NUREG/CR-4291
BNL-NUREG-51897

CONCLUSION AND SUMMARY REPORT ON PHYSICAL BENCHMARKING OF PIPING SYSTEMS

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Date Published — June 1985

DEPARTMENT OF NUCLEAR ENERGY, BROOKHAVEN NATIONAL LABORATORY
UPTON, NEW YORK 11973

Prepared for the U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Contract No. DE-AC02-76CH00016

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AN, RM

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STRUCTURAL ANALYSIS DIVISION
DEPARTMENT OF NUCLEAR ENERGY
BROOKHAVEN NATIONAL LABORATORY
UPTON, NEW YORK 11973

Prepared for
OFFICE OF NUCLEAR REGULATORY RESEARCH
UNITED STATES NUCLEAR REGULATORY COMMISSION
WASHINGTON D.C. 20555
FIN A-3225

ABSTRACT

Physical benchmark evaluations were used to assess the accuracy and adequacy of the analysis methods and assumptions used in typical piping qualification evaluations. Physical benchmark evaluations have been completed for six systems involving both laboratory and in situ tested piping. In each evaluation elastic finite element methods were used to predict the time history response of a system for which physical test results were available. In the analytical simulations the measured support excitations and the measured damping properties were used as input and the acceleration and displacement response of piping interior points were predicted as output. The linear analysis methods were found to provide reasonable estimates of system response. For a near linear system and using conservative estimates for system damping, a good correlation of response traces and acceptable estimates of response peaks can be expected. Using realistic estimates of uniform system damping, large underestimates of peak response components were observed and deviations of 100% or greater should be expected.

EXECUTIVE SUMMARY

Over the past years a program has been underway at Brookhaven National Laboratory (BNL) to evaluate the analysis methods used by industry to qualify nuclear power plant piping. One element of this program has been the development of physical benchmark solutions for piping systems tested under other programs. The basic premise of this effort is that the relative accuracy of computational methods can be gauged by the direct comparison of physical test results to the analytical predictions of those results. A total of six evaluations have been performed under this program. These have included simple and complex laboratory tested systems and in situ tested power plant systems. In all cases but one the evaluations were performed blind after the test programs, conducted by others, were completed.

The linear analysis methods were found to provide reasonable estimates of system response. The estimates of system natural frequencies were good being within 5% for the lowest modes and within 10% for the higher modes. The agreement between predicted and measured displacements and accelerations ranged from good to poor with the estimates for displacements being better. In a typical problem good correspondence would be achieved for many points but deviations of 100% or greater would be observed for other points. In these cases plausible explanations for the deviate behavior were advanced, but not tested. For accelerations, instances of consistent under- or overprediction were observed, with these effects ascribed to the damping assumption used in the analysis.

For some points in the various systems little or no correlation between predicted and measured response, or extreme deviations between these response traces, was observed. In the majority of cases, the deviate behavior was observed for points in the close proximity of supports. In those cases, the poor correlation was atrributed to postulated nonlinear characteristics of the support in question. Given the high incidence of this phenomenon less credence should be placed in linear estimates of support loads and affects. On average, these effects were local and did not compromise the validity of the linear estimates of gross system response.

In each evaluation an experimental estimate of uniform system damping was used. For each of the laboratory tested systems this assumed level of damping was later judged to be too large. In each of these evaluations, a general level of underprediction was observed with peak acceleration amplitudes being underestimated by as much as 100%. Although it was postulated that an adjustment of the damping assumption would correct this, the root cause of this deficiency should be established unequivocally. In any case, the relative high rate of underprediction observed should caution against the use of high estimates for system damping in performing analyses.

In summary, the linear analysis methods were found to provide reasonable estimates of system response. The estimates for system natural frequencies were good while the estimates for displacements and accelerations ranged from poor to good. For a near linear system and using conservative estimates for

system damping, good correlation of response traces and acceptable estimates of response peaks can be expected. Using realistic estimates of uniform system damping, large underestimates of peak response components were observed and deviations of 100% or greater should be expected.

ACKNOWLEDGEMENTS

The authors wish to thank Drs. John O'Brien and Mark Hartzman of the U.S. Nuclear Regulatory Commission for their assistance and support in this work. We would also like to thank Blake Johnson and William Walton of ANCO Engineers, Inc. who provided the bulk of the experimental data.

The assistance of Ms. Joan Murray and Ms. Liz Gilbert in typing this manuscript is also deeply appreciated.

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1.0 INTRODUCTION

The dynamic analysis of piping systems represents a major engineering effort in the safe design of nuclear power plants. Such analysis is typically performed using computer programs based on the finite element method, which consider the structure elastic over the entire deformation range. These computer programs can be used to predict the time history response of the system or to provide a conservative estimate of that response using the response spectrum method of analysis. The response spectrum method is normally used in the production analysis of power plant piping.

Over the past years a major program has been underway at Brookhaven National Laboratory (BNL) to evaluate the analysis methods used by industry to qualify nuclear power plant piping. This program has various elements including the development of analytical benchmark problems and solutions, the development of analysis methods, the evaluation of new and alternate analysis methods and the development of physical benchmarks.

Herein a detailed description of the last two evaluations in the physical benchmarking effort, as well as a summary description of the overall effort, will be provided. The basic premise of this effort is that the accuracy of computational methods can be gauged by the direct comparison of physical test results with the analytical predictions of those results. The evaluations have included simple and complex laboratory tested systems and actual power plant systems tested in situ. In all cases the evaluations were performed after the test programs, conducted by others, were completed.

At the outset of the effort it was decided that the evaluations should be performed, as nearly as possible, in the same fashion and with the same degree of foreknowledge as power plant piping system analyses are performed. That is, the analysis would be based on the as-built system dimensions and linearized system properties, input functions at all support points would be defined and linear response would be assumed. To assure that no foreknowledge of the measured response was factored in, each evaluation (except one) was performed blind with only the measured inputs provided at the time of analysis and the measured response data made available for comparison only after the analyses were complete. Further, after evaluation, no attempts to improve the results with refined analyses was undertaken.

The last two evaluations involved prototypical piping systems laboratory tested by ANCO Engineers, Inc. at their facility in Culver City, CA. The tests were conducted under the joint sponsorship of the USNRC and EPRI and were undertaken to expand the data base on damping in piping systems and to assess the design margins inherent in ASME Class 2 and 3 piping. The specific tests simulated involved a three-dimensional pipe run with no branches designated XEQ1C1 and a three-dimensional pipe run with branches designated XEQ3C2, each subjected to seismic like excitations. For test XEQ1C1 an independent evaluation of the blind prediction results was performed by EG&G Idaho prior

to the transmittal of test results to BNL. For test XEQ3C2 the measured results were transmitted to BNL only after the NRC program manager received the blind prediction results. For both tests the correspondence between measured and predicted results was considered fair. This report provides a description of these analyses with a comparison of the predicted and measured responses.

2.0 SYSTEM DESCRIPTION

2.1 Main Pipeline

This system consisted of 6 and 8 inch SCH 40 steel pipe routed in a multi-bend configuration and supported and excited by four hydraulic actuators as shown in Figure 1. The pipe run was approximately 70 feet long and contained 10 elbows, one simulated valve, two reducers and two welding neck flanges at the end points. The piping was designed and constructed to ASME code rules and specification using ASTM materials. A description of the material selection and fabrication processes and the overall test program are provided in Reference 1.

The pipe was supported at its end points, S1 and S4, and two intermediate points, S2 and S3, Figure 1. At the end points, each pipe flange was bolted to an actuator driven baseplate-carriage structure which was constrained and supported by a linear bearing assembly designed to allow motion in only one horizontal direction. The hydraulic actuator could impart preprogrammed seismic-like motions to the base plate. The two intermediate points were also supported from actuator driven carriages. At these points, however, the pipe was connected, both horizontally and vertically, to the carriage thru pin connected rigid strut elements clamped to the pipe. Figure 2 shows ANCO sketches of this support arrangement. These carriages were also constrained to move in one horiontal direction. The rigid struts were fabricated from 1-1/2 inch SCH 40 pipe.

A simulated valve was installed in the pipeline. The main body of the valve was made of hot finished steel tubing and was welded to the test pipe according to the ASME Code.

Instrumentation was attached to the piping and carriages to monitor accelerations, displacements, strains and forces. The instrumentation of interest to this effort were those monitoring displacements and accelerations, the locations of which are shown in Figure 3. As will be noted, accelerations were monitored in three directions at the end point carriages, but only in one direction at the two interior point carriages. Further, the measurement of only displacement inputs were made. The test records were digitized at 0.005 second intervals with a total record length of 30.0 seconds.

The test simulated was designated XEQ1C1. It involved uniform, seismic like excitations of all the actuators in the X direction. The inputs, although similar and nearly in phase, were not identical. The excitation level was chosen to produce stresses in the elastic range. An experimental estimate of the damping level during test was 4% with the system filled with water.

Computer generated time history traces of the input displacement and acceleration forcing functions for the test are shown in Figures 8 through 14. On each of these figures the upper curve is the input acceleration while the lower curve is the corresponding input displacement. Node number 1 corresponds to carriage S1, node 37 to S2, node 67 to S3 and node 87 to carriage S4. The accelerations depicted were all measured. Of the displacements

depicted, only the displacements in the X direction at carriages S1 and S4, node 1 and 87, were measured. The other displacement traces depicted were developed by numerically integrating and baseline correcting the corresponding measured acceleration function using the Trifunac methods in Reference 2. The acceleration of carriage S1 in the vertical or Z direction is not shown since it was a null trace. The peak input acceleration was in excess of 0.5 G;s for node 67X, at approximately 15.5 seconds. The amplitude of the accelerations in the directions perpendicular to the direction of excitation, Y and Z directions, were approximately 10% of the amplitude of the acceleration in the direction of excitation, X direction.

2.2 Main Pipeline with Branch Lines

This system consisted of a 6 inch and 8 inch SCH 40 steel main line and two 3 inch SCH 40 steel branch lines as shown in Figure 4. Each termination point ended in a welding neck flange which was bolted directly to an actuated carriage. All elbows, reducers and flanges were standard components. The simulated valve was retained and one carriage mounted intermediate support system with rigid struts, S2, was included. The intermediate support was similar to those used in the tests of the main pipeline shown in Figure 2. Again the piping was designed and constructed to ASME code rules and specifications uing ASTM materials.

As with the first pipeline, instrumentation was attached to monitor accelerations, displacements and strains. The locations of accelerometers and displacement transducers are shown in Figure 5. The input accelerations were monitored at each support point. Input displacements were monitored only at carriages 1 and 3, and then only in the X coordinate direction. The test records were digitized at 0.005 second intervals with a total record length of 30.0 seconds.

The test simulated was designated XEQ3C2. It involved near uniform, seismic-like excitations of all the actuators in the X direction. The excitation level was chosen to produce peak stresses in the elastic range. An experimental estimate of the damping level during test was 4% with the system filled with water.

Computer generated time history traces of the input displacement and acceleration forcing functions for the test are shown in Figures 31-44 with the acceleration shown in the upper curve and the displacement shown in the lower curve. The correspondence between node number and actuator is node 1-S1, node 30 and 31-S2, node 53-S3, node 72-S4 and node 87-S5. Of the displacement traces only those for actuators S1 and S3 in the X direction were measured. All other displacement traces were developed using the Trifunac methods. The peak input acceleration was essentially 1.0 G for node 30X at approximately 18 seconds. The accelerations in the direction of excitation (X) were two and ten times greater than the accelerations in the Y and Z directions.

3.0 ANALYSIS DESCRIPTION

3.1 Main Pipeline

The finite element model of the system is shown in Figure 6. It consists of 86 pipe elements and 87 nodes. The pipe support and input points were nodes 1, 37, 67 and 87. At nodes 1 and 87 the input acceleration and displacement in all three coordinate directions were defined. At nodes 37 and 67 only the input acceleration and displacement in the X coordinate direction, (the direction of excitation) were defined. Other node point locations correspond to the location of instrumentation and to design features.

The simulated valve is defined by nodes 54-59. The section properties of the included pipe elements were selected to duplicate the simulated valve. A concentrated mass of 94 pounds was included at node 59, the valve hat.

The support motions were all introduced to the respective support points through linear spring to ground elements. For the two end points, nodes 1 and 87, the associated spring stiffness was 1.0E + 12 lbs/in to simulate a rigid connection. For the two interior support points, nodes 37 and 67, the spring stiffnesses were 1.136 E+6 and 1.125 E+5 lbs/in respectively, chosen to simulate the extension characteristics of the rigid struts. At nodes 38 and 68 additional spring elements were introduced to simulate the vertical acting carriage mounted struts. These had assigned stiffnesses of 1.62 E+6 and 1.844 E+6 lbs/in.

For the analysis the independent support motion, modal superposition, time history algorithms in the BNL code PSAFE2, Reference 3, were used with a 10 mode approximation and an integration time step of 0.001 second. A uniform damping value of 4% was employed based on ANCO estimates from the test results. The response estimates were digitized on 0.025 second intervals.

A characteristic of the PSAFE2 methodology is that both the acceleration and displacement must be defined for each input point. The predicted response estimates are based on the algebraic summation of the response induced by each of these components. An advantage of this procedure is that, if both components are measured, they are used directly. A disadvantage is that, if only one component is measured, the second must be developed by numerical preprocessing.

The instrumentation of the input for this test was extensive but not complete. As mentioned under system description, the majority of the input displacements were not measured. For these the corresponding acceleration records were processed to develop input displacement records. Although these should simulate the actual inputs, they will not duplicate them, and this will be a source of error. Further, the instrumentation at the two interior carriages, S2 and S3, was even less comprehensive. At these points only the acceleration of the carriage in the direction of excitation was measured. The actual acceleration of the pipe in any of the three coordinate directions was not measured. At best, in the analysis, the estimate of pipe acceleration in the direction of excitation, at these points, is approximate and the acceleration in the vertical and other coordinate direction unknown. In the analysis,

the accelerations in the vertical direction (Z) at these points was set to a null record and the accelerations in the third coordinate direction (Y) were left undefined. Further the rotations at these boundary points were undefined while the rotations at the two terminal points, S1 and S4, were set to null records. The acceleration and displacement records used as input for this analysis are shown in Figures 8-14.

The analysis was performed blind. Only a description of the system and a definition of the input forcing functions were provided to BNL prior to analysis. When the analysis was completed, a record of the response estimates were transmitted to EG&G Idaho, Inc. for an independent assessment of the results. When that assessment was completed, the measured response data was provided for BNL review and inclusion in this report. A copy of the EG&G Idaho, Inc. letter report summarizing their assessment is included as Appendix A.

3.2 Main Pipeline With Branch Lines

The finite element model of the system is shown in Figure 7. It consists of 86 pipe elements and 89 nodes. the pipe support and input points were nodes 1, 30, 31, 53, 72 and 89. Points 30 and 31 correspond to the interior carriage S2, horizontal and vertical supports respectively. At nodes 1, 53, 72 and 87 the input acceleration and displacement in all three coordinate directions were defined. At nodes 30 and 31 the input acceleration and displacement in the X and Z coordinate directions, respectively, were defined. Other nodal points correspond to the location of instrumentation or system design features, with nodes 32-39 defining the simulated valve.

The support motions were introduced to the respective support points through linear spring to ground elements. For nodes 30 and 31 the associated spring stiffnesses were 1.158 E+5 and 1.700 E+6 lbs/in respectively to simulate the extension characteristics of the rigid struts. At all other points the associated spring stiffness was 1.0 E+12 lbs/in to simulate rigid connections.

Again the PSAFE2 code was used for the analysis with a 10 mode approximation, an integration time step of 0.001 second and uniform damping of 4%. The response estimates were digitized on 0.025 second intervals.

The instrumentation of the input for this test was essentially as comprehensive as that used in the main pipeline test. The accelerations at all input points, but only selected displacements, were monitored. Again for the interior carriage, S2, the pipe motions were not monitored directly. The acceleration and displacement records used as input for this analysis are shown in Figures 31 to 44.

The analysis was performed blind but in this instance EG&G Idaho, Inc. did not perform an assessment of the results. Instead when the analysis was complete a record of the response estimates were transmitted to the NRC Project Manager. On receipt the measured response data was forwarded to BNL.

4.0 ANALYSIS RESULTS

4.1 Main Pipeline

A listing of the predicted and experimental estimates of the natural frequencies for the Main Pipeline are presented in Table 1. The correspondence is very good through the seventh mode. Since the experimental estimates were determined using low excitation level, hammer tests it may be inferred that the analytical model is an adequate representation of the system for low level excitation.

Time history traces of the measured and predicted displacements, for the points monitored during the test, are shown in Figures 15-19. The time history traces of the measured and predicted accelerations, for the points monitored,are shown in Figures 20-30. On each of these figures the upper curve is the measured response while the lower curve is the predicted response, each plotted to the same scale. Each figure label indicates the pertinent node number and coordinate direction.

Considering displacements, the correspondence between predicted and measured results is fair. The curves exhibit similar character and dominant frequency content. Peaks align and the overall expansions and contractions are similar. The measured responses do exhibit greater high frequency content which is particularly evident at the earlier times. On average, the response predictions underestimate the measured responses. This appears to be true for both peak and averaged amplitudes. Further, the locations of maximum peaks do not coincide. Referring to Figures 18 and 19 the correlation seems better for the points on the 60 inch vertical run between S2 and S3. Referring to Figure 17 the correlation seems worst for this point at the elbow above S2. For this point the response was underpredited and the maximum disparity exhibited, expressed as a ratio, was 1.8 at 15 second.

A review of the acceleration time history traces, Figures 20-30, indicates that the correspondence between predicted and measured results is again only fair. For accelerations we do have results for each coordinate direction. If the results are reviewed by coordinate direction (Figures 20, 24 and 29 for Y, 23, 27 and 30 for Z and all others for X) it will be noted that the correspondence is worst for the Z or vertical direction and best for the X or direction of excitation. For the Z direction the predicted results all markedly underestimate the measured results. Other than frequency content, there appears to be little similarity between results for this direction. For the Y direction there is again a general level of underprediction but it is not as pronounced. General characteristics seem similar but maximum peaks do not correspond. Considering the X direction, the degree of correspondence is best with a general level of underprediction evident. For this direction absolute peaks agree well for three points, Figures 21, 25 and 26 and overestimates occur for three points Figures 22, 25 and 26. The worst disparity in acceleration occurs for point 29 in the Z direction at 15 seconds. Expressed as a ratio it was a 4.3 underestimation. This disparity, in fact, occurred for the peak measured acceleration for all points.

4.2 Main Pipeline With Branches

A listing of the predicted and experimental estimates of the natural frequencies for the Main Pipeline with Branches are presented in Table 2. The correspondence is good through the fifth mode and good for the eighth and ninth modes. The greatest discrepancy occurs for the sixth mode where the degree of correspondence is within 9%.

Time history traces of the measured and predicted displacements, for the points monitored during test, are shown in Figures 45-50. The time history traces of the measured and predicted acceleration are shown in Figures 51-63. All of these figures are presented in the same format as used for the Main Pipeline.

Referring to Figures 45-50 for displacements, the predicted responses range from underpredictions to overpredictions. The degree of correspondence is very poor for displacements in the Y direction, Figures 45-48. For these there is virtually no similarity between the predicted and measured response curves, with the predicted response providing large overpredictions. For displacements in the X direction the degree of correspondence is much better. For all points displacement correspondence is good from 2.5 to 12.5 seconds. Below 12.5 seconds the predicted results tend to exceed the measured results to a small degree. Above 12.5 seconds the trend reverses and the measured responses exceed the predicted responses and show higher frequency content. For one point 41 X (Figure 50) the correspondence is good over the entire time span. The maximum disparity expressed as a ratio is 4.9 overprediction for point 27 in the Y direction. For the direction of excitation, the maximum disparity ratio was 1.6 underprediction, at 16.5 seconds.

The predicted acceleration traces show little distinct correspondence with the measured acceleration traces. Expansion and contraction trends are not pronounced in either data set, making comparison difficult. Peaks correspond at times and do not at other times. Predicted amplitudes range from uniform overprediction to uniform underprediction but these trends do not appear to be direction orientated. Again the correspondence seems more consistent between 2.5 and 12.5 seconds. Above 12.5 seconds the measured traces show an increase in amplitude which is particularly evident in Figures 57 and 60 and also evident in Figures 51-53. Below 2.5 seconds many measured traces are surprisingly quiescent. The peak disparity ratio was 4.2 underprediction at 16 seconds for point 64 X (Figure 61). This disparity occurred for the peak measured acceleration for all points.

5.0 DISCUSSION OF RESULTS

5.1 Main Pipeline

As mentioned earlier, the results for the Main Pipeline were reviewed and assessed by EG&G Idaho. As theirs represents an independent, unbiased opinion, their observations and conclusions will be presented here.

"Some general observations and conclusions to this evaluation are:

1. The shapes of the corresponding plots are similar, but magnitudes are different. Frequency response comparisons, such as power spectral densities (PSD) or Fourier transforms, were not made because digitized BNL motions were not supplied.

2. In general, the displacement case comparisons are much closer than the acceleration comparisons.

3. Overall, experimental values range higher than the BNL values for both cases, exemplified by the high percentage underestimates by BNL.

4. The five peak evaluations give a clearer picture because this eliminates the time variable and enables point-by-point comparisons.

5. Based primarily on the overall underestimates of the peak response magnitudes, the BNL predictions are judged to be a "fair" estimate of the ANCO test data.

The variation in predicted and measured values may not necessarily be entirely due to the computer results. The tolerance on the reported experimental data is not known. In addition, the structural damping used for the analysis may have been higher than the actual damping present in the piping system. Since the computer code used a linear method of analysis, the small but inevitable nonlinearities inherent in any piping system could also make a contribution to the overall deviations in predicted and measured responses. The BNL predictions probably represent the state-of-the-art in computer predictions for piping system response today; thus it is recommended that an assessment be made as to why the motions were underestimated since this affects the design margins that would be present in a piping stress analysis."

BNL concurs entirely with the above and with the Idaho opinion that the predictions are judged to be only a fair representation of the test results. Damping level, non-linearites and the accuracy of the experimental data are all cited as contributors to the overall deviations. To these BNL would add the incompleteness of the measurement of the input forcing functions. At each point of excitation the acceleration and displacement of the pipe in all coordinate directions should have been monitored to assure optimum analysis simulation. The failure to monitor the actual pipe motions in all coordinate directions at the two interior carriage locations is felt to be particularly significant in this regard. Further, for a system such as this which exhibits three dimensional coupling some measurements of displacement response in the unexcited directions should have been made.

