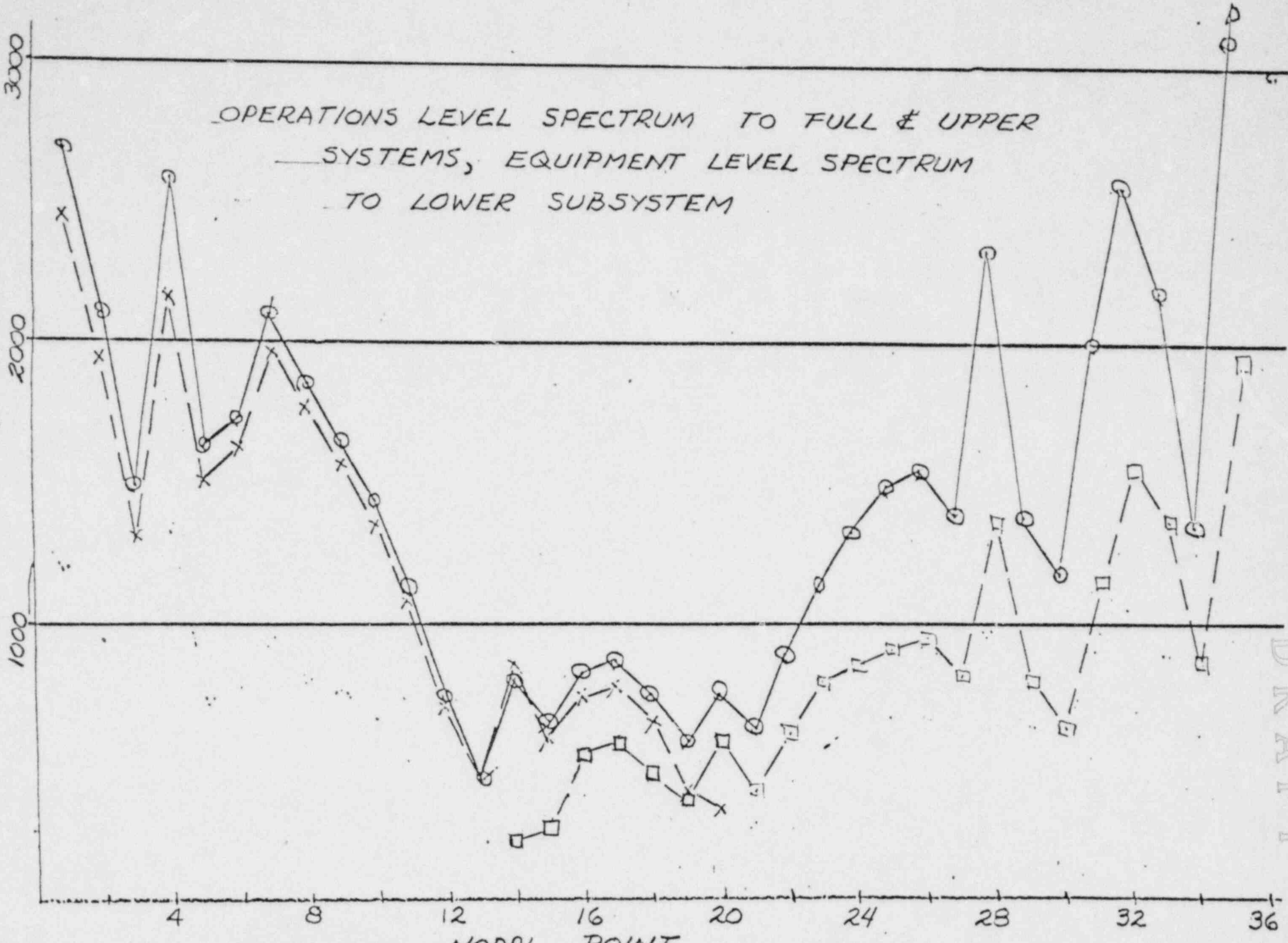

OPERATIONS LEVEL SPECTRUM TO FULL & UPPER
SYSTEMS, EQUIPMENT LEVEL SPECTRUM
TO LOWER SUBSYSTEM
3000
2000
1000
4
8
12
16
20
24
28
32
36
NODAL POINT

FIGURE 28

The stress level in the full system exceeds the subsystem stress levels at all nodes. If the lower portion is excited by the operations level spectrum, the stress levels are raised but are still slightly lower than the stresses in the full section. This is shown in Figure 29.

In the previous section, it was noted from Figure 20 that the subsystem approach gave stresses that were equal to or greater than the stresses calculated from the full systems. This was the case for two different spectra that were applied and are shown in Figures 19 and 21. In this section, with a differently shaped spectrum, but with the same overlap region, opposite results are obtained. The subsystem method now underestimates the stresses in the system. This change in the approximating ability of the subsystem method depends upon the shape of the input spectrum as well as the frequency shift caused by the subsystem method.

To examine this further, the dynamic characteristics of the piping system shown in Figure 19 were obtained. These are listed in Tables 11, 12 and 13.

Regulatory Guide 1.122 provides smoothing guidance for developing floor design response spectra. To account for variations in the structural frequencies owing to uncertainties in such parameters as material properties of the structure and soil, damping values and the approximations in the modeling techniques used in seismic analysis, the computed floor response spectra from the floor time histories should be smoothed and the peaks associated with each of the structural frequencies broadened. This requirement for floor response spectra was used to emphasize some of the response differences that could develop in modeling a system, unless care is taken in limiting the choice of the model.

A natural frequency of the full system is seen to be in the vicinity of the peak of the operations level spectrum. If this peak is broadened as shown in Figure 30, it will cover this natural frequency. If this new, smoothed spectrum is used in the subsystem analysis, and applied to all subsections as well as to the full system, the results show an even greater disparity between the two methods.