As a case in point it was noted that the accelerations in the vertical direction were all markedly under predicted. Vertical struts were attached to the interior carriages yet their inputs to the pipe was not monitored. It is reasonable to assume that some vertical excitation was introduced to the pipe at these locations. If they were significant, modeling them as null quantities, as was done in the analysis, could have contributed to the gross deviations observed for response in the vertical direction. Compounding this deficiency was the measured null amplitude of the vertical acceleration of carriage S1. Given the response results, it may be assumed that this instrument channel malfunctioned and a finite but unknown vertical input was introduced to the pipe at S1. Unfortunately, neither displacements nor accelerations in the vertical direction were monitored in the near vicinity of S1 and this supposition cannot be tested.

If only the results for the X coordinate direction (direction of excitation) are considered, the results would be judged good. The correlation between predicted and measured response is very good while a uniform level of underpredicted is evident. A somewhat different choice of uniform damping or the consideration of damping with frequency may have improved the amplitude correspondence. Alternately, owing to the three-dimensional coupling inherent in the system, a better definition of the vertical inputs may have provided the amplification of responses in the X and Y coordinate directions required. Had this physical benchmark evaluation been performed in a interactive fashion, these speculations could have been tested.

5.2 Main Pipeline With Branches

The response estimates for this evaluation are judged to be poor to fair. The correspondence between predicted and measured results are not as good as achieved for the Main Pipeline and again peak responses are grossly underpredicted. If the comparisons are limited to the first 12.5 seconds, the correspondence would be judged fair.

In this evaluation the poor correlation of results is felt to be primarily due to nonlinear characteristics inherent in the system. Many of the measured acceleration traces show a marked quiescence below 2.5 seconds and a distinct amplification above 12.5 seconds. This is most noticeable in the X coordinate direction but it is also evident in the other coordinate directions. The most extreme example of these characteristics is shown in Figure 60 for the acceleration of node 64 in the X coordinate direction. For this point there is a tenfold increase in response at 2.5 seconds and a two-or three-fold increase at 12.5 seconds. These changes are not evident in any of the input forcing function traces or in the predicted response traces. What caused these effects is not known but they may be associated with some nonlinear agent. For example, if a clearance gap existed at a input point, for low levels of excitation the clearance gap would not be traversed and the system would not experience the input. At a increased level of excitation, or due to a random impact, contact would be made and the system would experience a stepwise increase in input, which if large enough, would be maintained. Something similar to this seems to have occurred in the system at 2.5 seconds and again at 12.5 seconds. It may have been a clearance effect, but could also have

been a flange binding effect causing a stepwise decrease in damping. Since it is most evident at node 64, it was most likely associated with the inputs at S4 (node 72).

If the system were indeed responding in a stepwise linear fashion, the linear analysis method used would not provide reliable response estimates. At best, during a dwell period between ratcheting action, when the assumptions in the linear analysis prevailed, averaged response amplitudes might correspond but little correlation between the location of response peaks or the shape of response curves would be expected. This is the type of correspondence observed for the acceleration traces between 2.5 and 12.5 seconds.

If the comparison of results were restricted to the time span between 2.5 and 12.5 seconds the evaluation would be judged fair. The correspondence of displacement and acceleration in the X and Z directions is fair to good while the corresponce in the Y direction is poor. The peak acceleration would be underpredicted by 100%, but some adjustment of the uniform damping coefficient or the consideration of a variation of damping with frequency could correct that. The cause for the poor correlation in the Y direction is unknown. Possibly a close inspection of the predicted and measured system mode shapes would indicate a deficiency in the analytical model not evident from the natural frequencies.

6.0 SUMMARY OF PRIOR EFFORTS

This section details what has been learned from the physical benchmarking efforts at BNL. Including the two evaluations described in this report, a total of six physical benchmark evaluations have been performed under this program. Except as noted, each evaluation was performed blind. A summary description of the four earlier evaluations are presented below.

A. Z Bend

The Z Bend was the first system evaluated under this effort. It was a simple planar configuration of 4 inch SCH 40 steel pipe containing two bends and three straight lengths. It was supported from and excited by three independently acting hydraulic actuators designed to drive the pipe in the outplane direction. Concentrated masses, each weighing 100 pounds, were bolted to the pipe at four locations. Although the two end points actuators were fixed directly to the pipe, a clearance gap existed between the center actuator and the pipe.

This system was laboratory tested by ANCO Engineers, Inc. under an EPRI contract. The test was designated T1R1 and involved maximum responses to 70% of the yield levels. During the test each actuator was driven to produce a seismic-like displacement of the pipe-actuator attachment point. Although the motions at each attachment point were similar and in phase, they were not identical. The peak input displacement and acceleration were 0.27 inches and 1.23 G's respectively. Peak recorded accelerations in the planar (not excited) directions were 20% the acceleration in the outplane direction. The experimental estimate of system damping was 2% and this was used in the analytical simulation.

The response estimates for the Z Bend, both displacement and acceleration, were good at all points except for those in the near vicinity of the central actuator. Near the central actuator the predicted response showed the same characteristics as the measured response but peak response was underpredicted by a factor of two. This discrepancy was ascribed to the clearance gap at the central actuator which introduced nonliner effects.

B. Indian Point, Rigid Strut Support Configuration

The second evaluation was performed for a segment of the boiler feed system of the shutdown Indian Point Unit 1 Nuclear Power Plant. The line consists of 8 inch SCH 80 pipe extending from the biological shield wall to the upper drum of steam generator 13. The run is anchored at the shield wall and drum, contains an 8 inch swing check valve and was supported by 12 specially installed rigid struts.

The system was tested in situ under a cooperative program between ANCO Engineers, Inc. and EDS Nuclear, sponsored by EPRI. The test simulated was a snapback test designated S136R1Z and involved a snapback force of 4200 lbs applied in the Z direction at approximately midspan. Values of support stiffness corresponding to one-tenth the composite strut-backup structure

stiffness were used in the evaluation as these values were considered by the experimental team to provide a best fit to the observed response. The experimental estimate of damping was 3% and was used in the simulation.

The results for the Indian Point configuration were considered poor. General correlation was only achieved for some points in the near vicinity of the input. For most ponts there was poor correlation in either response character, frequency or amplitude. For some points in close proximity to the supports or anchors there was no correlation in any of these quantities. On the positive side the correlation for the peak acceleration amplitudes was good. The source for the poor agreement was felt to be the approximations used to model the supports and anchors in this system. The approximations seem appropriate to provide peak responses only. A description of the Z Bend and Indian Point evaluations are provided in Reference 4.

C. HDR URL Loop

The decommissioned Heissdampfreaktor in Kahl, West Germany has been used as a platform for many tests. One test involved subjecting the system to a 5 kg blast loading. Following this test, various organizations performed analytical simulations of the Recirculation Loop Piping (URL) of the reactor using both linear and nonlinear analysis methods. As a follow-on study to the U.S. effort in this area, BNL performed linear analyses of the system considering distinct, independent support excitations to compliment the analysis performed by EG&G Idaho for this system. The system included the reactor vessel, the two reactor pumps and the associated piping and supports. The supports were both spring and constant force hangers which were known to exhibit nonlinear characteristics. A complete description of the system is provided in an EG&G Idaho report, Reference 5.

This evaluation was not performed blind. BNL used the computer models and processed input data developed by EG&G in the evaluation. Two linear elastic evaluations were made considering both uniform and indpendent support excitations. The BNL results were found to be essentially equivalent to those obtained earlier. The consideration of independent support motions provided only a marginal improvement in results. The correlation between the measured and predicted results ranged from good to poor with the agreement for peak amplitudes being good, as indicated in Reference 6. The agreement achieved with these linear analyses were approximately equivalent to those obtained by others with nonlinear analysis methods. The generally poor correlation was ascribed to the known nonlinear characteristics of the support system.

D. Extended Z Bend

As noted above a clearance gap existed at one actuator in the original Z Bend test. Since this gap was felt to be the cause of the response discrepancies obtained, a new test for a similar test section was undertaken. The test involved a new test section which was solidly attached to the actuators. The test designated T6R1R, was conducted by ANCO Engineers Inc. under NRC contract. As above, the test again involved in phase seismic like excitations of the three actuators and 2% damping was used in the analytical simulation.

The response correlation obtained for the Extended Z Bend evaluation were good for displacements and ranged from good to poor for accelerations, as shown in Reference 7. Result correlations were best for points on the lower horizontal span and worst for points on the upper horizontal span. The poorest correlation was obtained for the acceleration of a point on the upper span in the near vicinity of the upper actuator. For this point, the correlation of results were good for the first 12 seconds of test and then deteriorated. The peak acceleration for this point was underpredicted by 50% at 15 seconds. The cause for this poor acceleration correlation achieved in this evaluation is not known. It is hypothesized that the clamp at the upper actuator loosened or deformed sufficiently during test to introduce nonlinear acceleration components. Since the system was dismantled before this evaluation was complete, the hypothesis could not be verified.

7.0 CONCLUSIONS

These physical benchmark evaluations provide a body of data from which the relative adequacy of linear piping analysis methods may be assessed. All of the evaluations were made using BNL analysis methods, but these are considered to be equivalent to the methods available in industry and are currently used to qualify nuclear power plant piping. The conclusions below reflect views developed over several years of physical benchmarking, and through discussions with NRC's staff and contractors.

The correspondence between predicted and experimentally determined estimates for the natural frequencies of the systems were good. Frequencies typically were within 5% for the lowest modes and, where available for comparison, within 10% for the higher modes. The degree of correspondence between the associated mode shapes was not assessed in this effort because the required test data were not available for review. To some extend the discrepancies observed between predicted and measured response may be attributable to poor estimates of the significant mode shapes.

The correspondence between predicted and measured displacements ranged from good to poor. In general, the estimates of total displacements were better than the estimates of system accelerations in a given problem. Typically, the time history traces of predicted displacements showed the same character and wave shape as the measured traces and very good correspondence for the locations of peak amplitudes. For many points, the correspondence was so good that only with careful examination could differences be noted. However, for other points, amplitude differences of two or greater would be observed, although good correspondence of wave character would be maintained. In these instances, the deviations were usually ascribed to boundary or support element effects.

The correspondence between predicted and measured accelerations also ranged from good to poor. Typically, there was fair to good correspondence in wave character and shape with the measured traces showing more high frequency content and sporadic peaks. The correspondence for peak amplitude locations was good at times and poor at other times. Again many of the deviations observed were ascribed to boundary element effects. Further, for acceleration, more instances of consistent under- or overprediction were observed, with these affects ascribed to the damping assumption used in the analysis.

Regarding damping, experimental estimates of uniform system damping were used in every evaluation. For each of the laboratory tested systems the assumed level of damping was later judged to be too large. In each of these evaluations, a general level of underprediction was observed with peak acceleration amplitudes being underestimated by as much as 100%. For the two in situ tested systems peak response amplitudes were estimated well. For these either the estimates of damping were better or system wide nonlinear affects mitigated the developement of high response peaks. In any case, the relative high rate of underprediction observed should caution against the use of high estimates for system damping in performing analyses.

For some points in the various systems little or no correlation between predicted and measured response, or extreme deviations between these response traces, was observed. In each such instance, a plausible explanation for the deviate behavior was advanced, but not tested. In the majority of cases, the deviate behavior was observed for points in the close proximity of supports. In those cases, the poor correlation was attributed to postulated nonlinear characteristics of the support in question. Given the high incidence of this phenomenonless credence should be placed in linear estimates of support loads and effects. On average, these effects were local and did not compromise the validity of the linear estimates of gross system response.

Commenting on the format of the effort, performing the evaluations blind and involving several organizations assured the propriety of the results. In this mode however, the inherent time lags precluded the investigation of observed effects. Before an evaluation was complete, the physical system was either dismantled or totally modified. The explanations advanced to account for deviate behavior could thus never be verified. This is a distinct shortcoming of the effort. Some of the deviations noted could have broad significance if they reflect fundamental deficiencies of the analysis methods. A case in point is the general level of under prediction observed. The root causes of this should be established unequivocably. In this regard a interactive program dedicated to the investigation and benchmarking of the analysis methods would have provided a more comprehensive evaluation of those methods. Deviate behavior could have been investigated in subsequent tests incorporating system changes or attend instrumentation.

In summary, the linear analysis methods were found to provide reasonable estimates of system response. The estimates for system natural frequencies were good while the estimates for displacements and accelerations ranged from poor to good. For a near linear system and using conservative estimates for system damping good correlation of response traces and acceptable estimates of response peaks can be expected. Using realistic estimates of uniform system damping large underestimates of peak response completeds were observed and deviations of 100% or greater should be expected.

TABLE 1

Predicted and Measured Natural Frequencies for Main Pipeline.

Mode No.	Predicted Hz	Measured Hz
1	4.45	4.62
2	7.24	7.11
3	9.08	9.16
4	11.45	11.66
5	13.79	13.54
6	18.01	17.71
7	18.77	18.53
8	20.46	23.94
9	25.21	25.87
10	26.72	28.06

TABLE 2

Predicted and Measured Natural Frequencies for Main Pipeline with Branches.

Mode No.	Predicted Hz	Measured Hz
1	6.67	6.2
2	6.87	6.5
3	8.27	8.0
4	11.60	11.0
5	14.72	14.7
6	16.33	15.0
[illegible]	16.79	16.0
[illegible]	20.38	20.6
[illegible]	21.22	21.5
10	29.71	

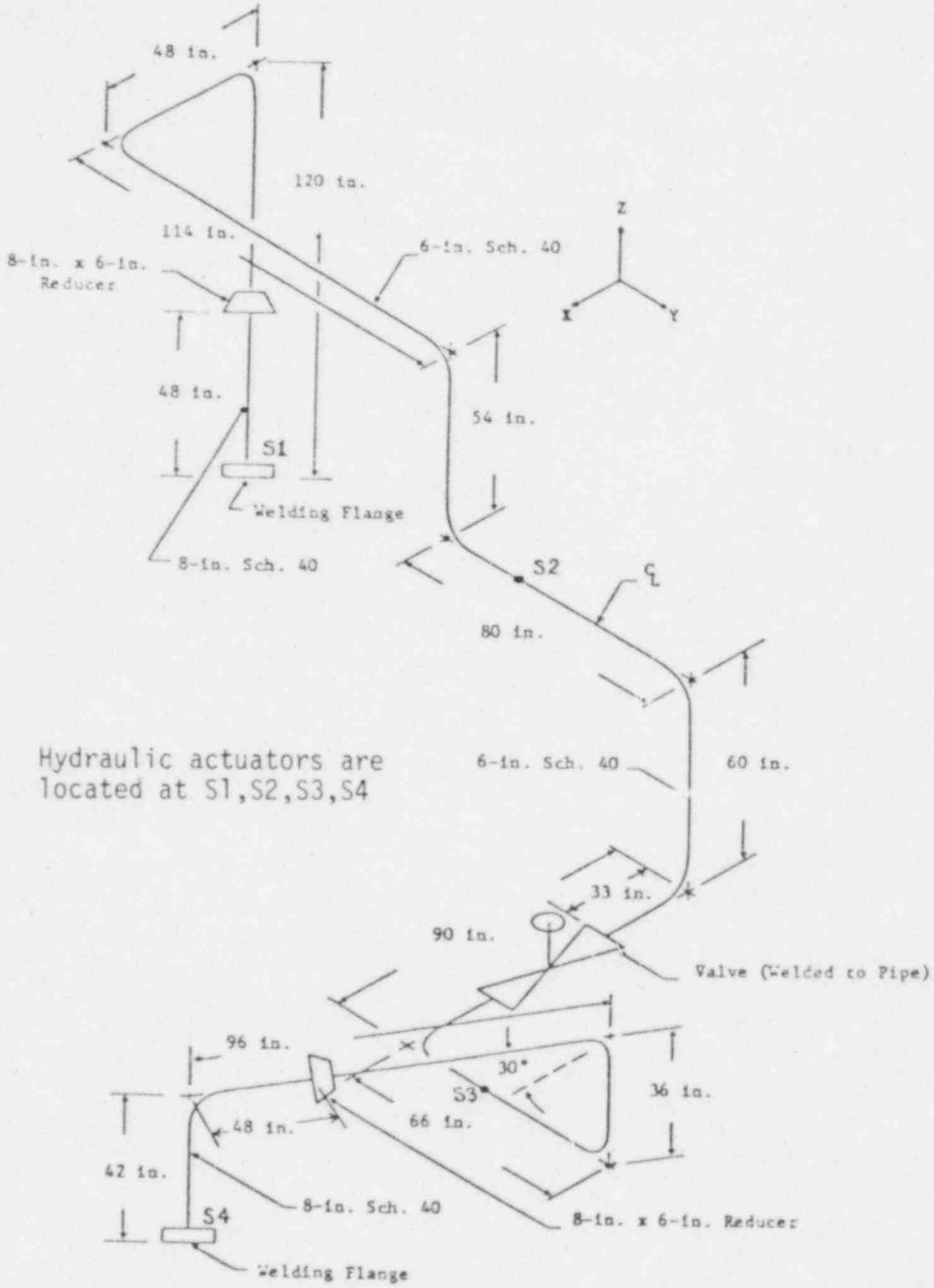
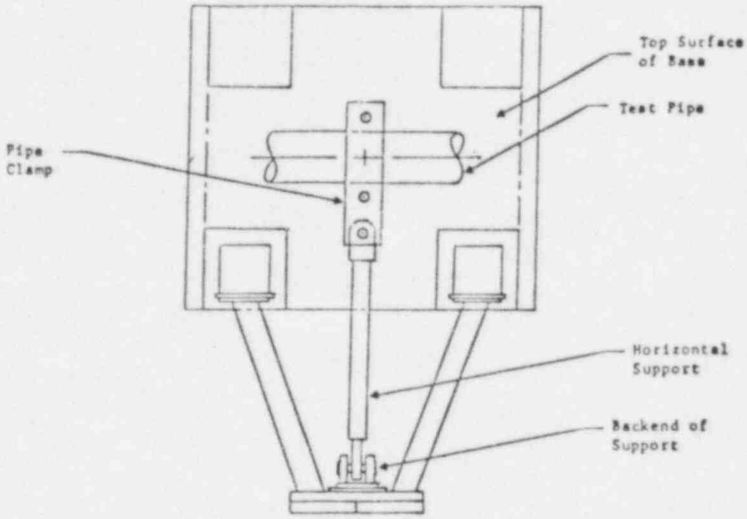
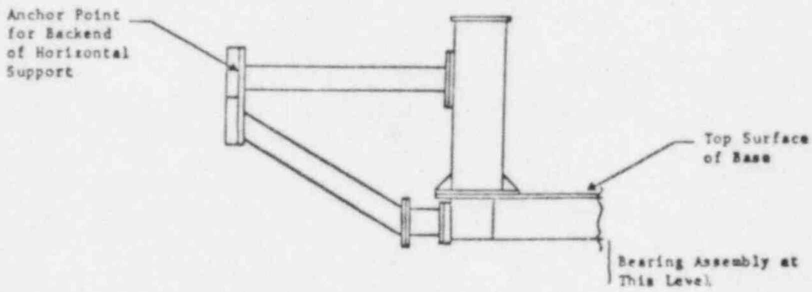


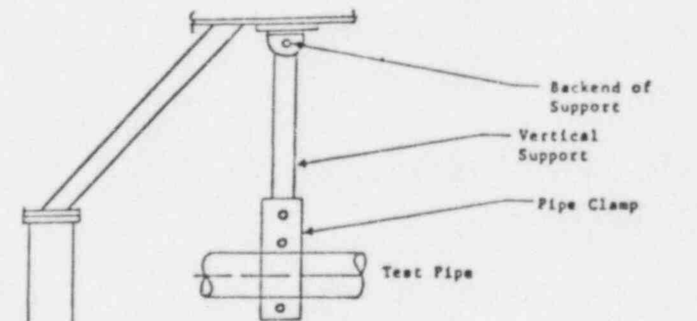
Fig. 1. Main Pipeline



(a) Top View of Base, Including Horizontal Support Frame, Horizontal Support, and Top Surface of Base