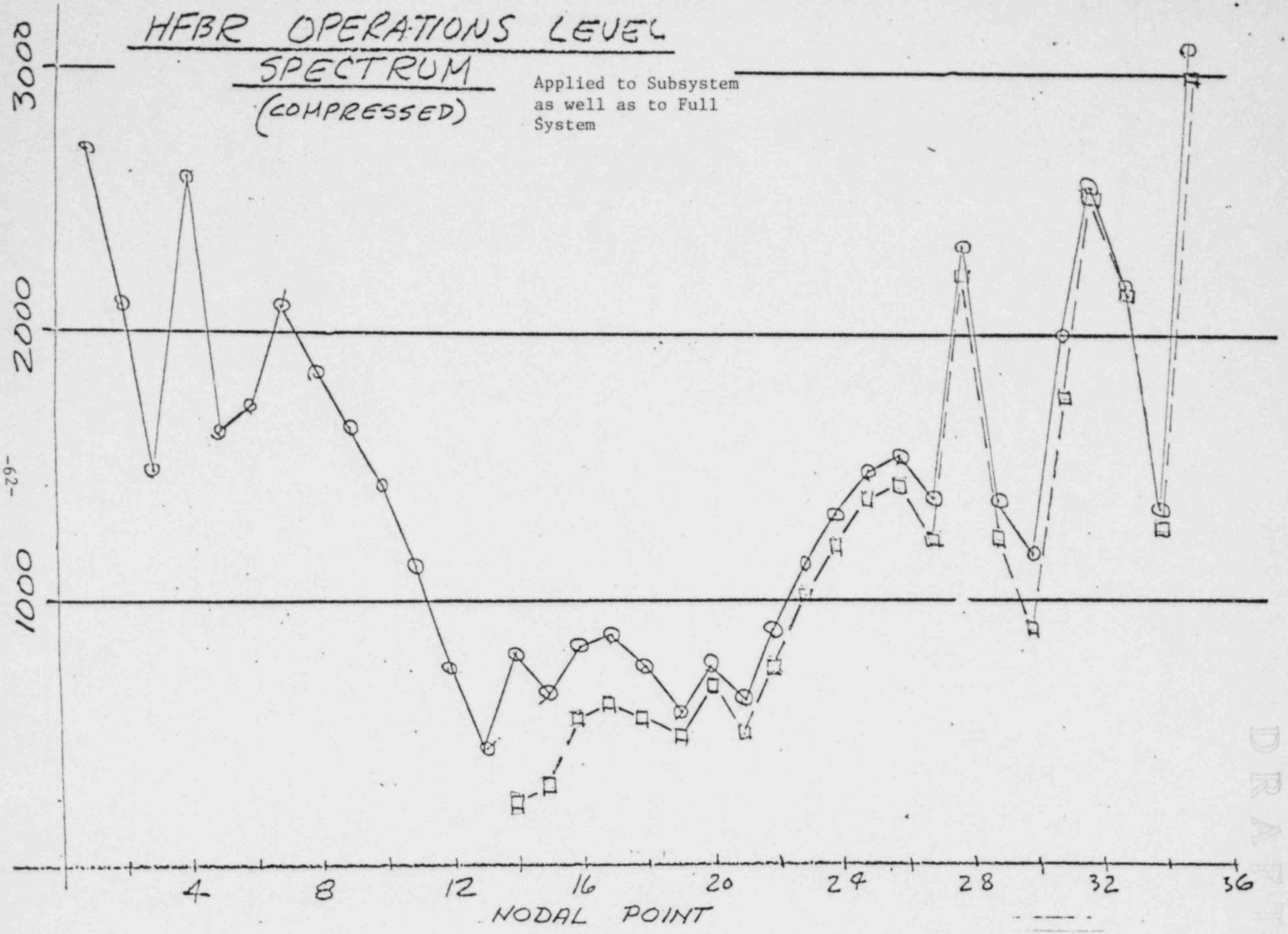

HFBR OPERATIONS LEVEL
SPECTRUM
(COMPRESSED)
Applied to Subsystem
as well as to Full
System
3000
2000
1000
4
8
12
16
20
24
28
32
36
NODAL POINT

FIGURE 29

Table 11

CASE I, COMPLETE PIPELINE, SUPER SPECTRUM

PRINT OF FREQUENCIES

MODE NUMBER	CIRCULAR FREQUENCY (RAD/SEC)	FREQUENCY (CYCLES/SEC)	PERIOD (SEC)	MODE	MODAL PARTICIPATION FACTORS X-DIRECTION	Y-DIRECTION	Z-DIRECTION
1	.1607E+03	.2557E+02	.3910E-01	1	-.9521E+00	.4923E+01	-.7680E+00
2	.2214E+03	.3523E+02	.2838E-01	2	.3209E-01	.5403E+00	-.4867E+01
3	.2343E+03	.3730E+02	.2681E-01	3	-.2318E+01	-.3517E+00	.2720E+01
4	.2402E+03	.3822E+02	.2616E-01	4	-.7694E+00	.8066E+01	.6551E+00
5	.4073E+03	.6483E+02	.1543E-01	5	-.2560E+01	-.1539E+01	.2074E+00
6	.4400E+03	.7003E+02	.1428E-01	6	.1722E+01	.2094E+01	-.1722E+00
7	.4698E+03	.7478E+02	.1337E-01	7	-.1134E+01	-.2789E+00	-.1042E+01
8	.5089E+03	.8099E+02	.1235E-01	8	-.2069E+01	.1642E+00	.2834E+01
9	.5371E+03	.8548E+02	.1170E-01	9	-.1900E+01	-.2166E+00	-.2408E+01
10	.5492E+03	.8741E+02	.1144E-01	10	.2447E+01	.9168E-02	.1475E+01
11	.5781E+03	.9200E+02	.1087E-01	11	.1077E+01	.9940E-01	.3205E+00
12	.6503E+03	.1035E+03	.9662E-02	12	-.1207E+00	.9670E-01	.6082E+01
13	.6839E+03	.1088E+03	.9186E-02	13	-.6582E+01	-.1423E+00	-.6840E+00
14	.8020E+03	.1276E+03	.7834E-02	14	-.7899E+00	-.2588E-02	.6397E+00
15	.8247E+03	.1313E+03	.7619E-02	15	-.2063E+01	-.1309E+00	-.2429E+00

Table 12

CASE II, UPPER SECTION ONLY, SUPER SPECTRUM

PRINT OF FREQUENCIES

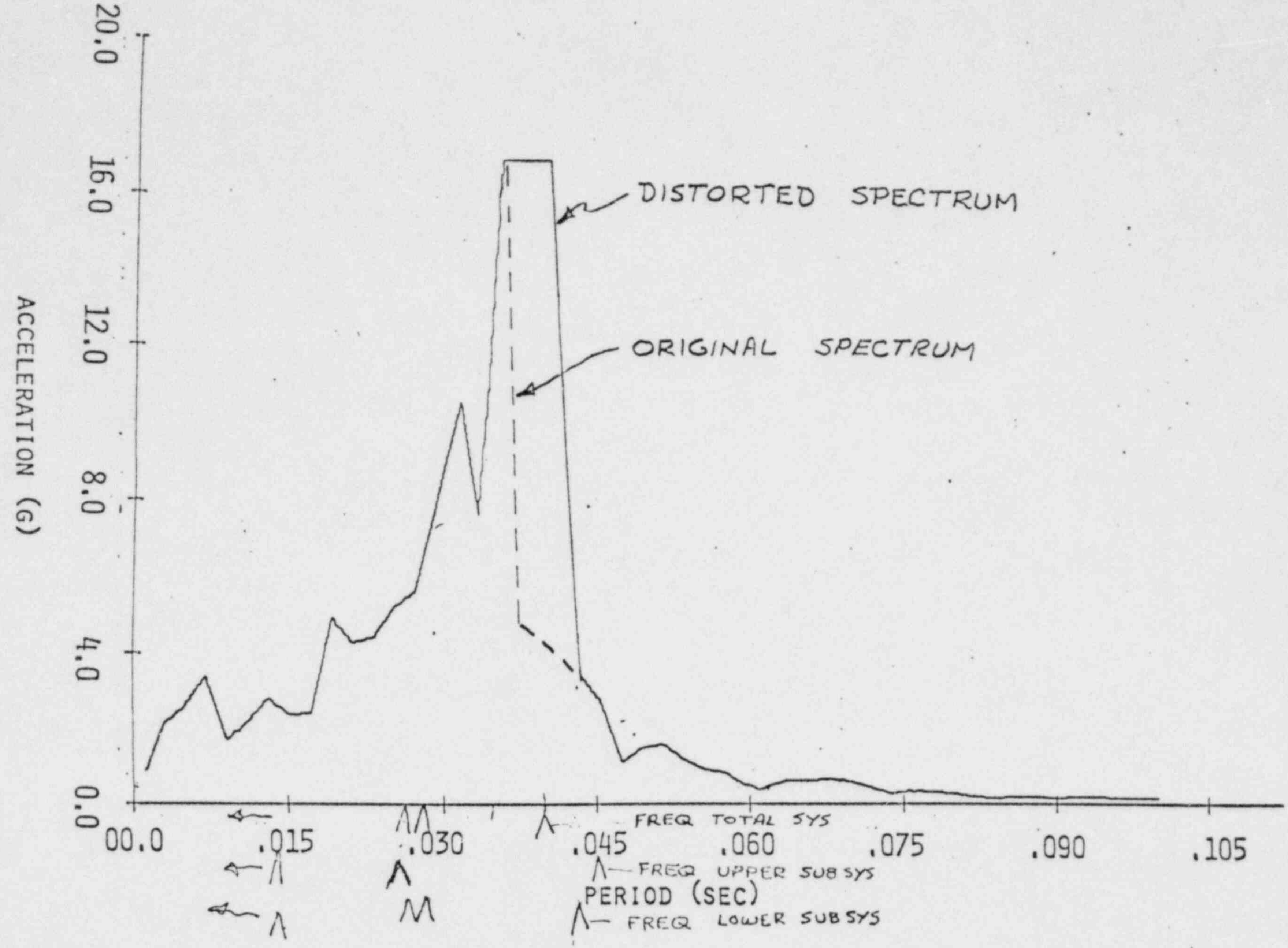
MODE NUMBER	CIRCULAR FREQUENCY (RAD/SEC)	FREQUENCY (CYCLES/SEC)	PERIOD (SEC)	MODAL PARTICIPATION FACTORS MODE	X-DIRECTION	Y-DIRECTION	Z-DIRECTION
1	.1379E+03	.2195E+02	.4555E-01	1	.1994E+00	-.7068E+01	.1787E+00
2	.2338E+03	.3721E+02	.2687E-01	2	-.2350E+01	-.3480E-02	.2640E+01
3	.4696E+03	.7474E+02	.1338E-01	3	-.1353E+01	-.1336E-01	-.1236E+01
4	.5130E+03	.8165E+02	.1225E-01	4	.1328E+01	-.2729E-02	-.1553E+01
5	.5503E+03	.8758E+02	.1142E-01	5	-.2238E+01	-.1042E+00	-.1521F+01
6	.6270E+03	.9979E+02	.1002E-01	6	-.1121E+01	.3122E-01	.5501E+01
7	.6420E+03	.1022E+03	.9786E-02	7	.5665F+01	.3919E-01	.1845E+01
8	.8013E+03	.1275E+03	.7841E-02	8	.7168E+00	.5126E-02	-.6681E+00
9	.9993E+03	.1590E+03	.6287E-02	9	.3895E+00	-.2091E+01	.3717E+0[illegible]
10	.1191E+04	.1896E+03	.5276E-02	10	.1233E+00	-.1588E+01	.8912E-01
11	.1291E+04	.2055E+03	.4867E-02	11	.9343E+00	-.1625E-01	-.1117E+01
12	.1312E+04	.2089E+03	.4788E-02	12	-.9932E+00	-.1180F+01	-.8895E+00
13	.1412E+04	.2246E+03	.4451E-02	13	-.1462E+01	-.9409E+00	-.1207E+01
14	.1451E+04	.2310E+03	.4329E-02	14	-.1199E+01	.2741E-01	.1510E+01
15	.1553E+04	.2472E+03	.4045E-02	15	-.2749E+00	-.1872E+00	-.3699F+00