(b) Side View of Horizontal Support Frame



(c) Side View Showing Vertical Support

Fig. 2. Intermediate Support Structure

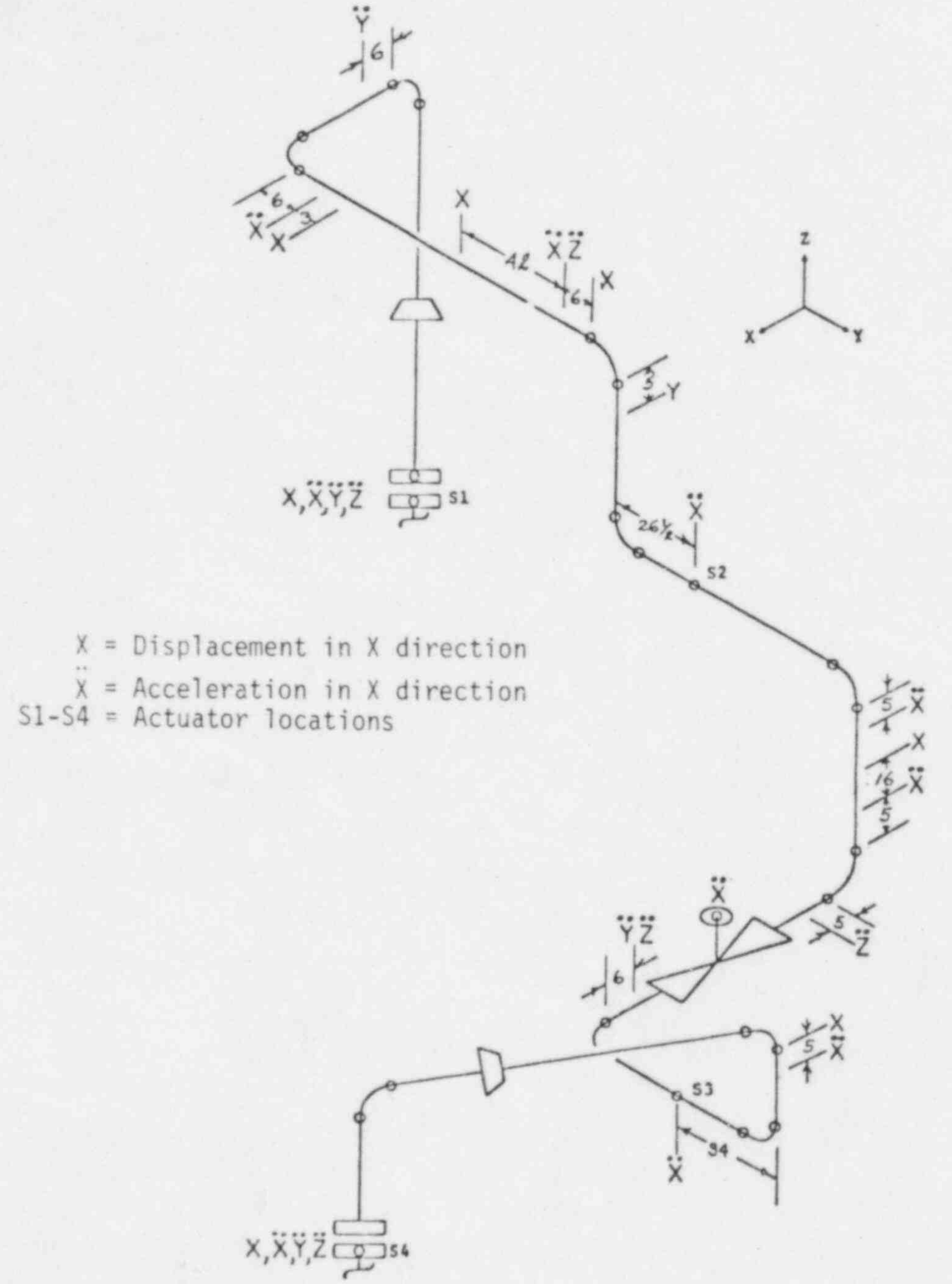


Fig. 3. Instrumentation Locations Main Pipeline

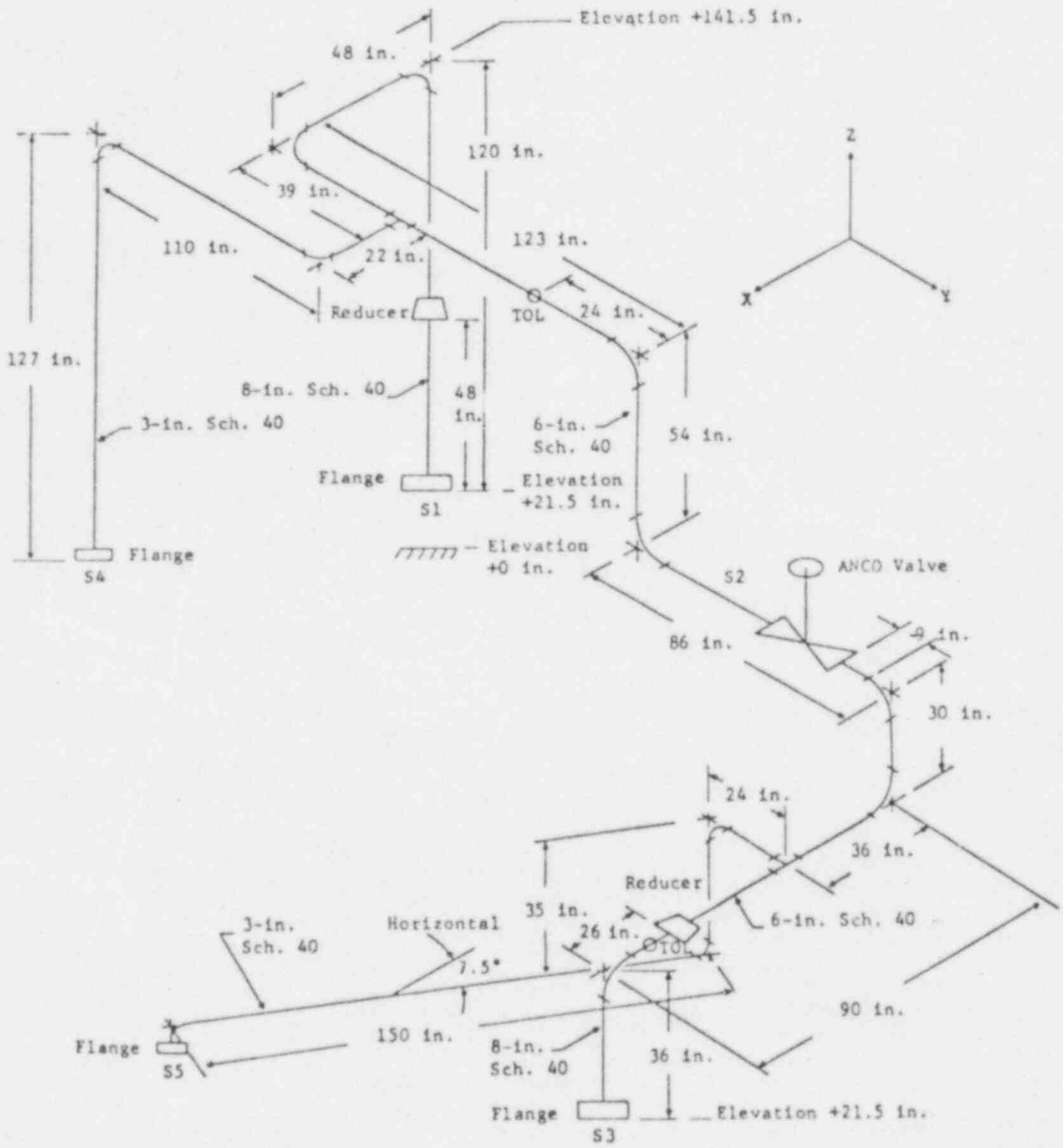


Fig. 4. Main Pipeline With Branches

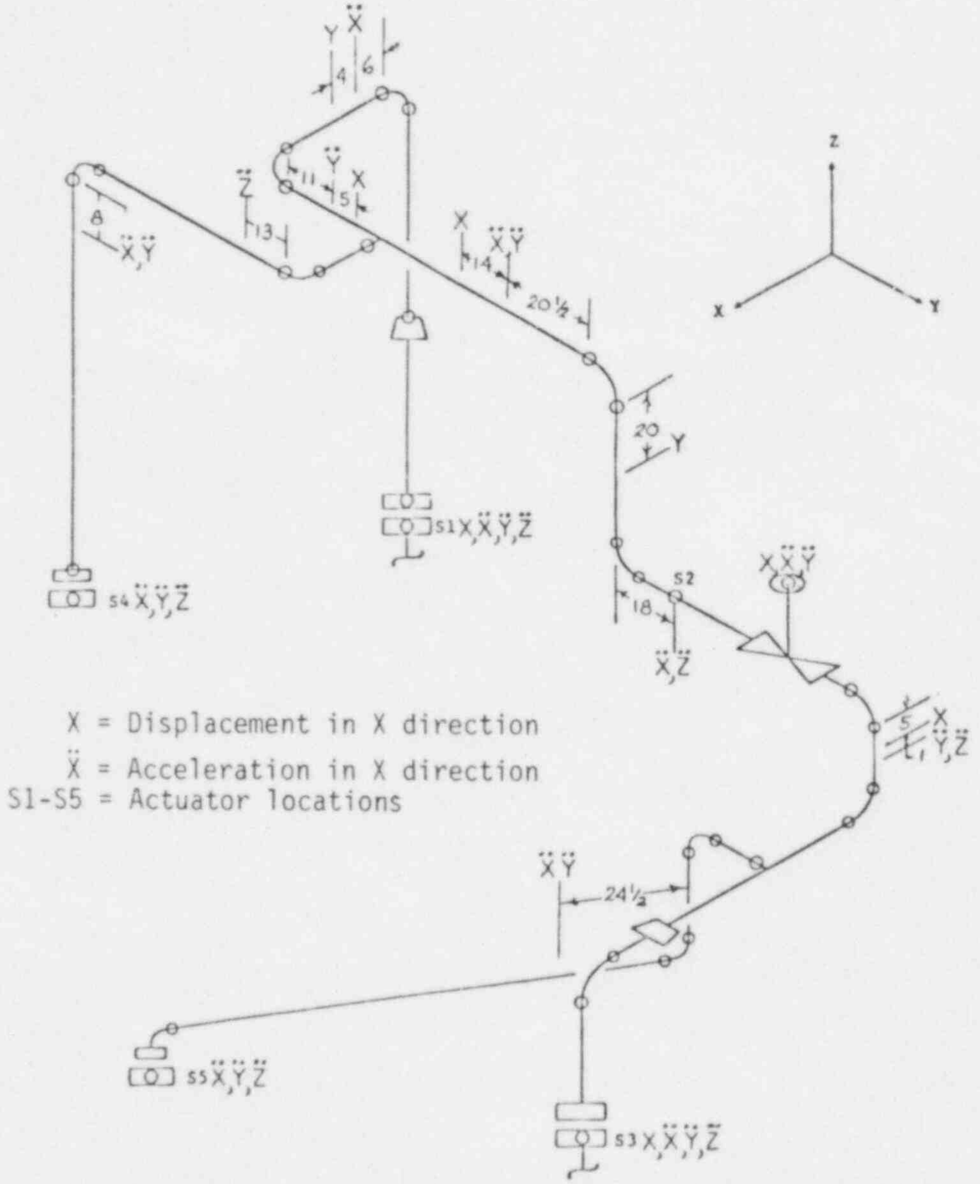


Fig. 5. Instrumentation Locations, Main Pipeline With Branches

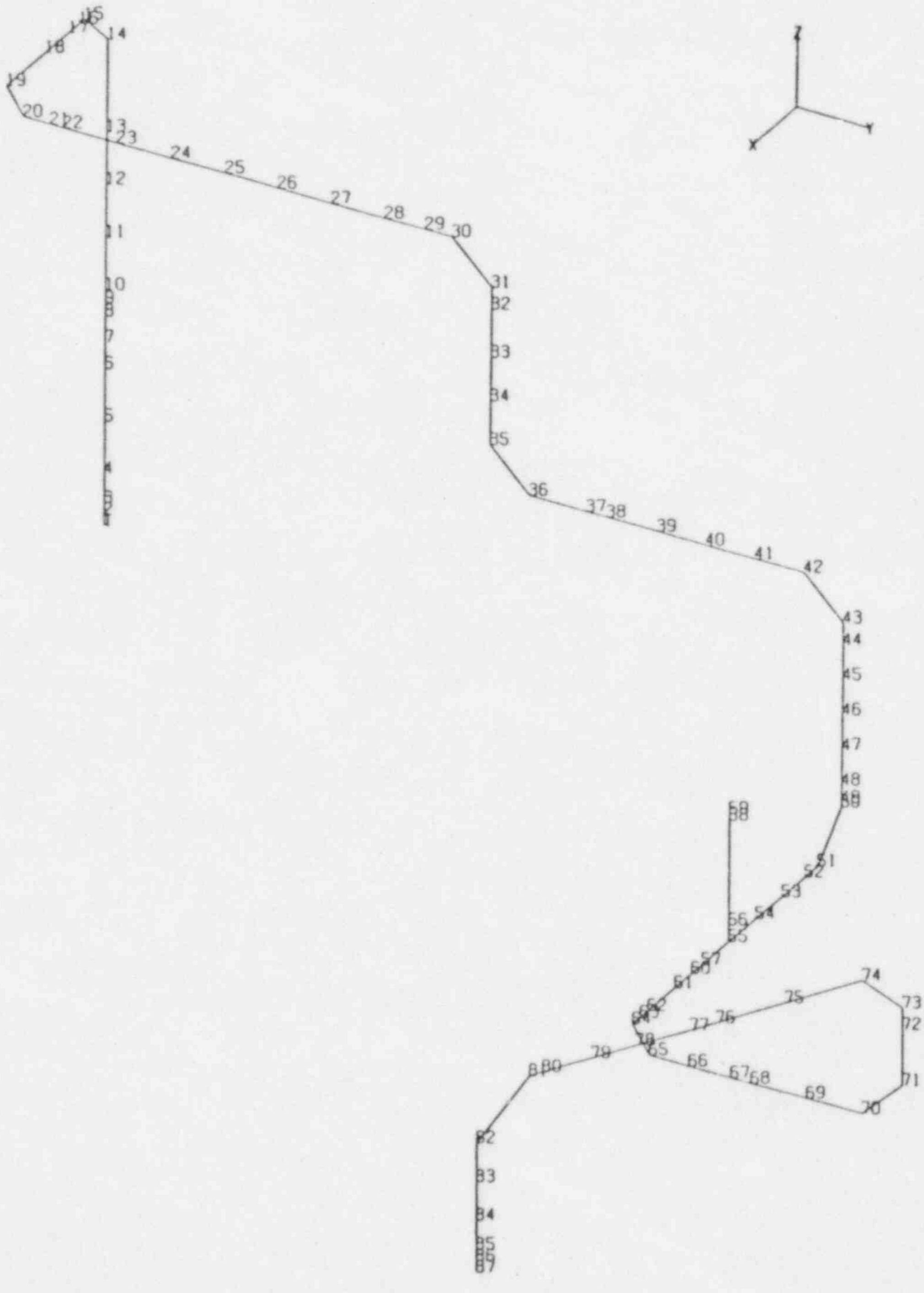


Fig. 6. Finite Element Model, Main Pipeline

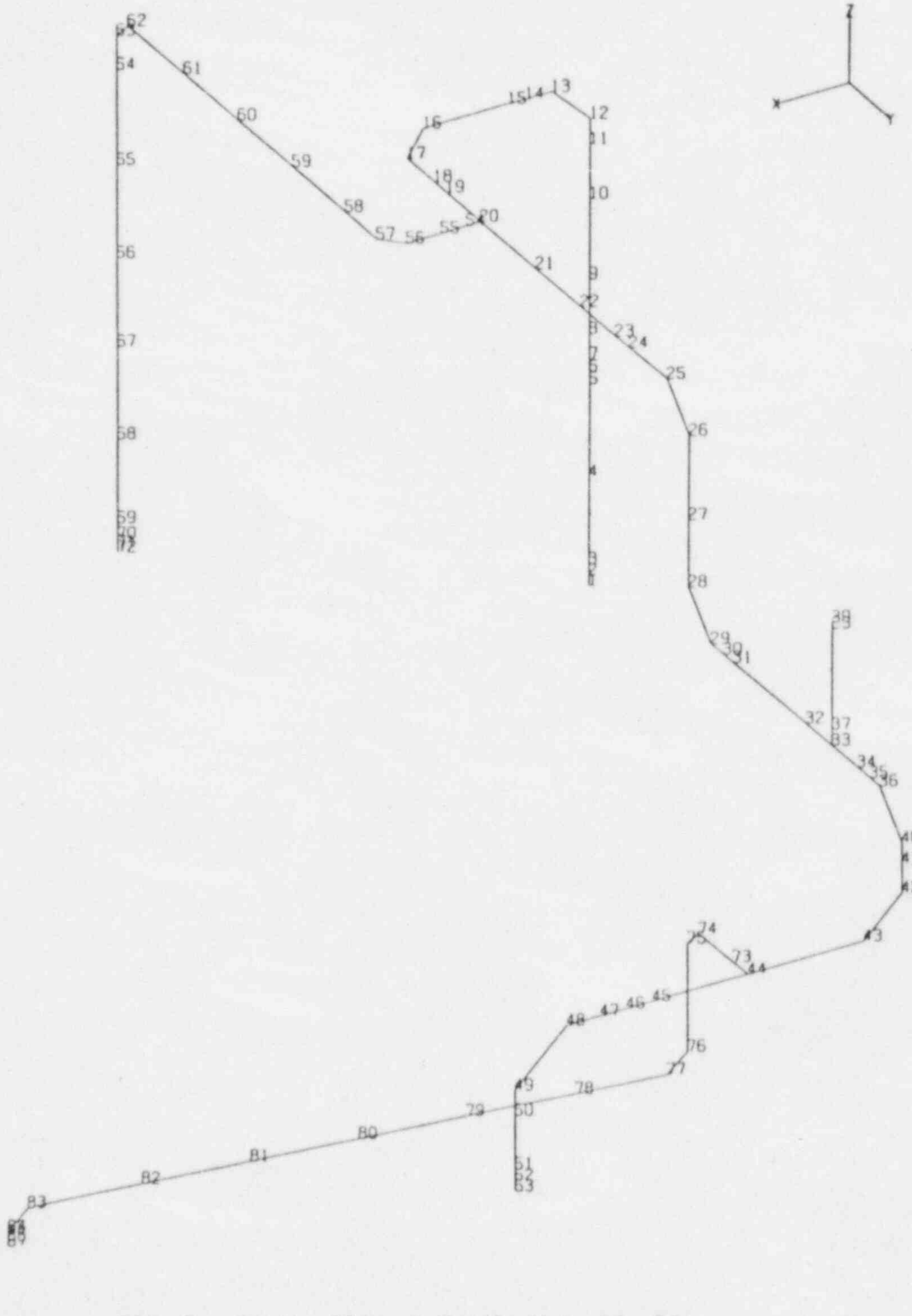
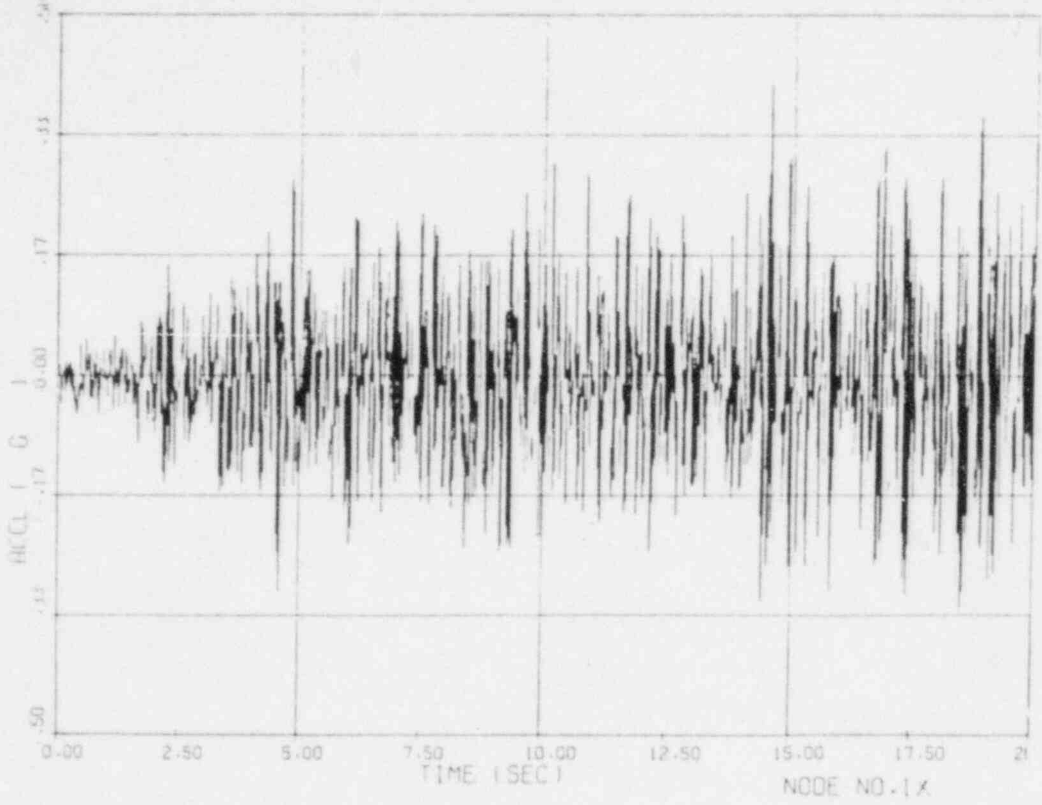
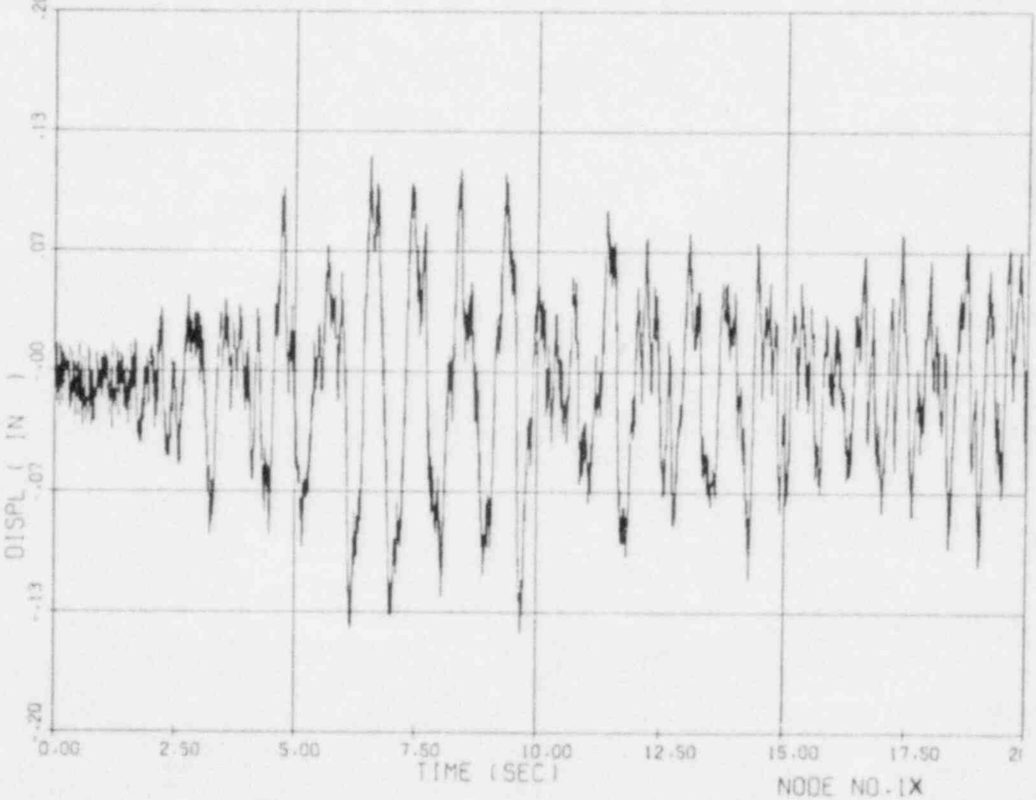


Fig. 7. Finite Element Model, Main Pipeline
With Branches

Time History Records
Main Pipeline

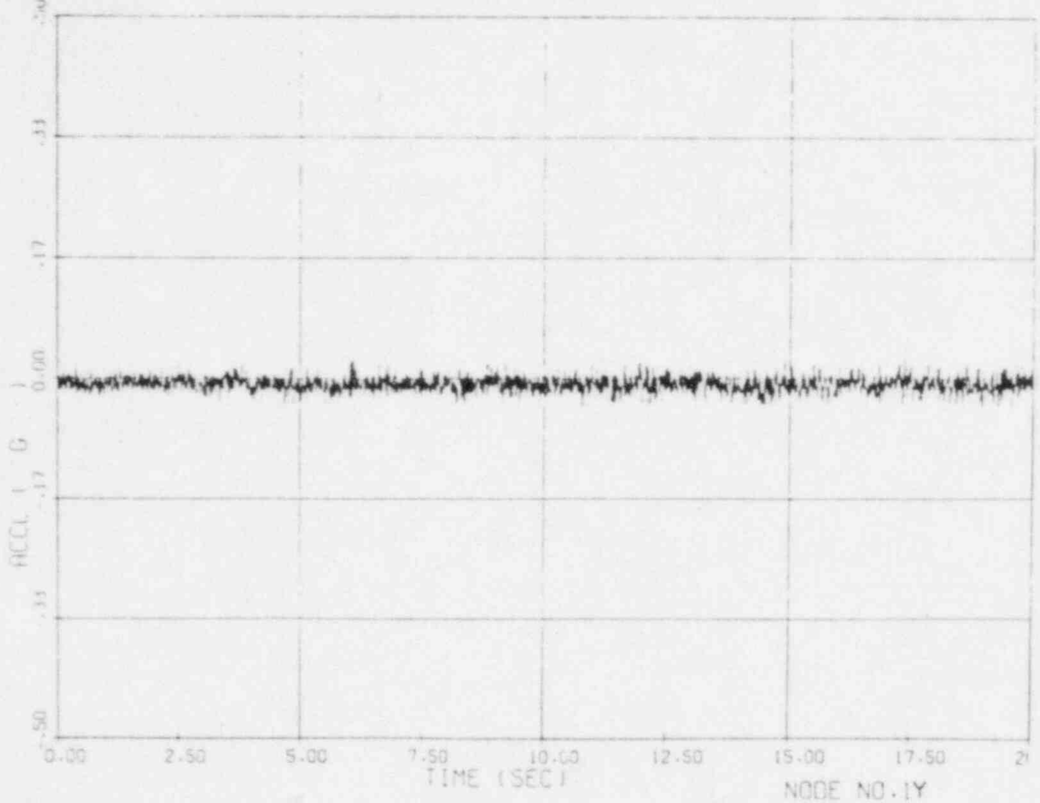


Acceleration

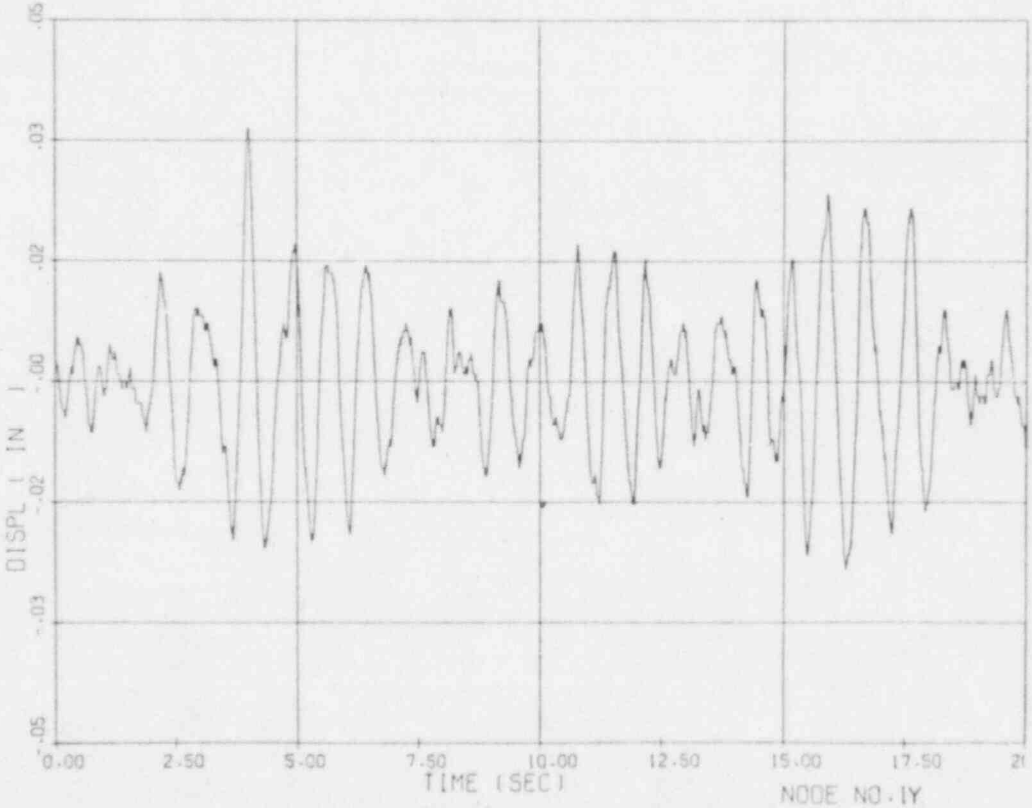


Displacement

Fig. 8. Input Main Pipeline Node No. 1X (Carriage S1)

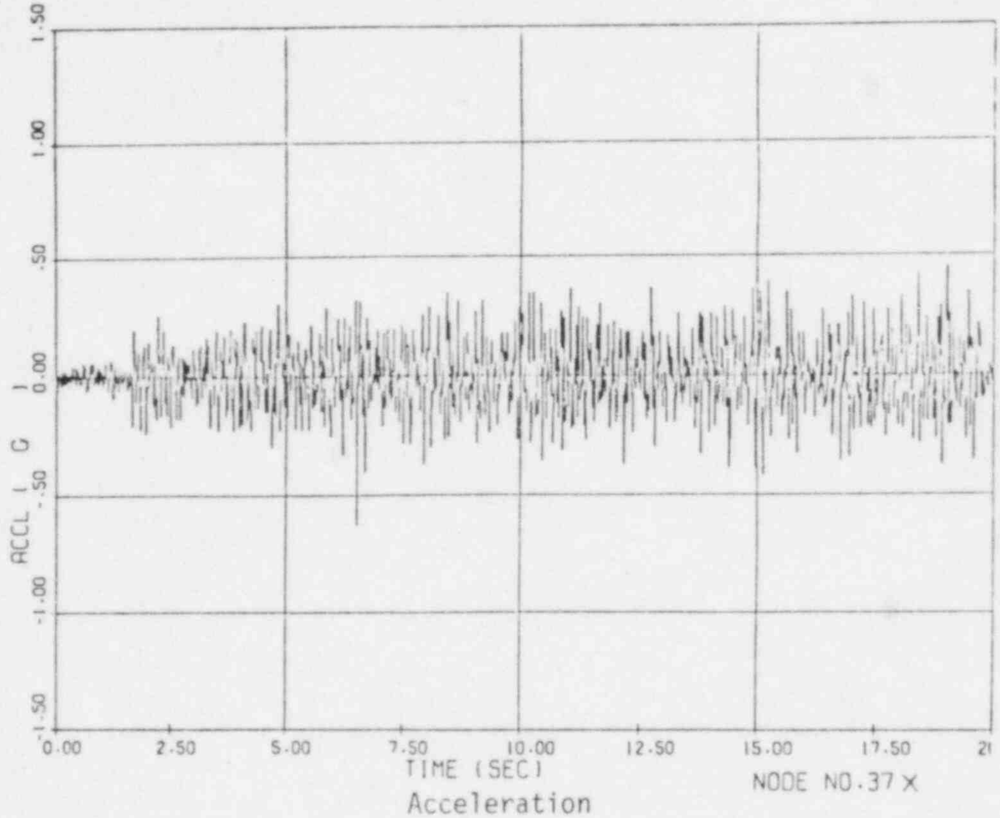


Acceleration

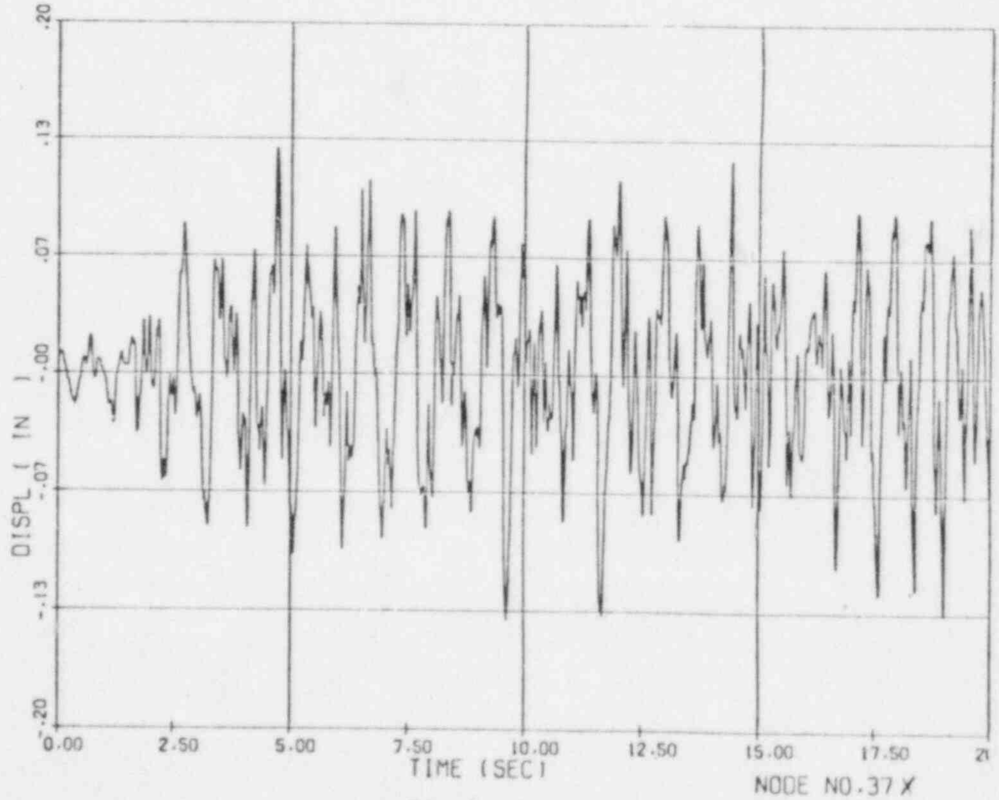


Displacement

Fig. 9. Input Main Pipeline Node No. 1Y (Carriage S1)

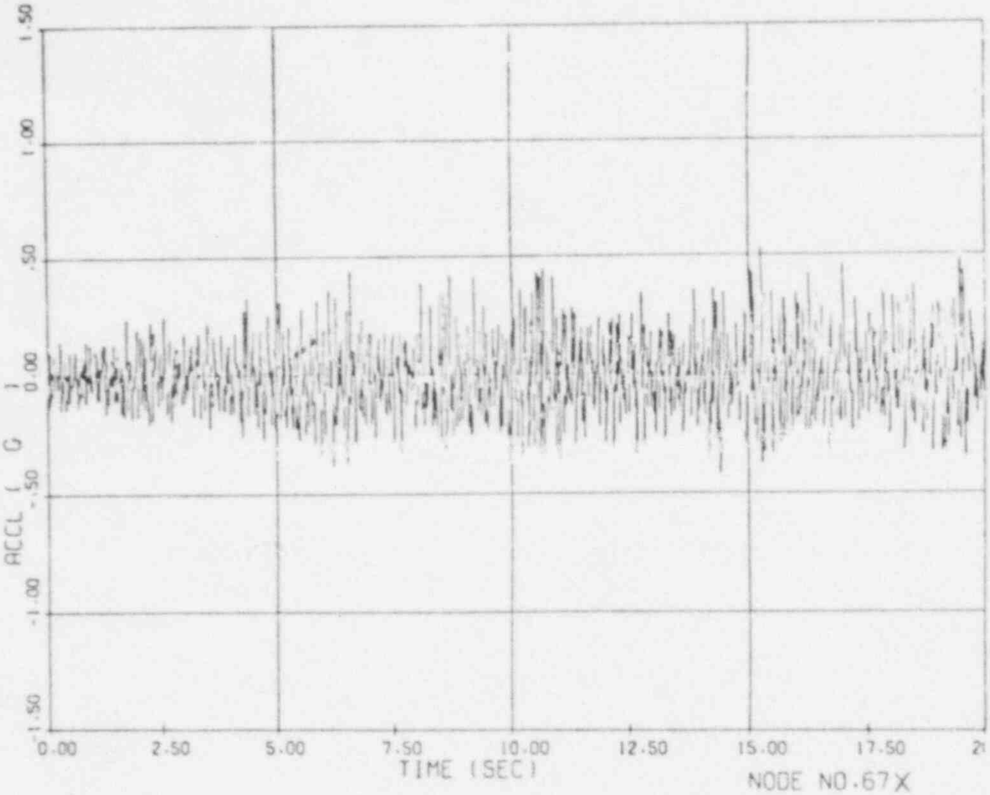


Acceleration

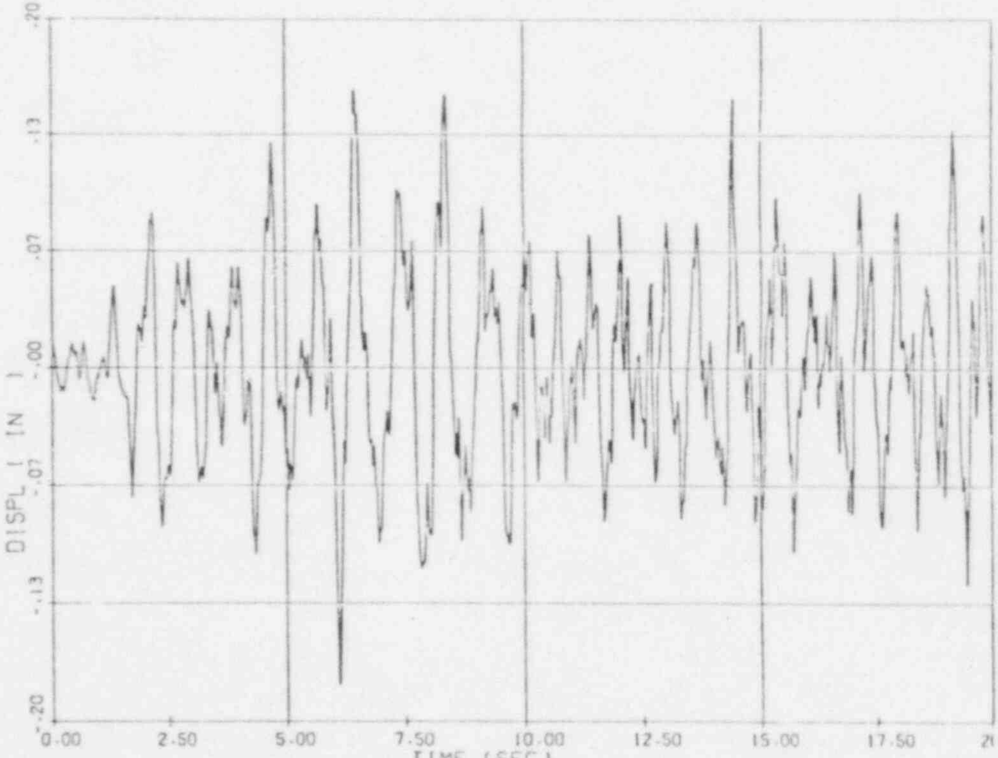


Displacement

Fig. 10. Input Main Pipeline Node No. 37X (Carriage S2)

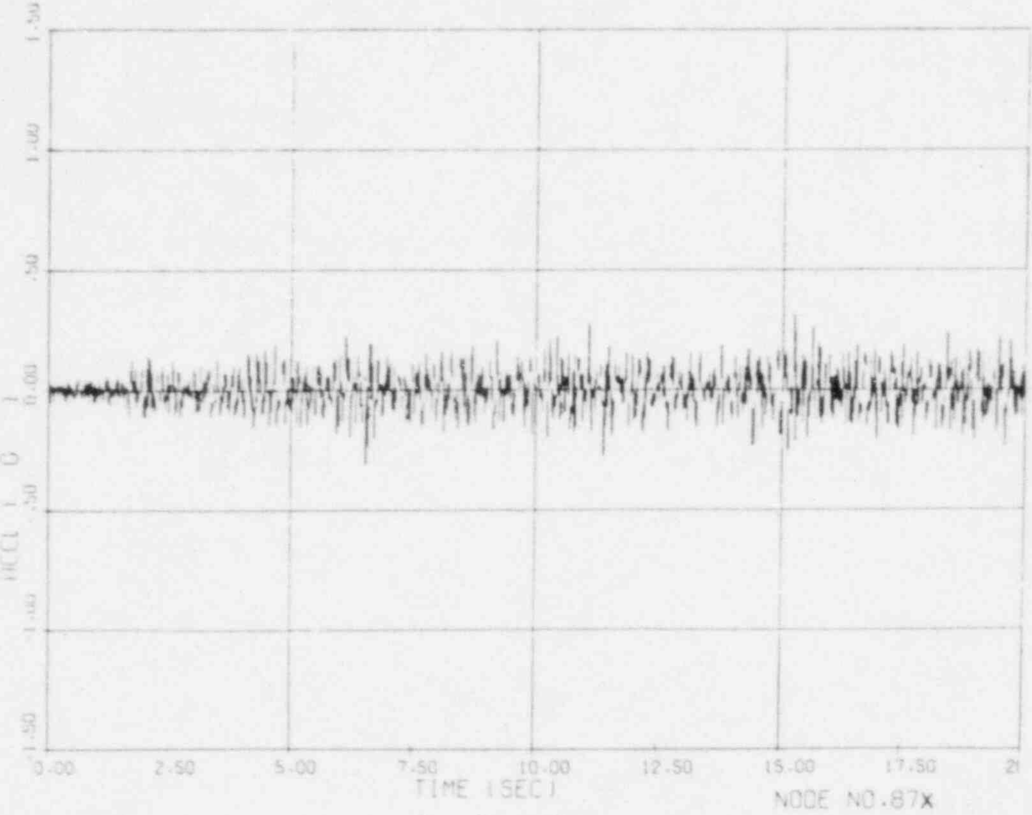


Acceleration

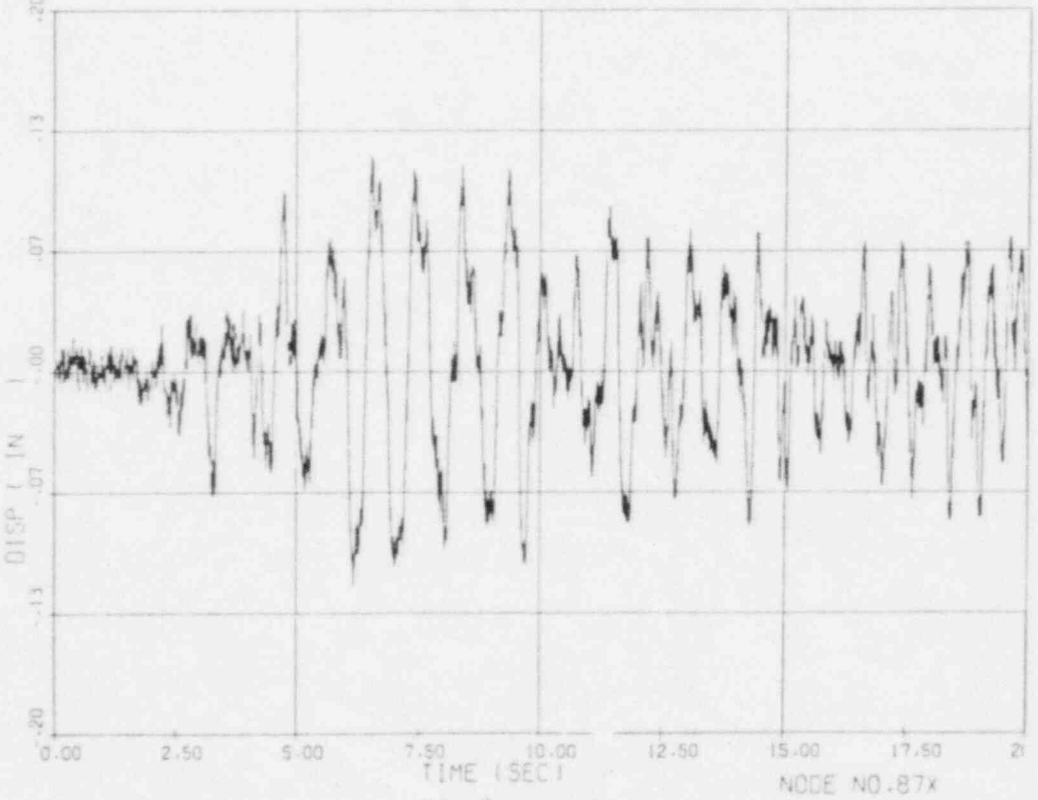


Displacement

Fig. 11. Input Main Pipeline Node No. 67X (Carriage S3)

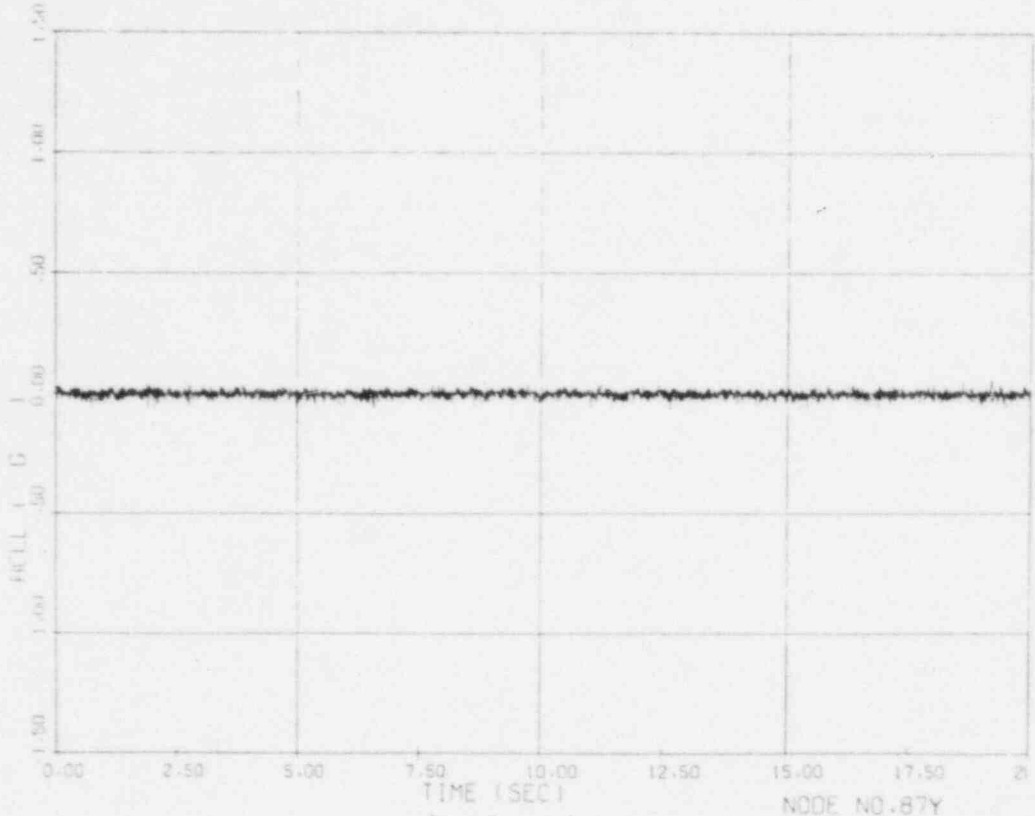


Acceleration

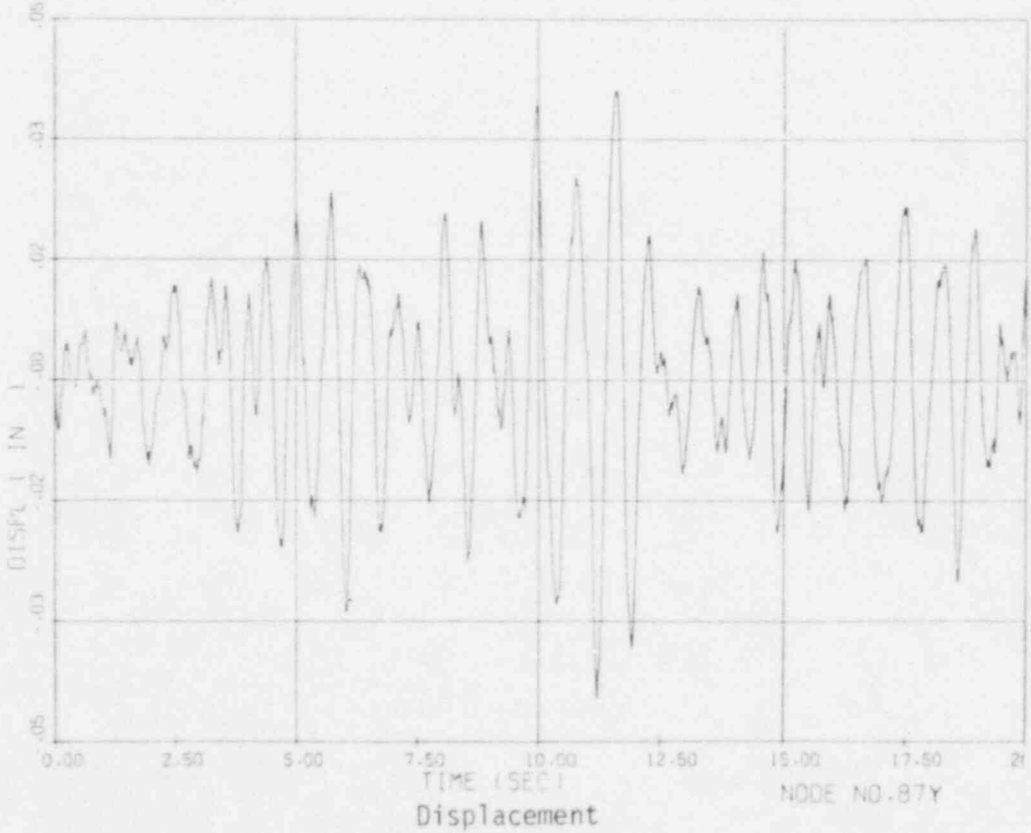


Displacement

Fig. 12. Input Main Pipeline Node No. 87X (Carriage S4)