Table 13

CASE IV, LOWER SECTION ONLY, SUPER SPECTRUM

PRINT OF FREQUENCIES

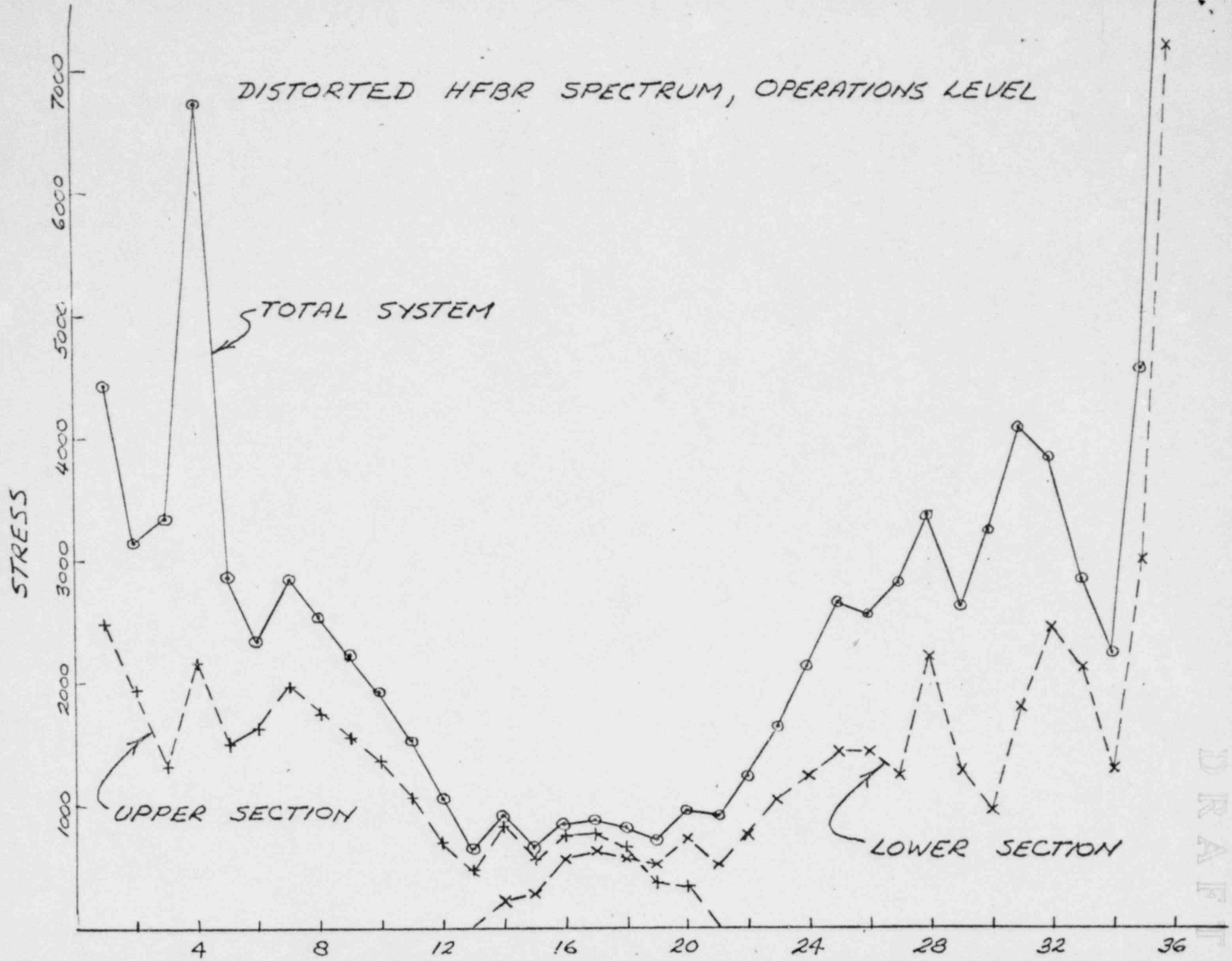
MODE NUMBER	CIRCULAR FREQUENCY (RAD/SEC)	FREQUENCY (CYCLES/SEC)	PERIOD (SEC)	MODAL PARTICIPATION FACTORS			
				MODE	X-DIRECTION	Y-DIRECTION	Z-DIRECTION
1	.1452E+03	.2311E+02	.4328E-01	1	.9497E+00	-.3269E+01	.6523E+00
2	.2214E+03	.3523E+02	.2836E-01	2	.6098E-01	.6797E+00	-.4900E+01
3	.2439E+03	.3882E+02	.2576E-01	3	-.7457E+00	.7191E+01	.6272E+00
4	.4083E+03	.6498E+02	.1539E-01	4	-.2421E+01	-.1269E+01	.3160E+00
5	.4512E+03	.7181E+02	.1393E-01	5	.1965E+01	.2250E+01	.6526E-01
6	.5179E+03	.8243E+02	.1213E-01	6	.3556E+00	-.2495E+00	-.2789E+01
7	.5568E+03	.8862E+02	.1128E-01	7	-.6364E+00	-.1625E+00	-.4071E+00
8	.5946E+03	.9463E+02	.1057E-01	8	.8618E-01	-.1174E+00	-.4736E+01
9	.6596E+03	.1050E+03	.9526E-02	9	-.5994E+01	-.1917E+00	-.2722E+00
10	.9758E+03	.1553E+03	.6439E-02	10	-.3776E+01	-.5619E-01	.2340E+00
11	.1057E+04	.1681E+03	.5947E-02	11	-.6175E+00	-.3191E+00	.2169E+00
12	.1100E+04	.1751E+03	.5710E-02	12	.8397E+00	-.1051E+01	.1318E+01
13	.1107E+04	.1762E+03	.5676E-02	13	-.7972E+00	-.2064E+01	-.7557E+00
14	.1146E+04	.1824E+03	.5481E-02	14	.9021E+00	-.7041E-01	-.2426E+01
15	.1362E+04	.2168E+03	.4613E-02	15	-.2838E+00	-.3584E-01	-.1378E+00



DISTORTED MODIFIED HFBR SPECTRUM, OPERATIONS LEVEL

FIGURE 30

The results are shown in Figure 31. It is seen that the subsystem method in this case substantially underestimates the stresses induced in the full system. The shape of the spectrum relative to the natural frequencies of the system and subsystems influences the comparison between the subsystem and full system stresses.



NODE PT

FIGURE 31