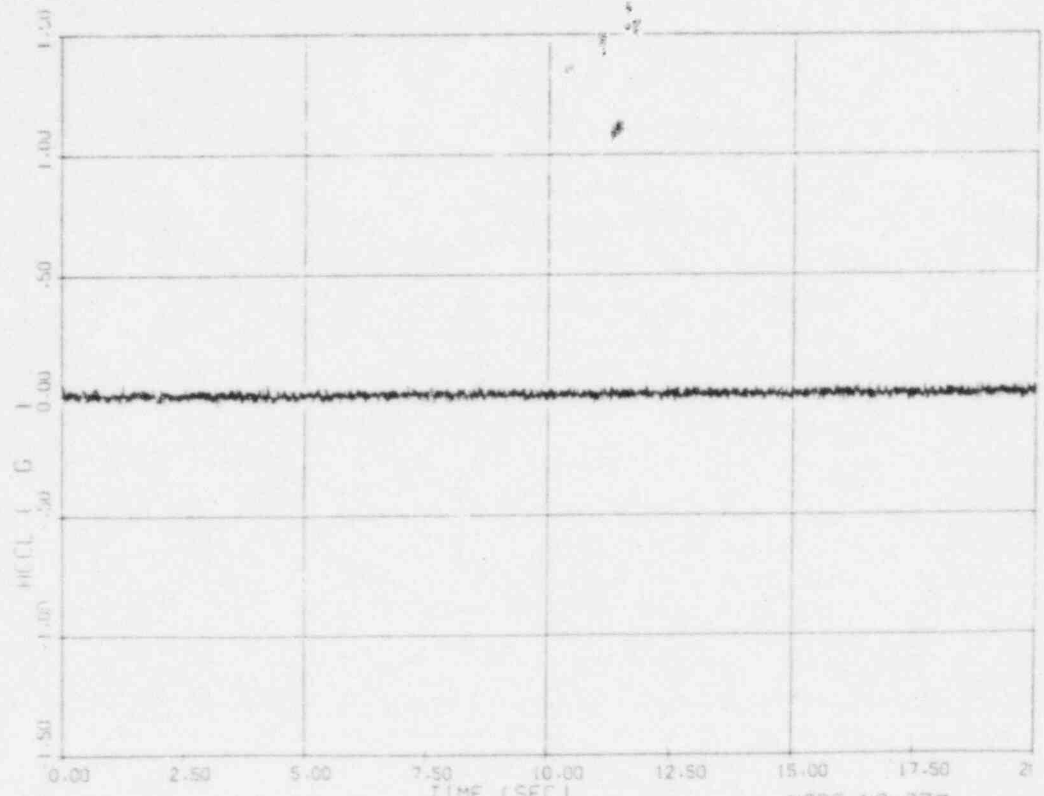


Acceleration

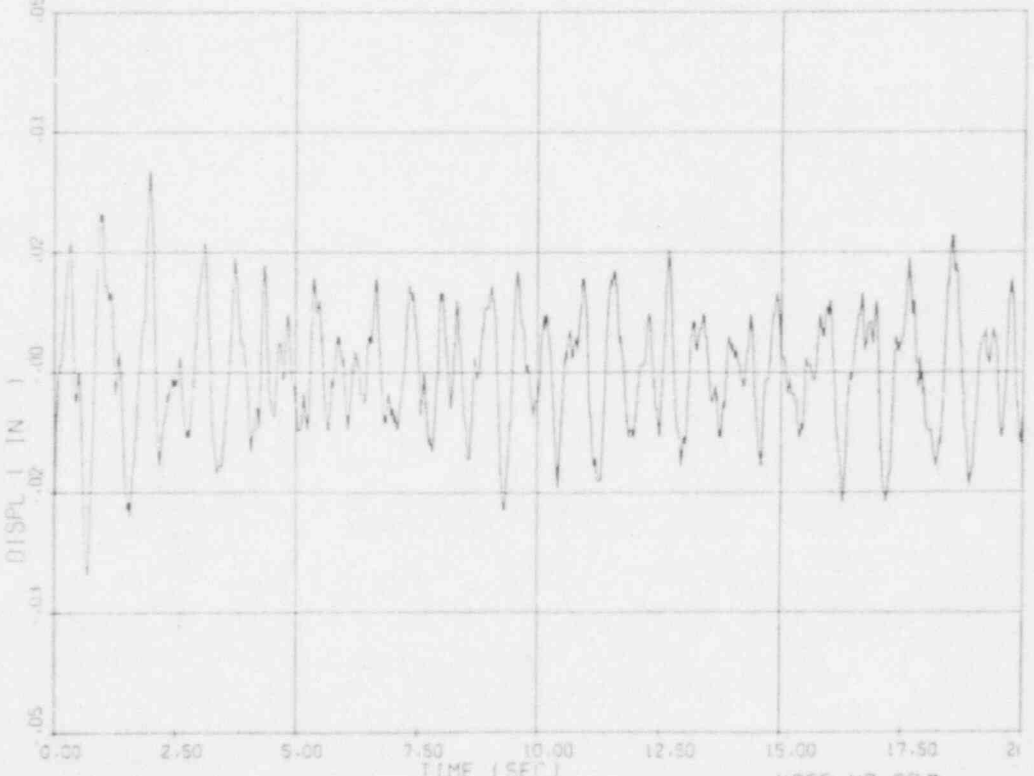


Displacement

Fig. 13. Input Main Pipeline Node No. 87Y (Carriage S4)

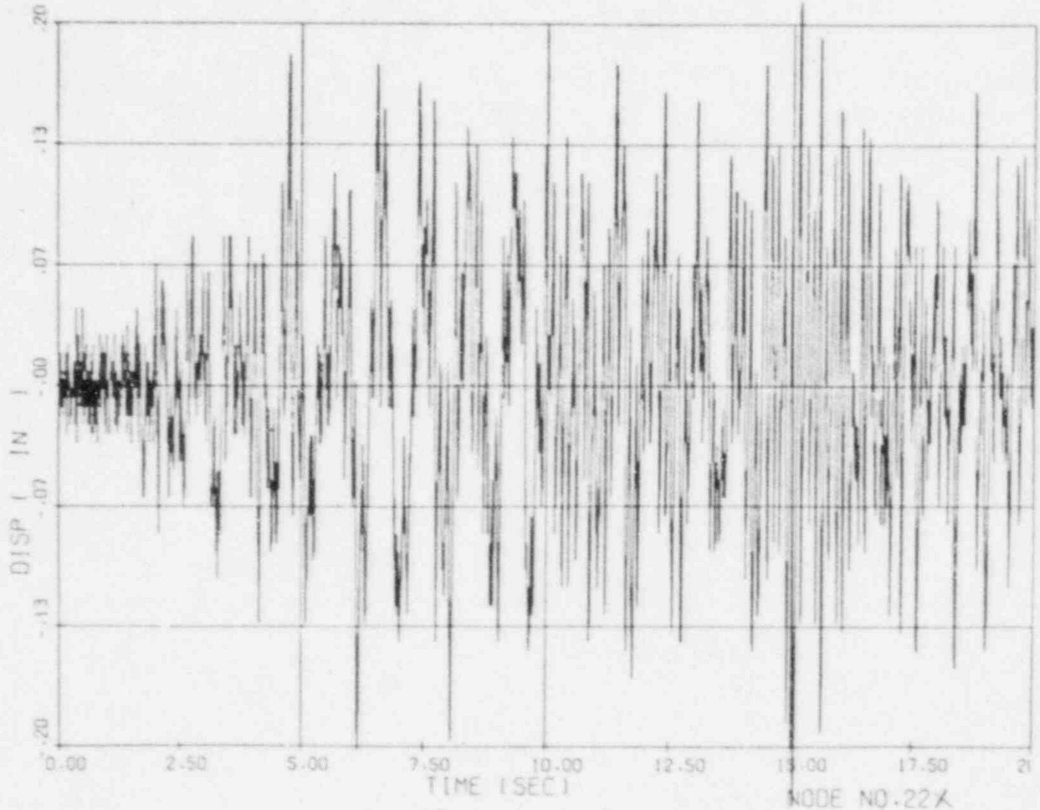


Acceleration

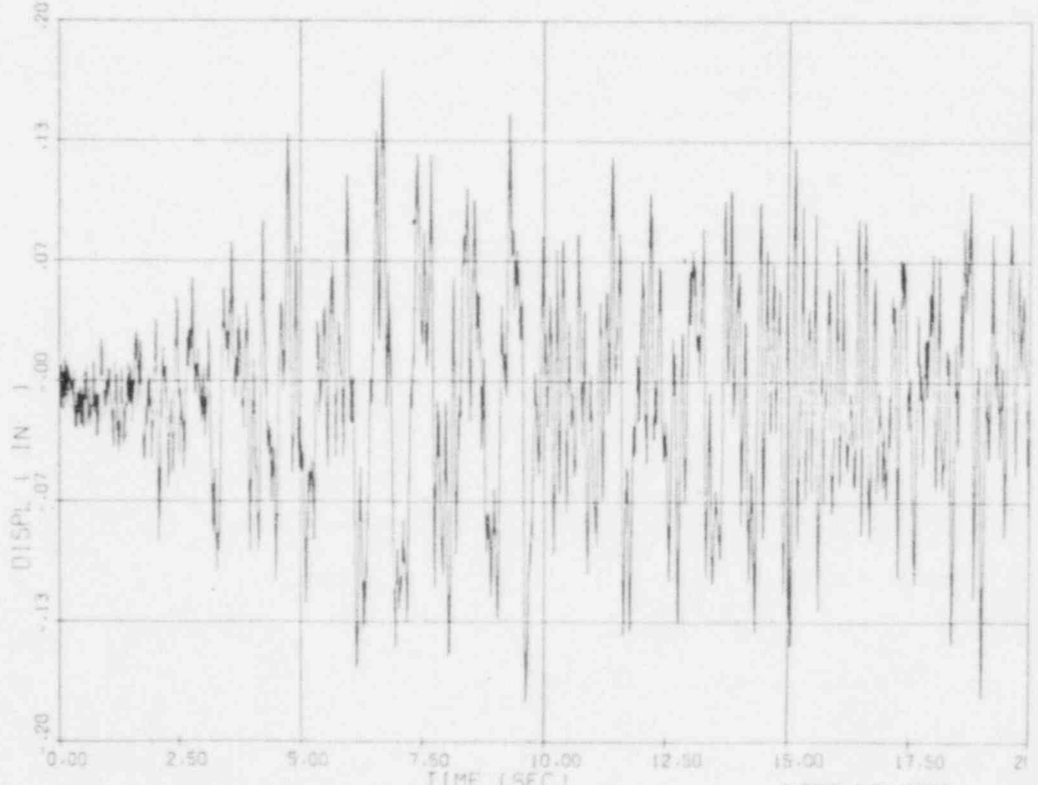


Displacement

Fig. 14. Input Main Pipeline Node No. 87Z (Carriage S4)

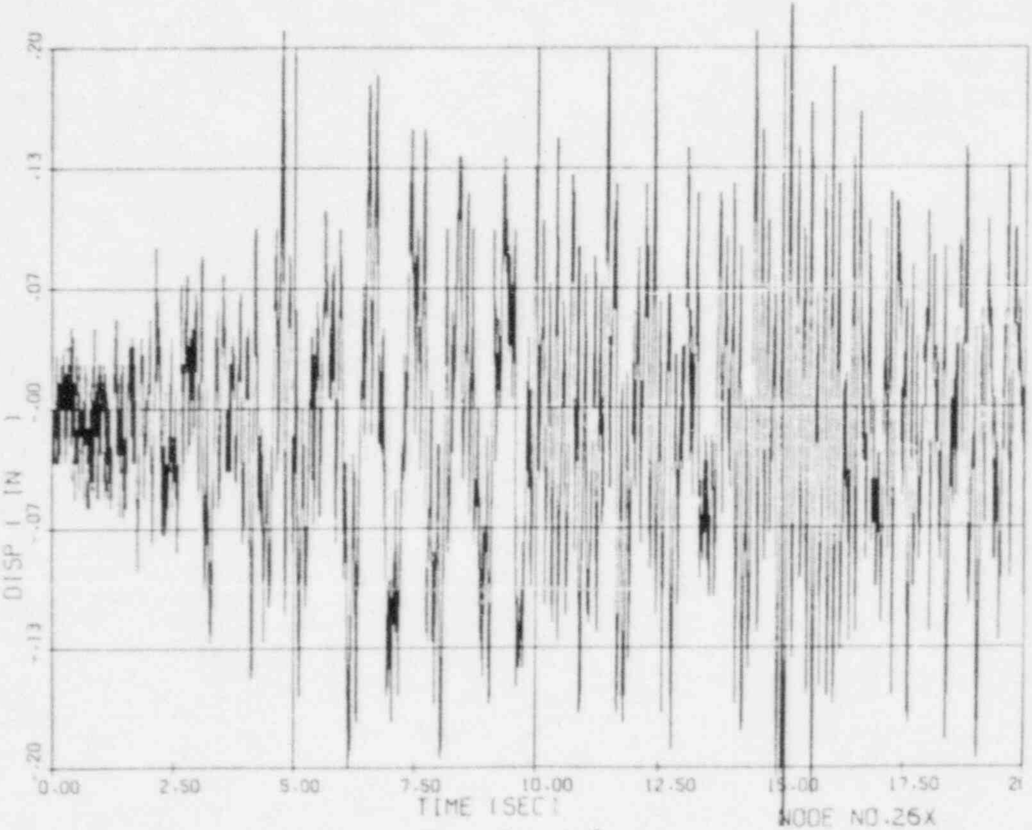


Experimental

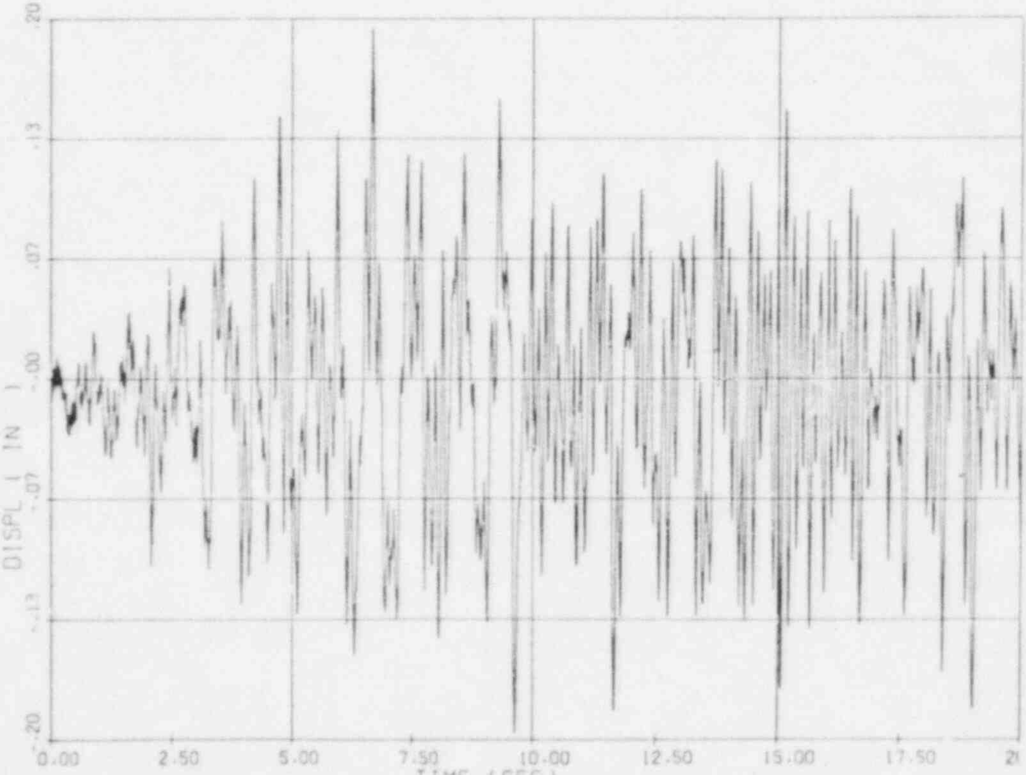


Analytical

Fig. 15. Displacement Response, Main Pipeline Node No. 22X

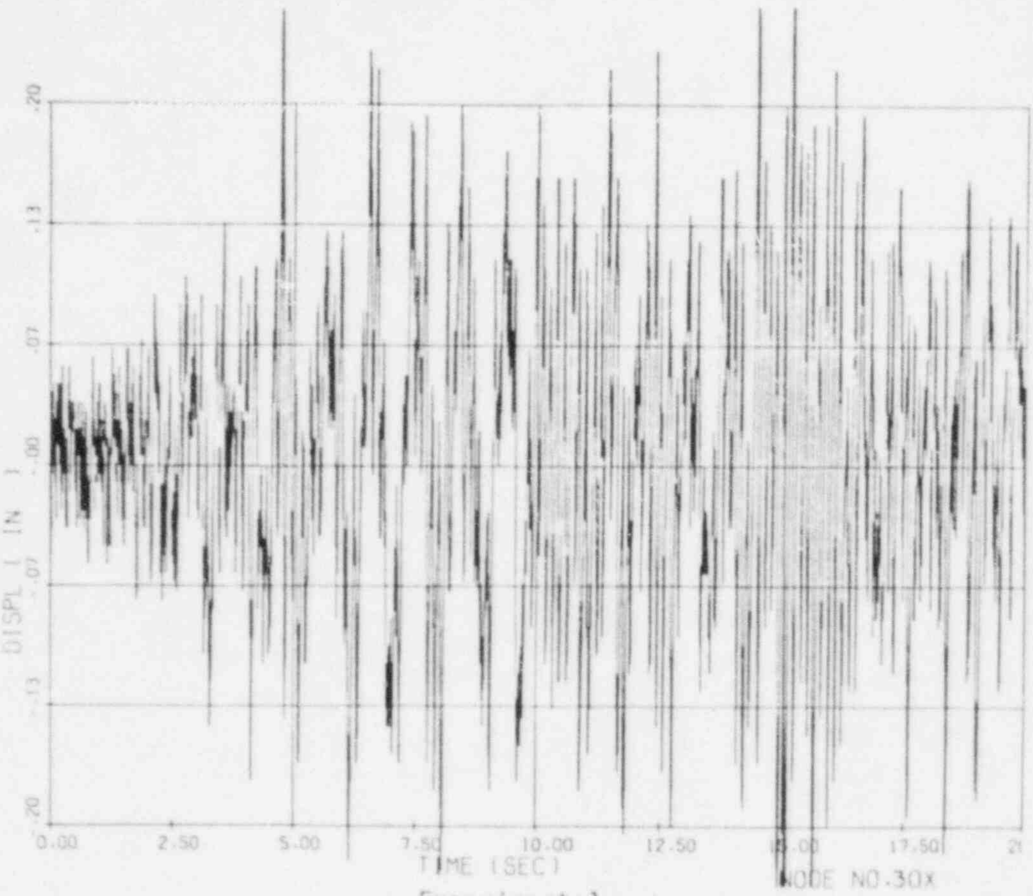


Experimental

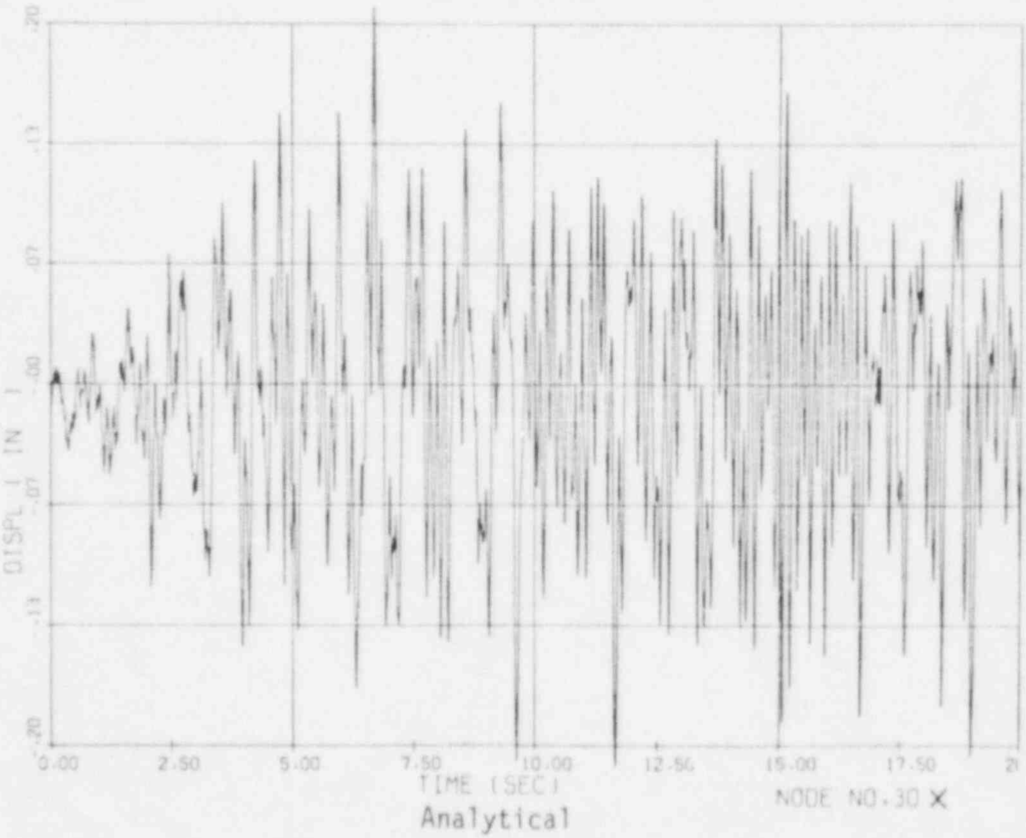


Analytical

Fig. 16. Displacement Response, Main Pipeline Node No. 26X

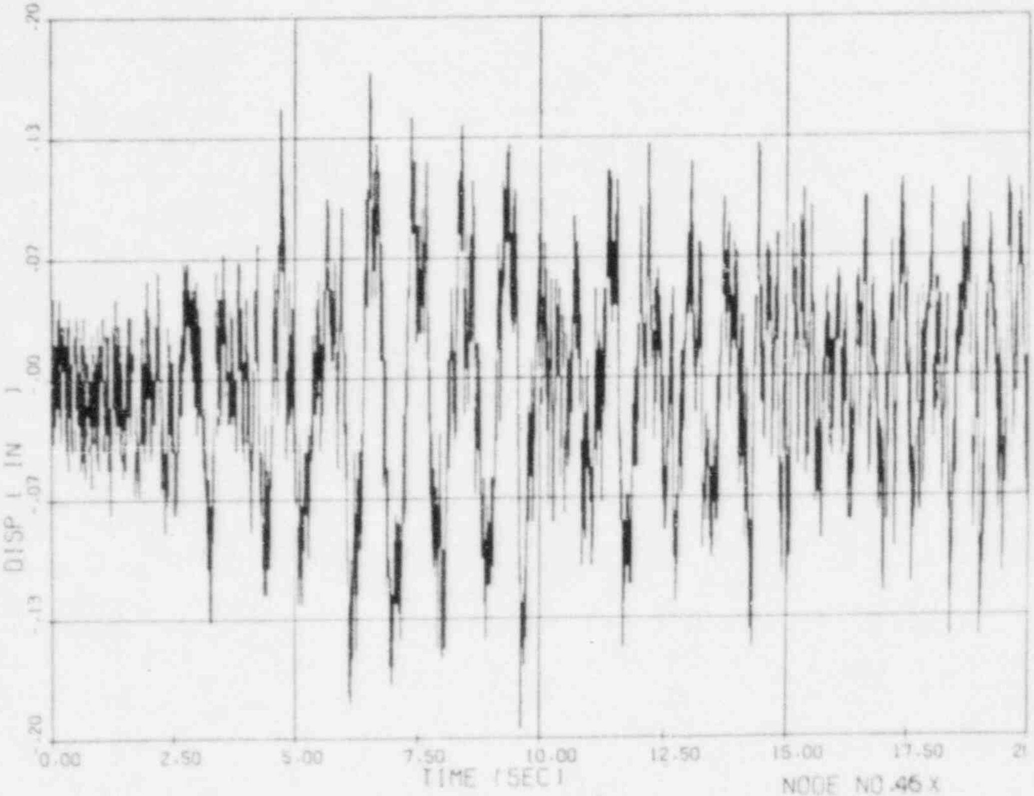


Experimental

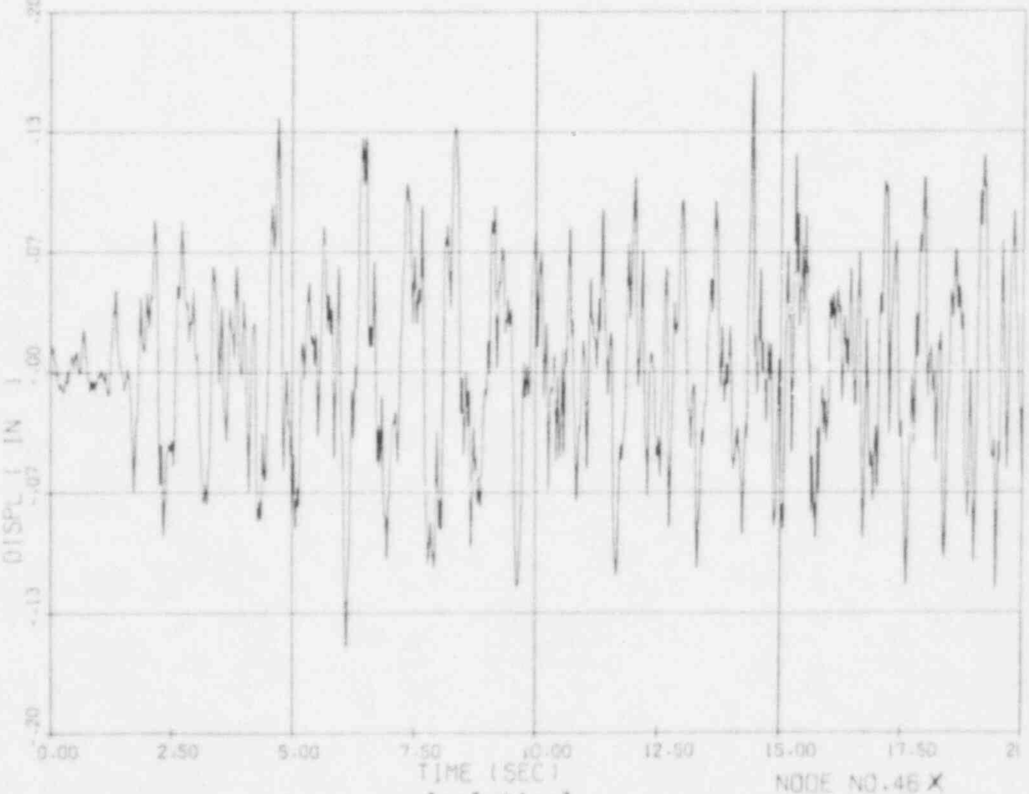


Analytical

Fig. 17. Displacement Response, Main Pipeline Node No. 30X

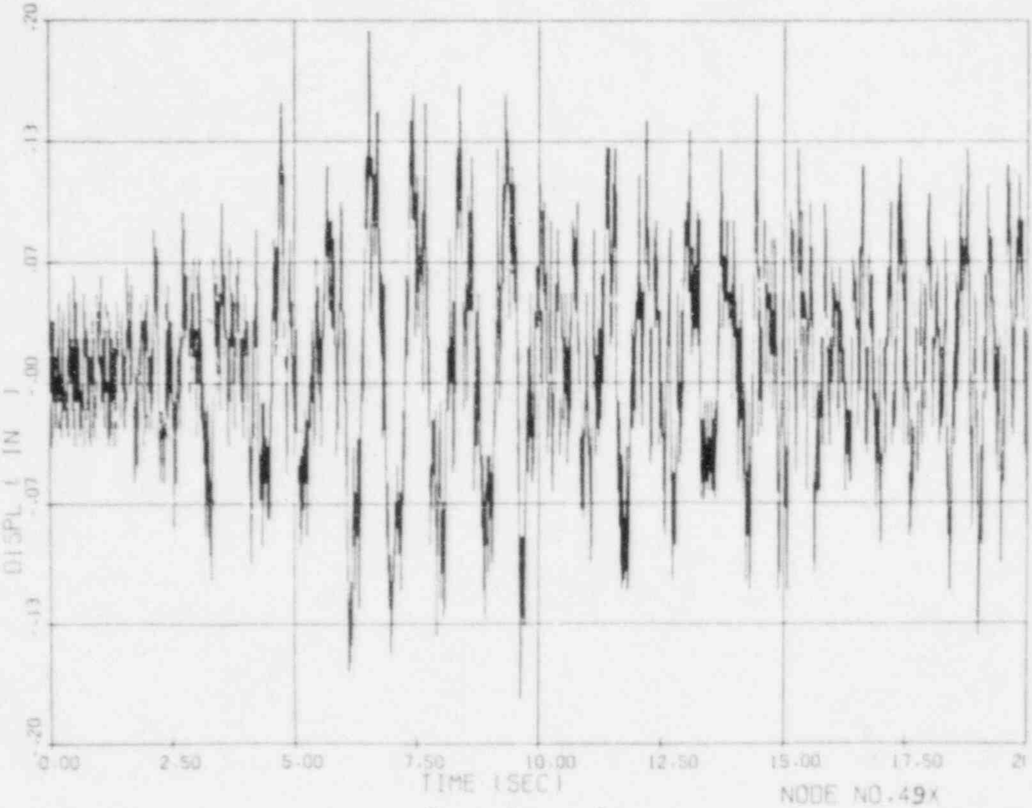


Experimental

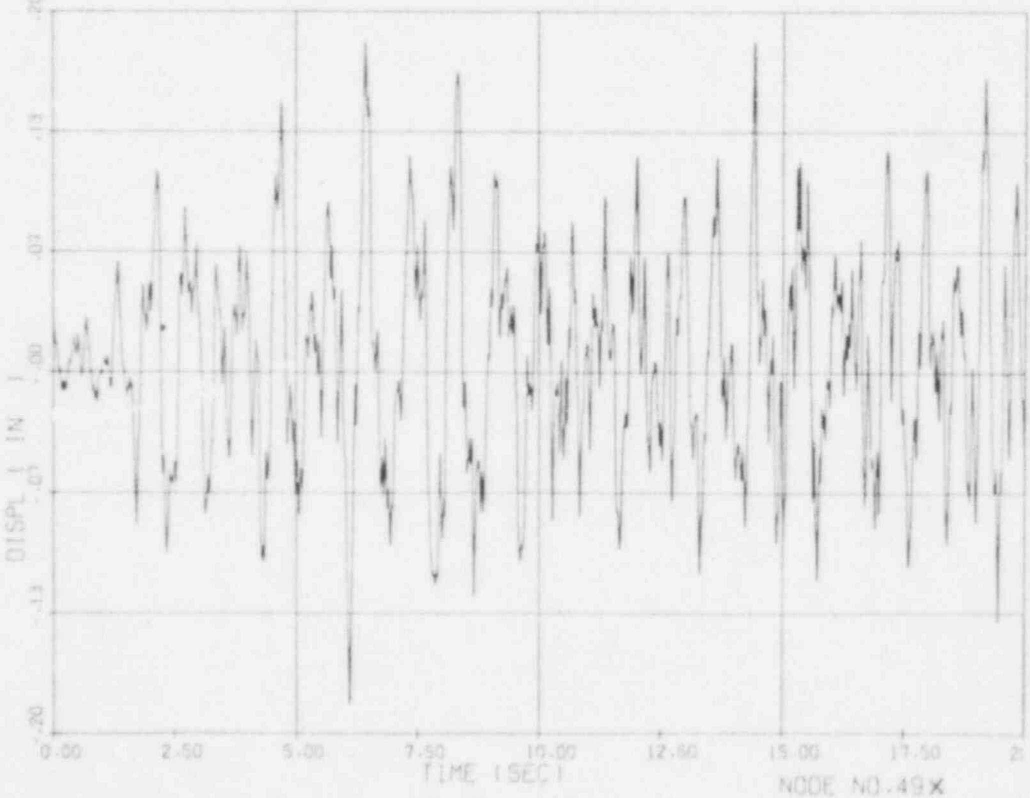


Analytical

Fig. 18. Displacement Response, Main Pipeline Node No. 46X

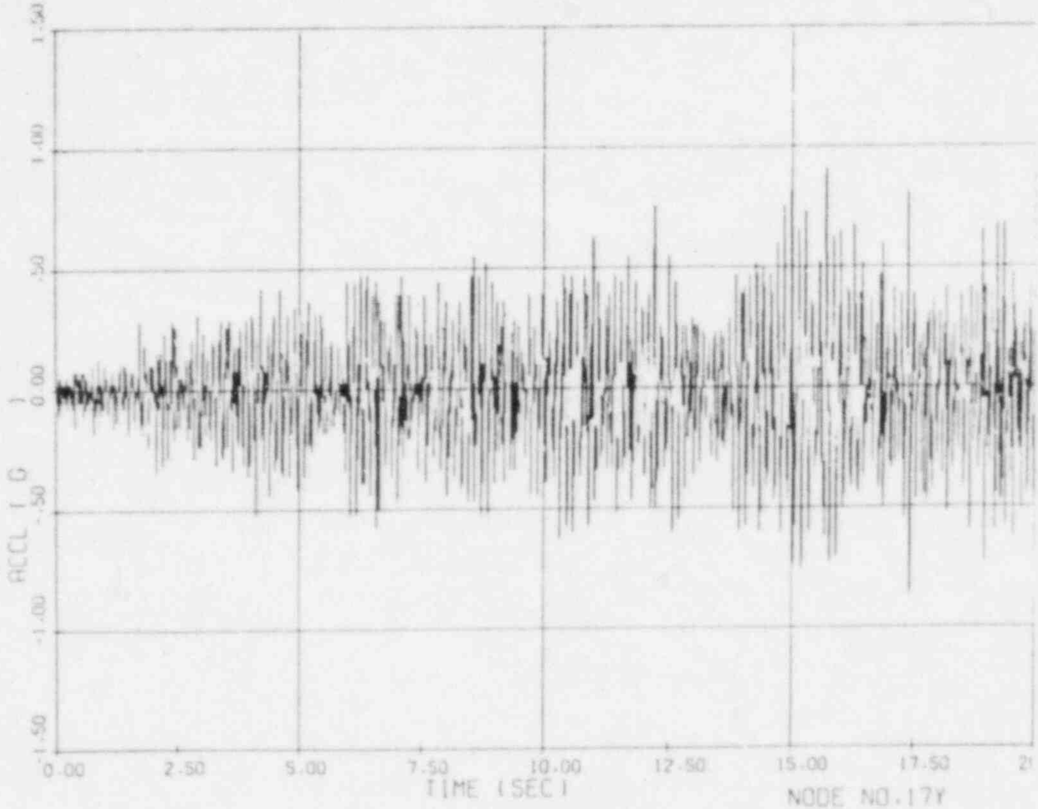


Experimental

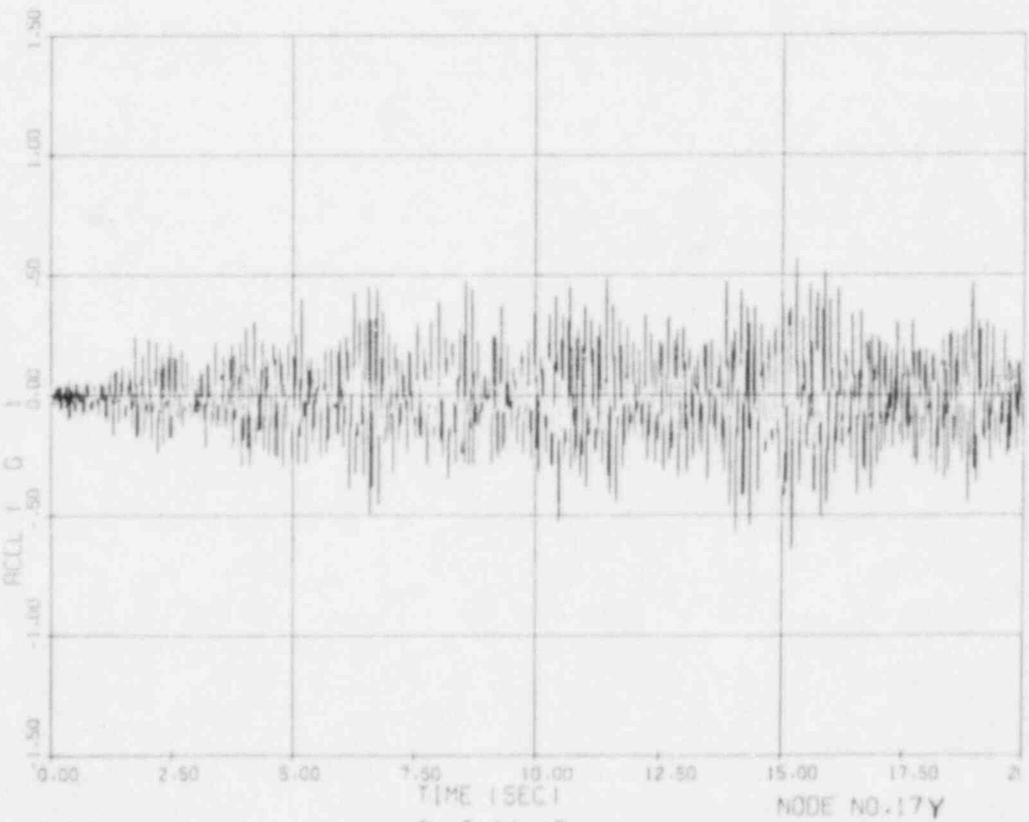


Analytical

Fig. 19. Displacement Response, Main Pipeline Node No. 49X

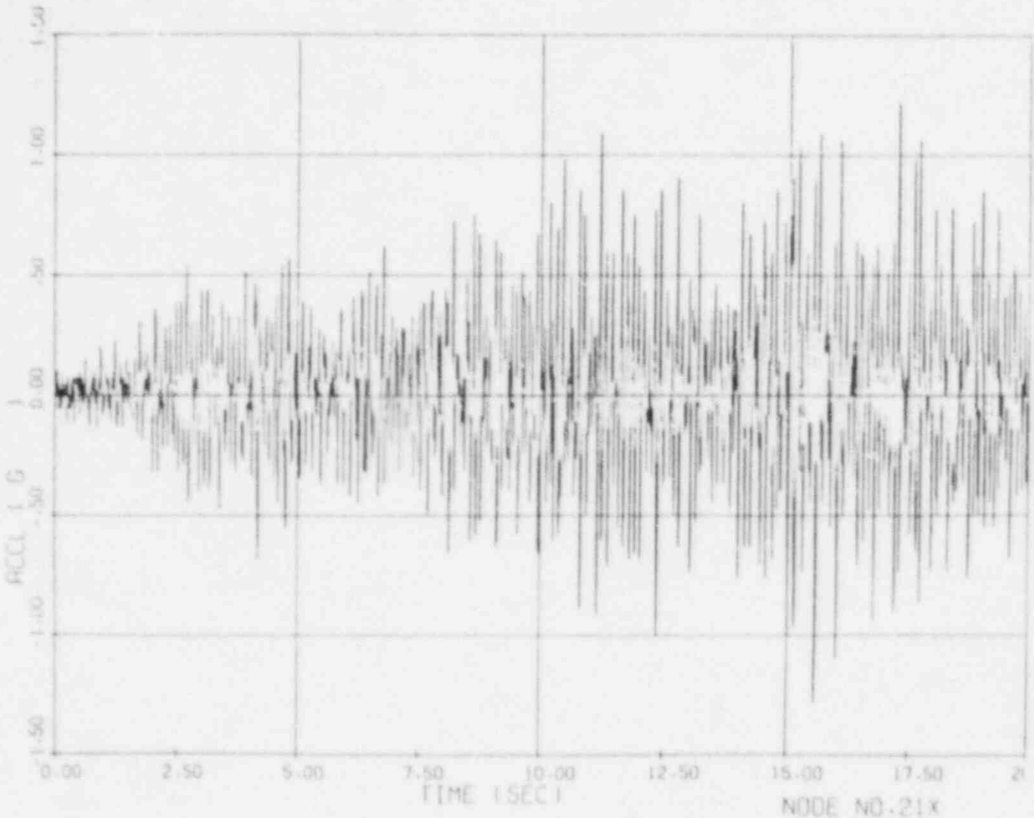


Experimental

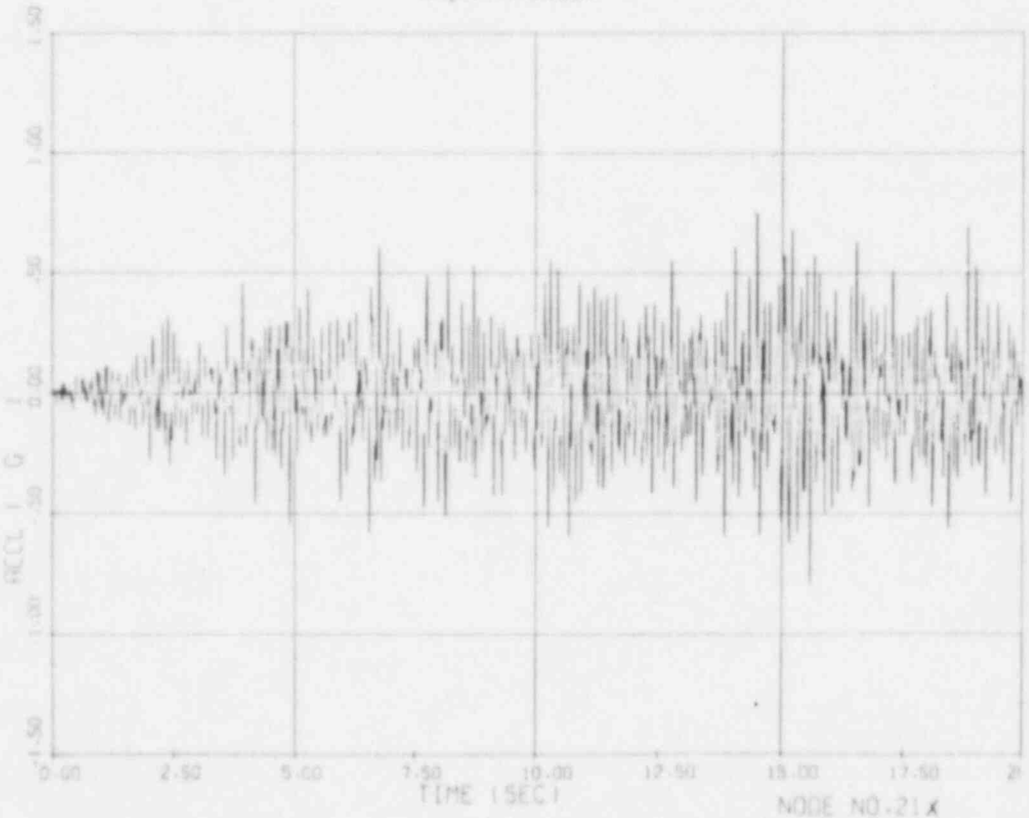


Analytical

Fig. 20. Acceleration Response, Main Pipeline Node No. 17Y

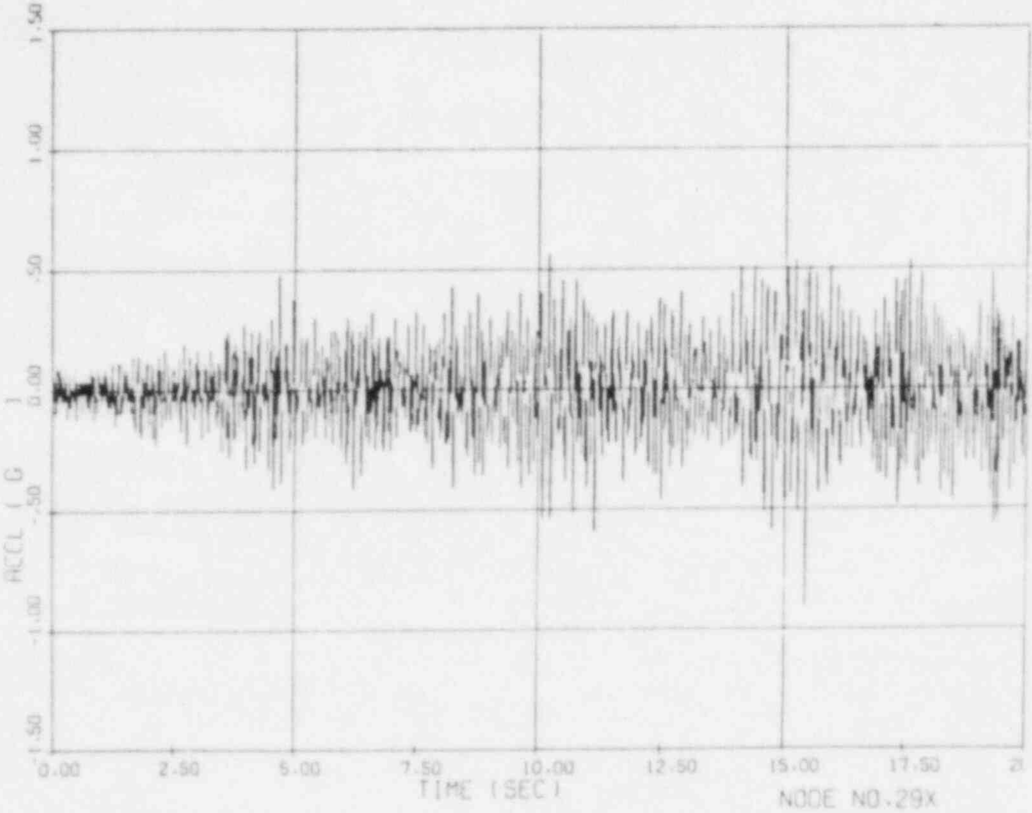


Experimental

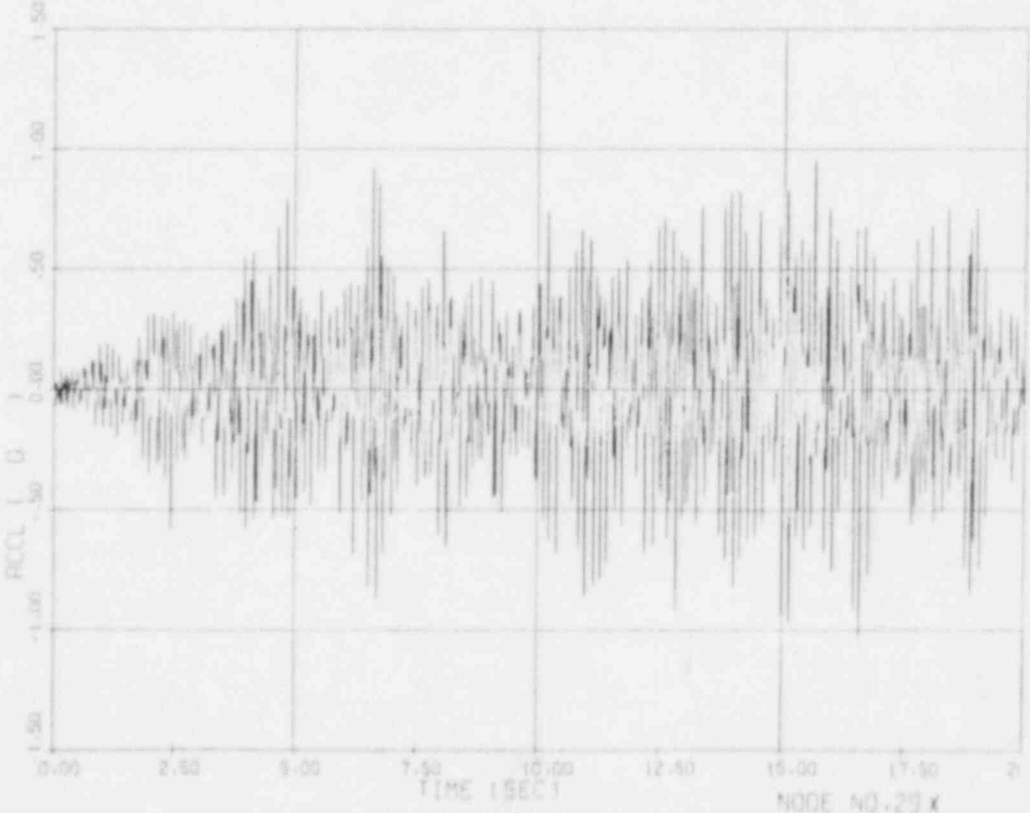


Analytical

Fig. 21. Acceleration Response, Main Pipeline Node No. 21X

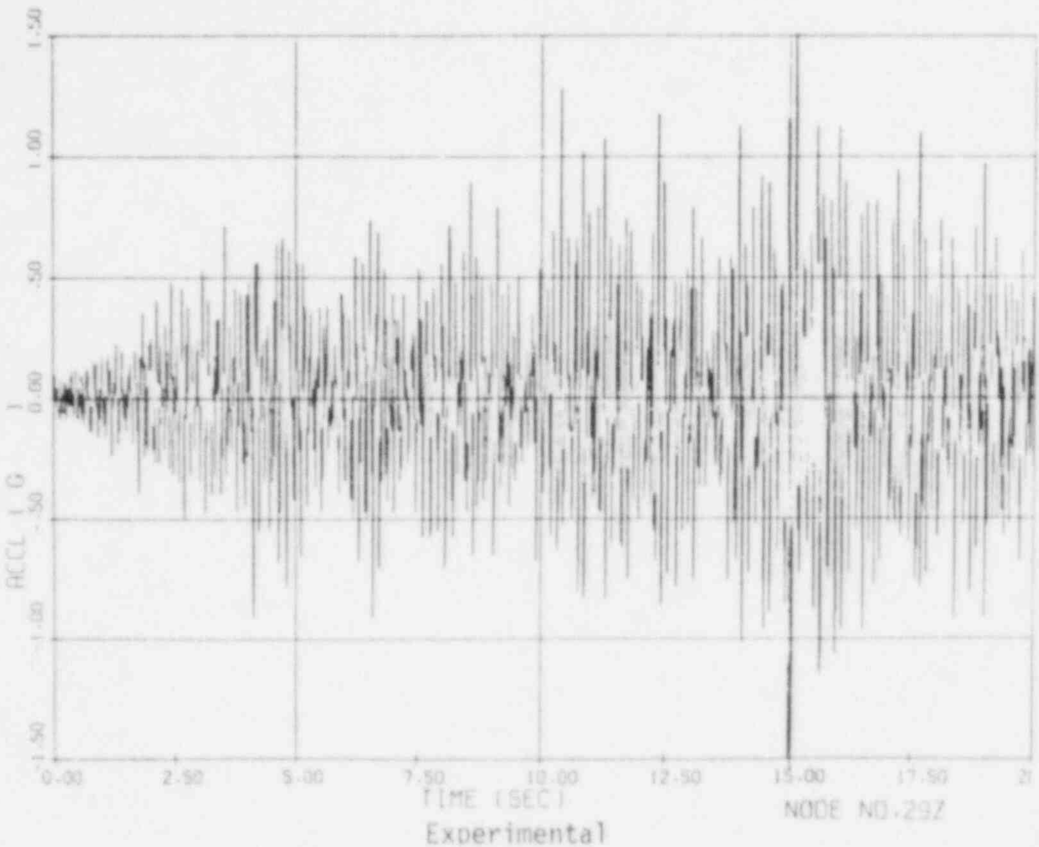


Experimental

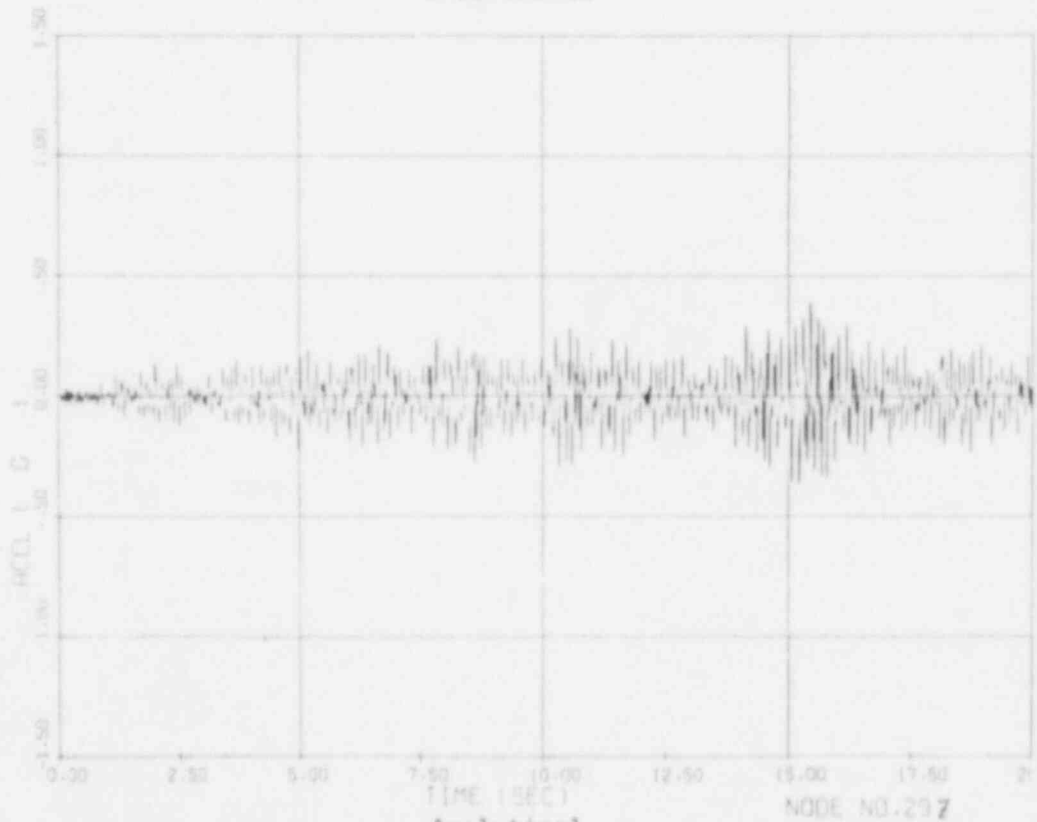


Analytical

Fig. 22. Acceleration Response, Main Pipeline Node No. 29X

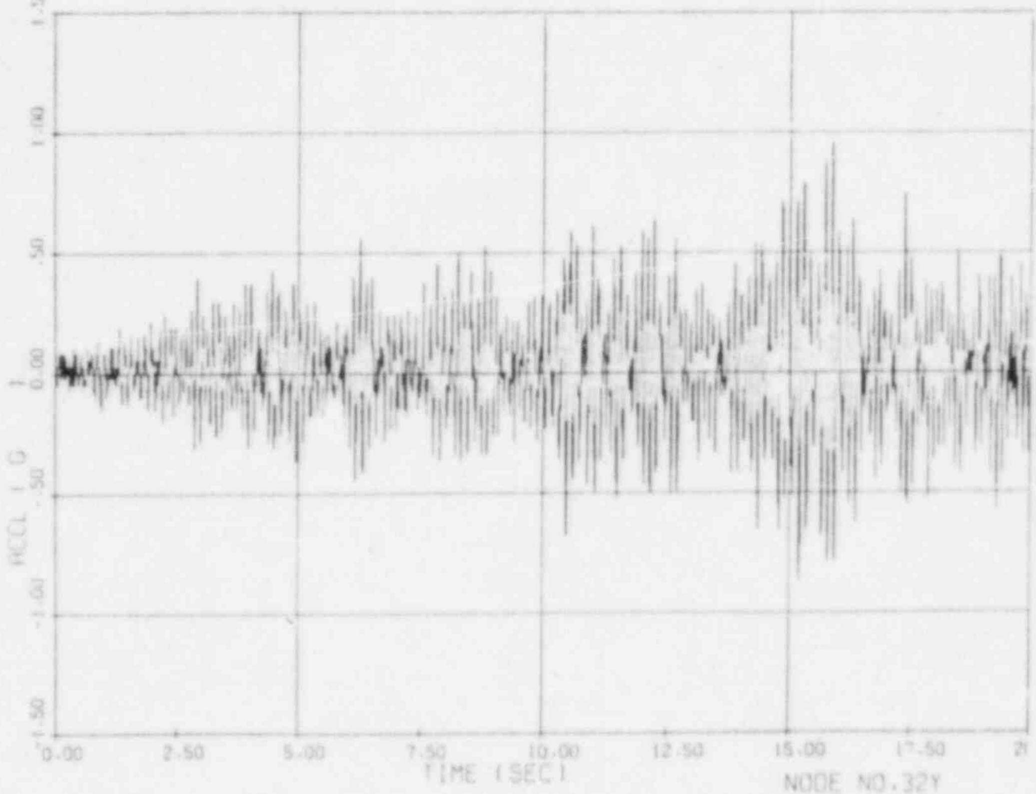


Experimental

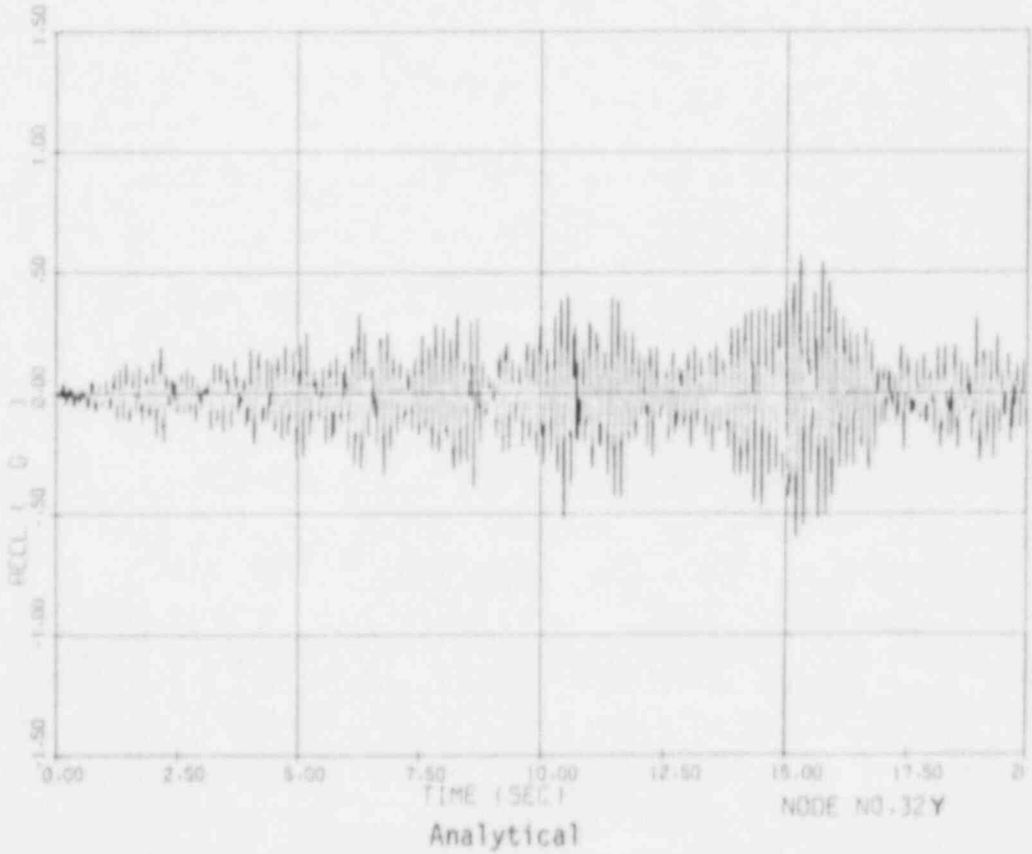


Analytical

Fig. 23. Acceleration Response, Main Pipeline Node No. 29Z

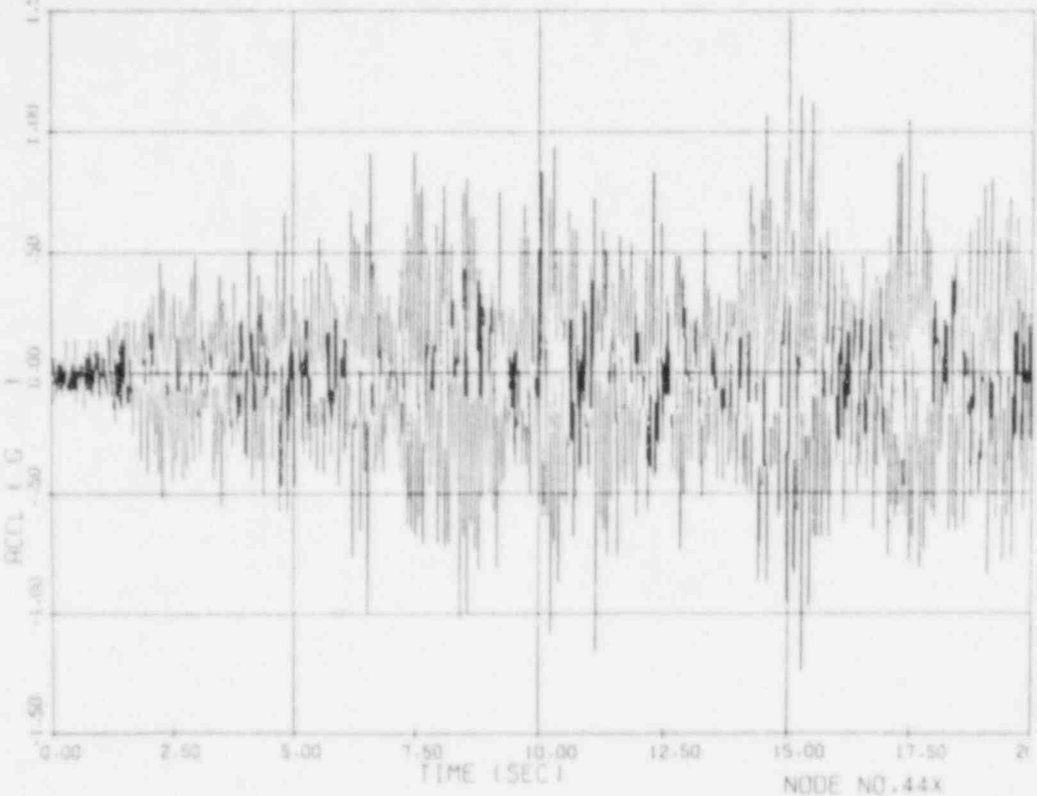


Experimental



Analytical

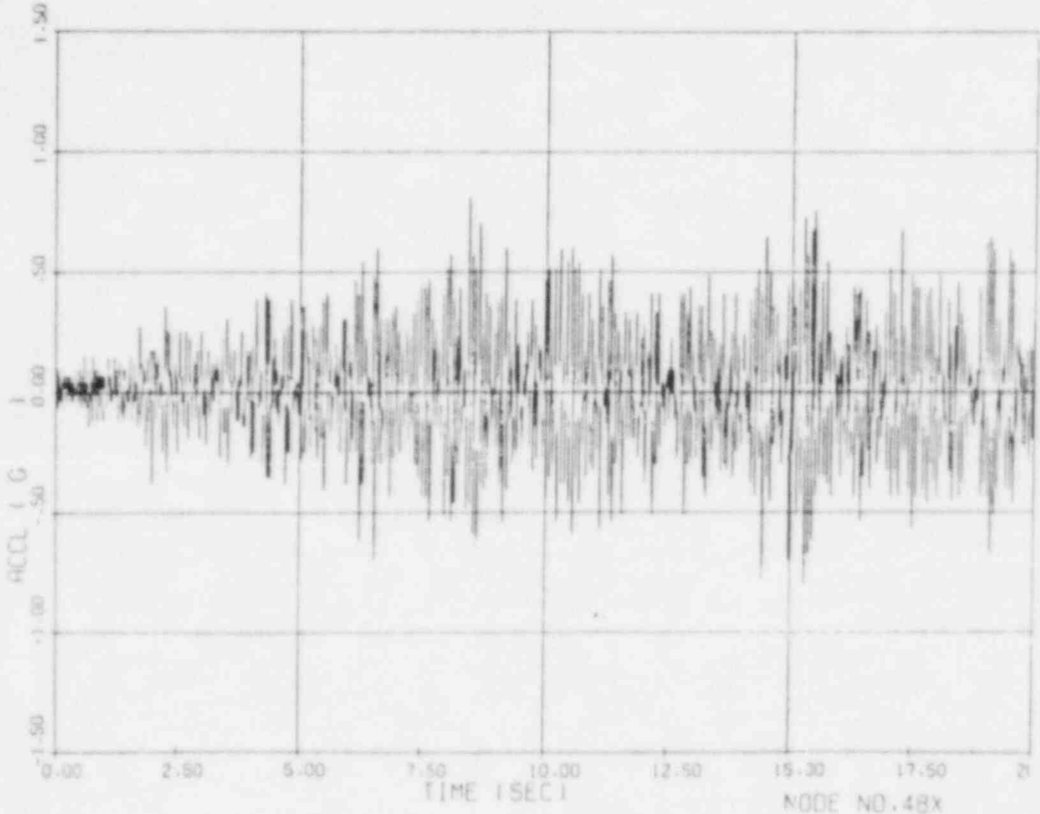
Fig. 24. Acceleration Response, Main Pipeline Node No. 32Y



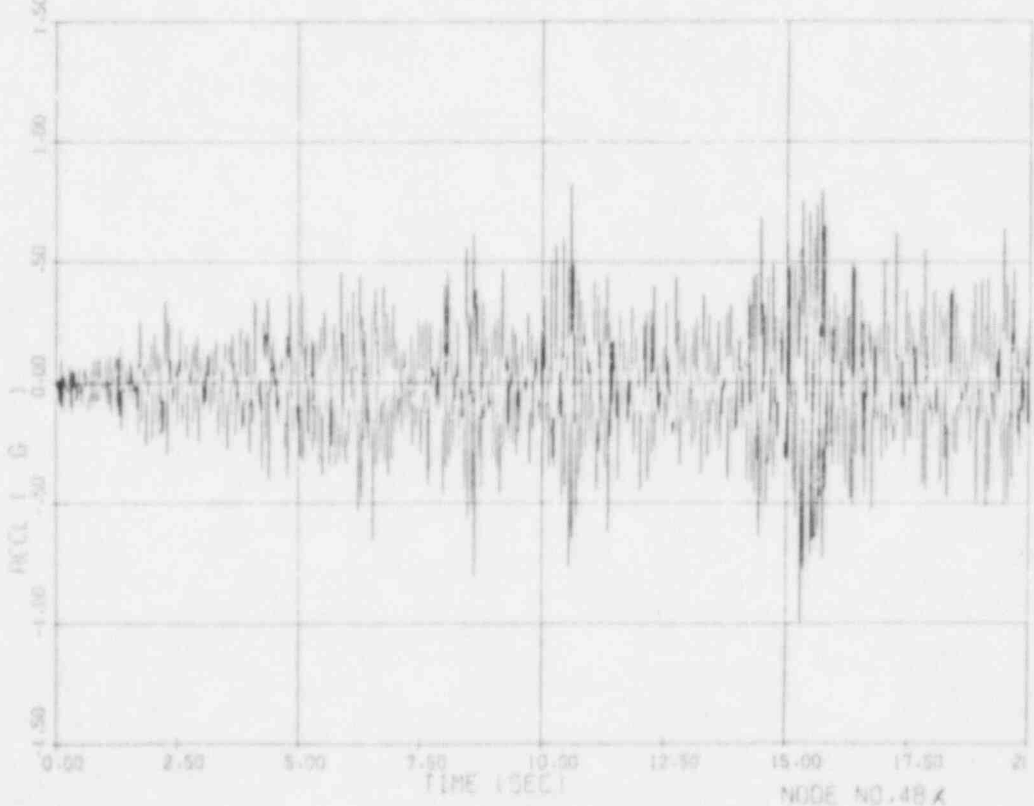
Experimental

Analytical

Fig. 25. Acceleration Response, Main Pipeline Node No. 44X

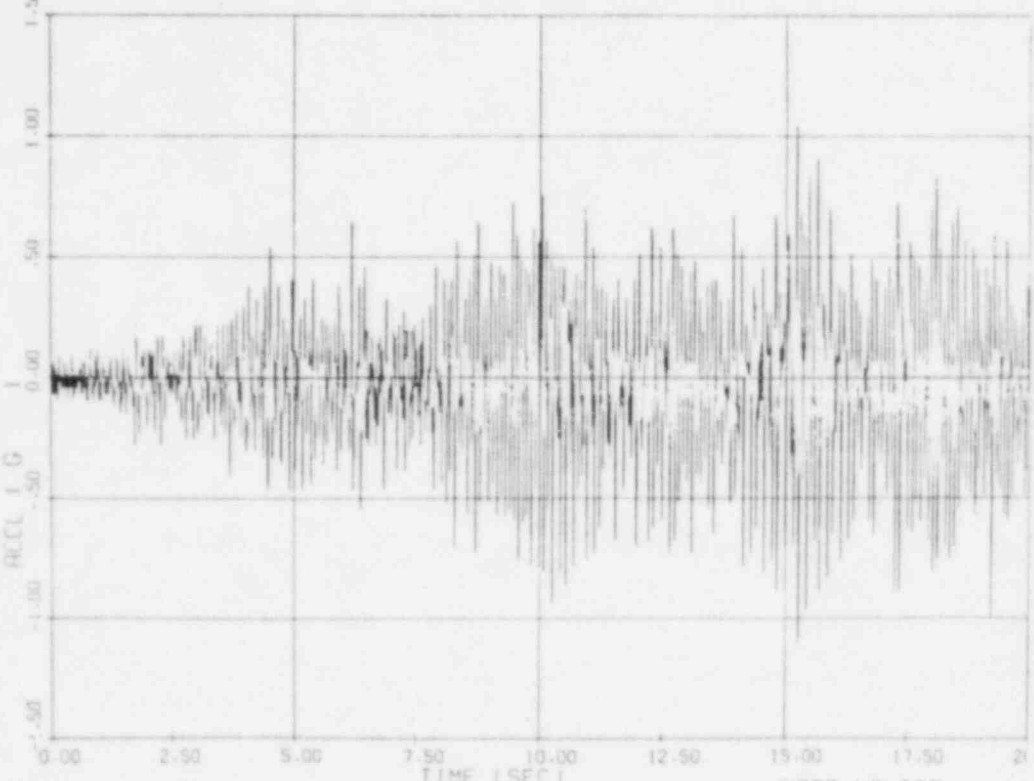


Experimental

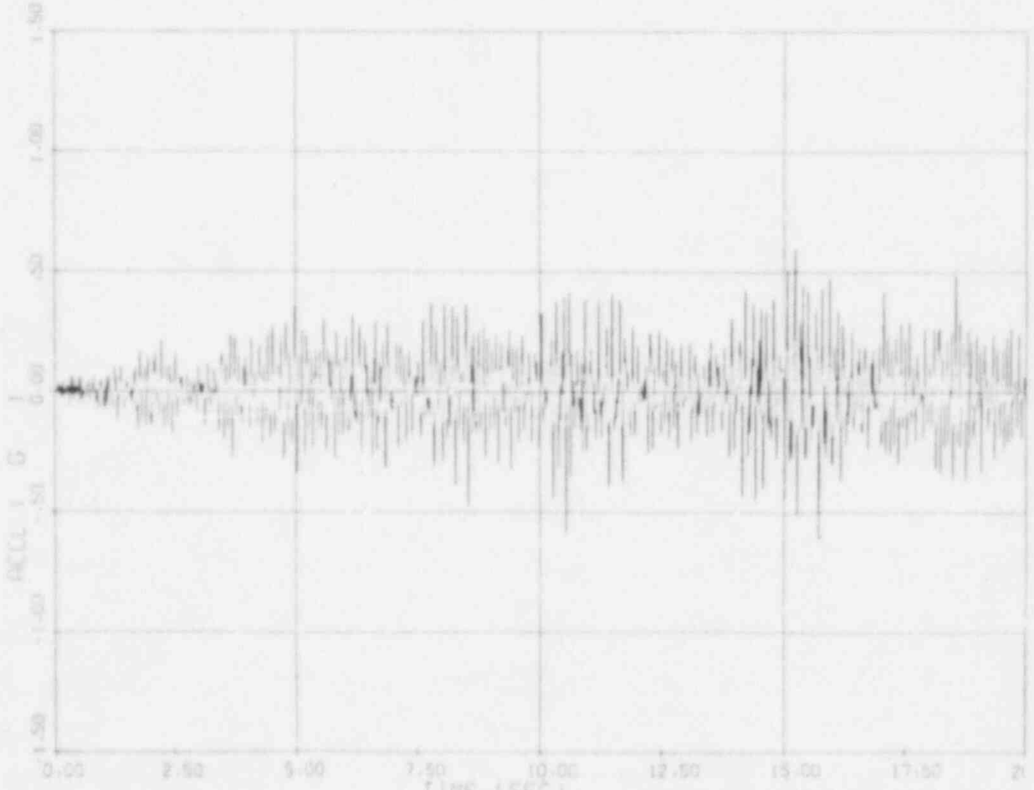


Analytical

Fig. 26. Acceleration Response, Main Pipeline Node No. 48X

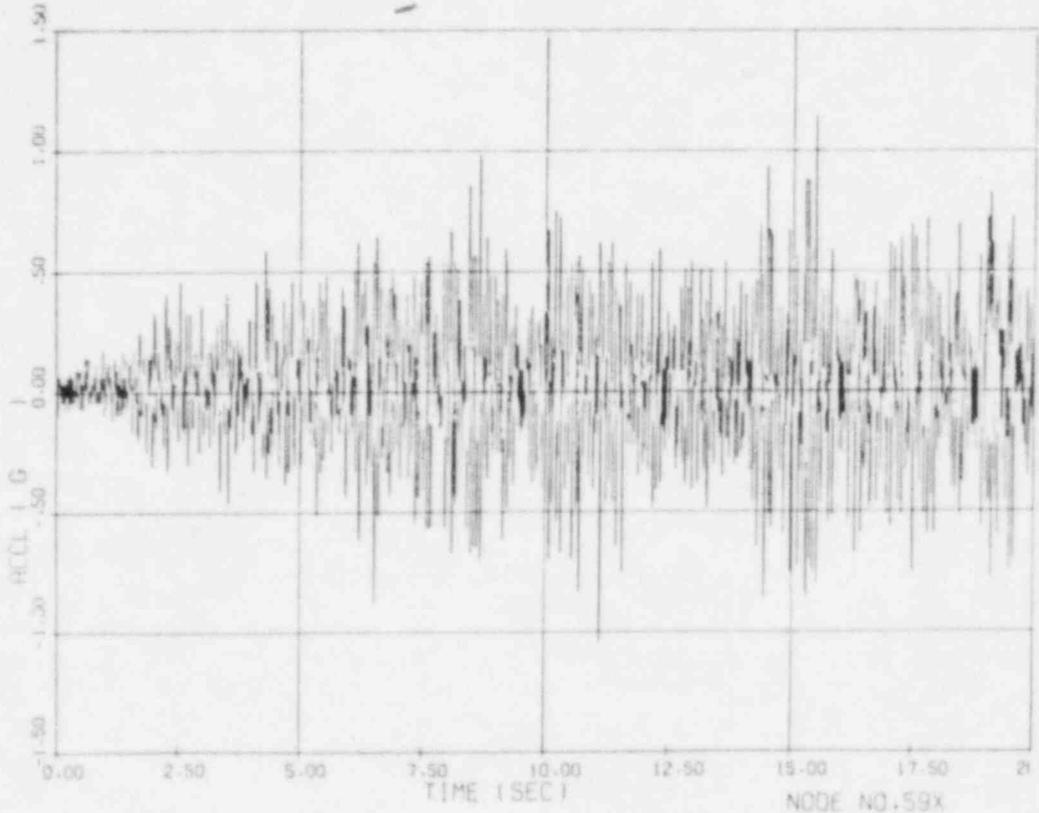


Experimental

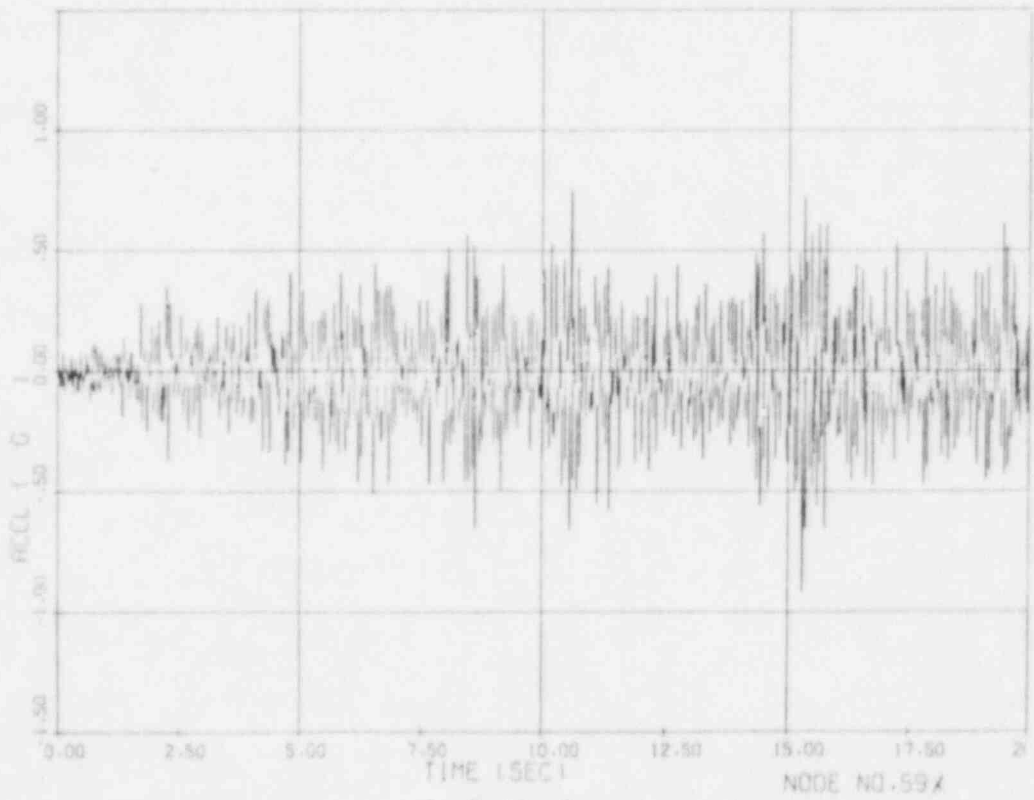


Analytical

Fig. 27. Acceleration Response, Main Pipeline Node No. 52Z

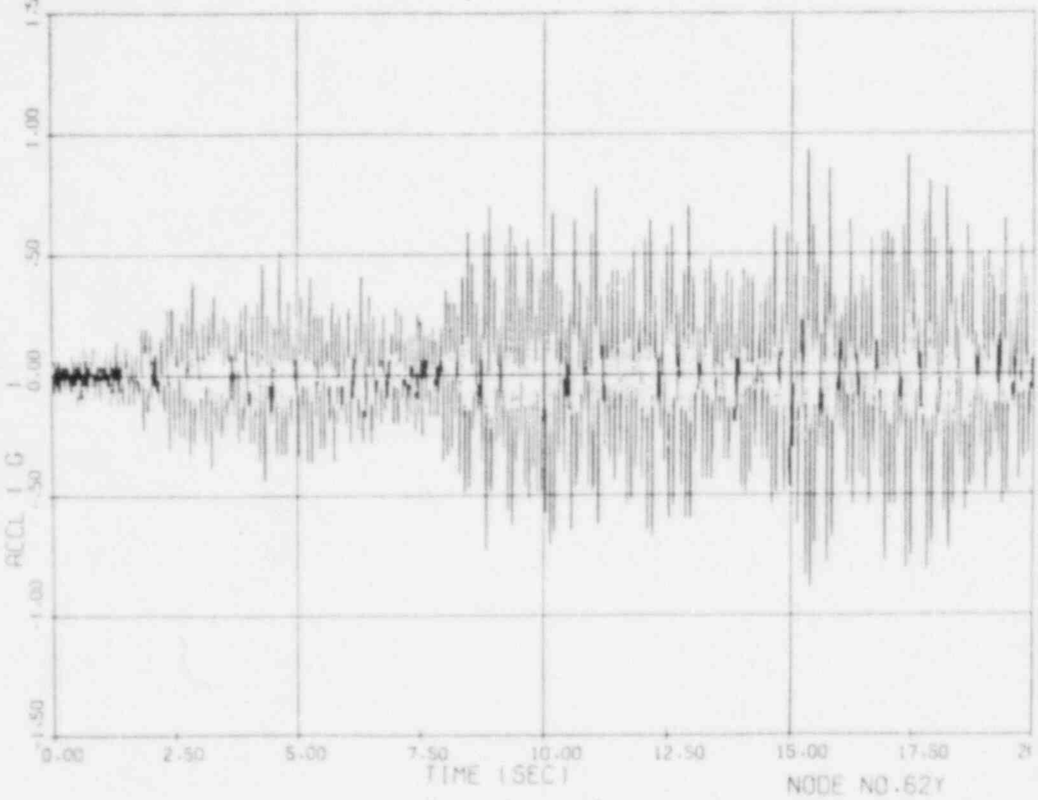


Experimental

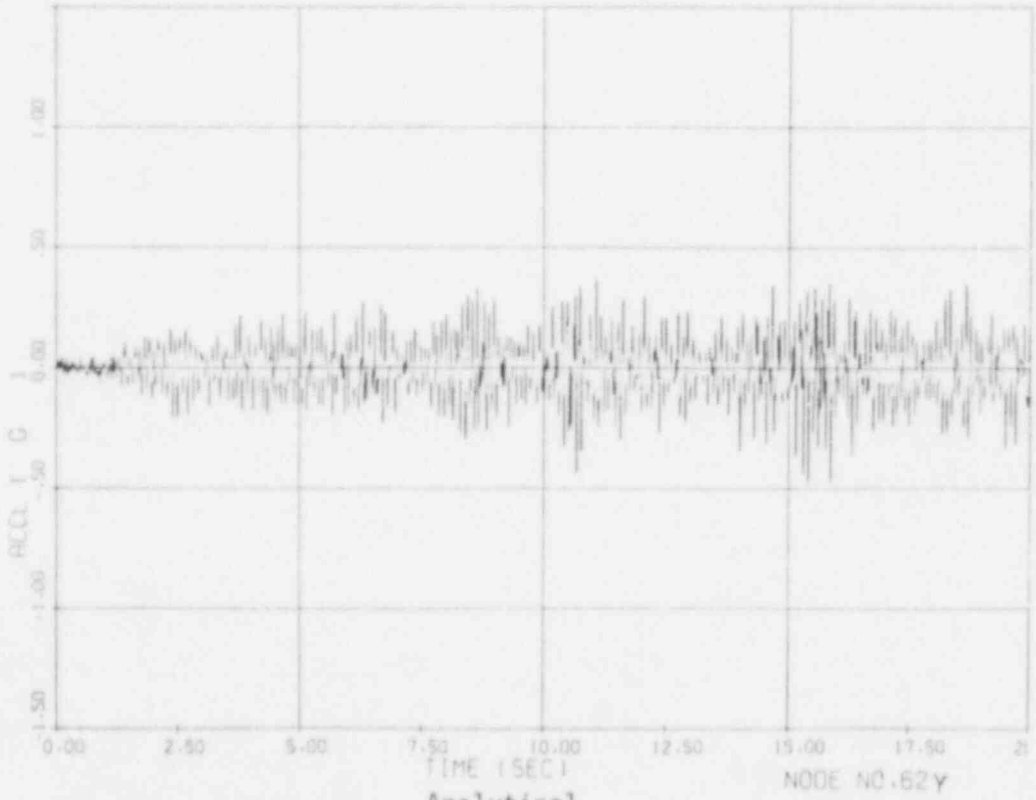


Analytical

Fig. 28. Acceleration Response, Main Pipeline Node No. 59X



Experimental



Analytical

Fig. 29. Acceleration Response, Main Pipeline Node No. 62Y

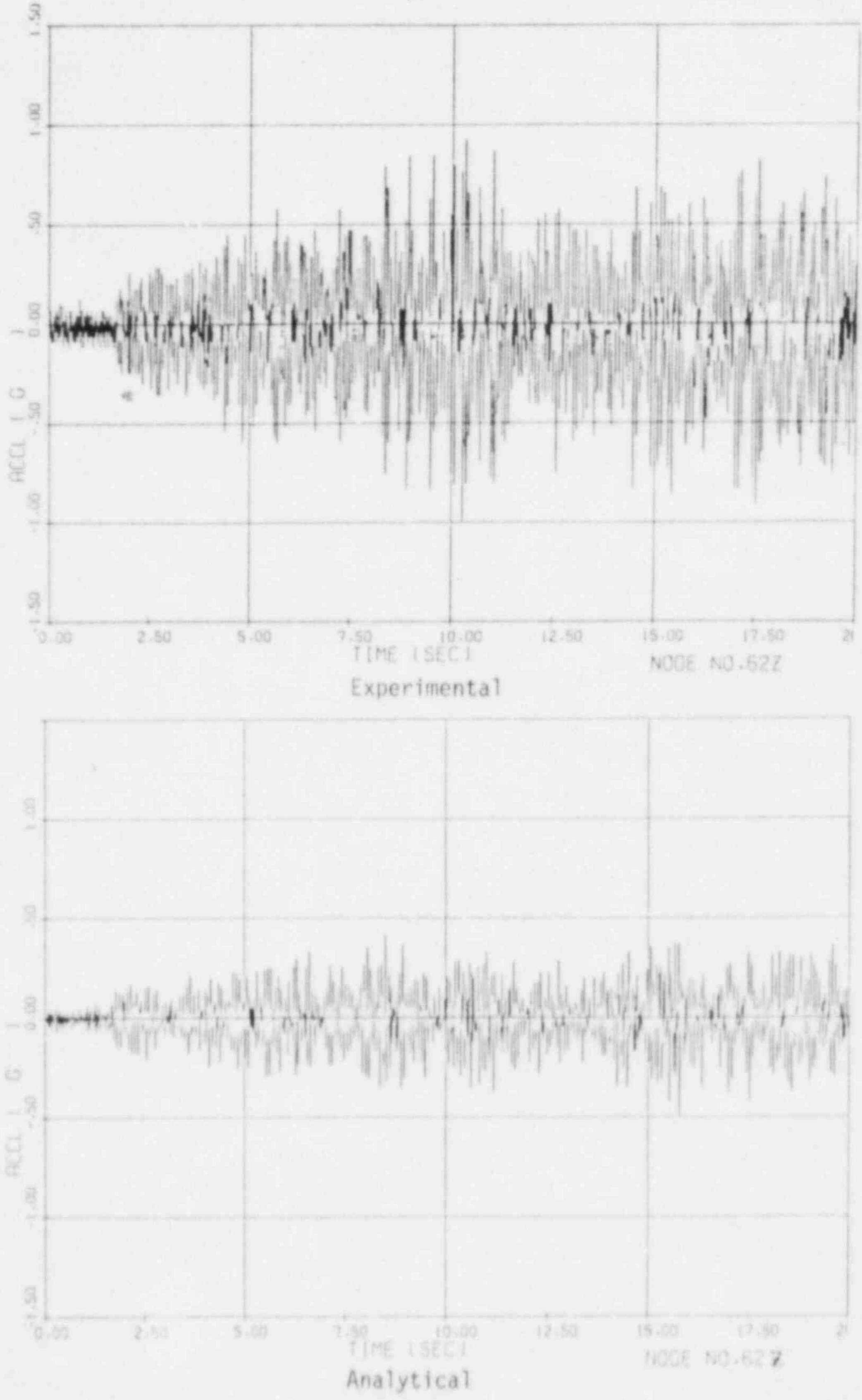
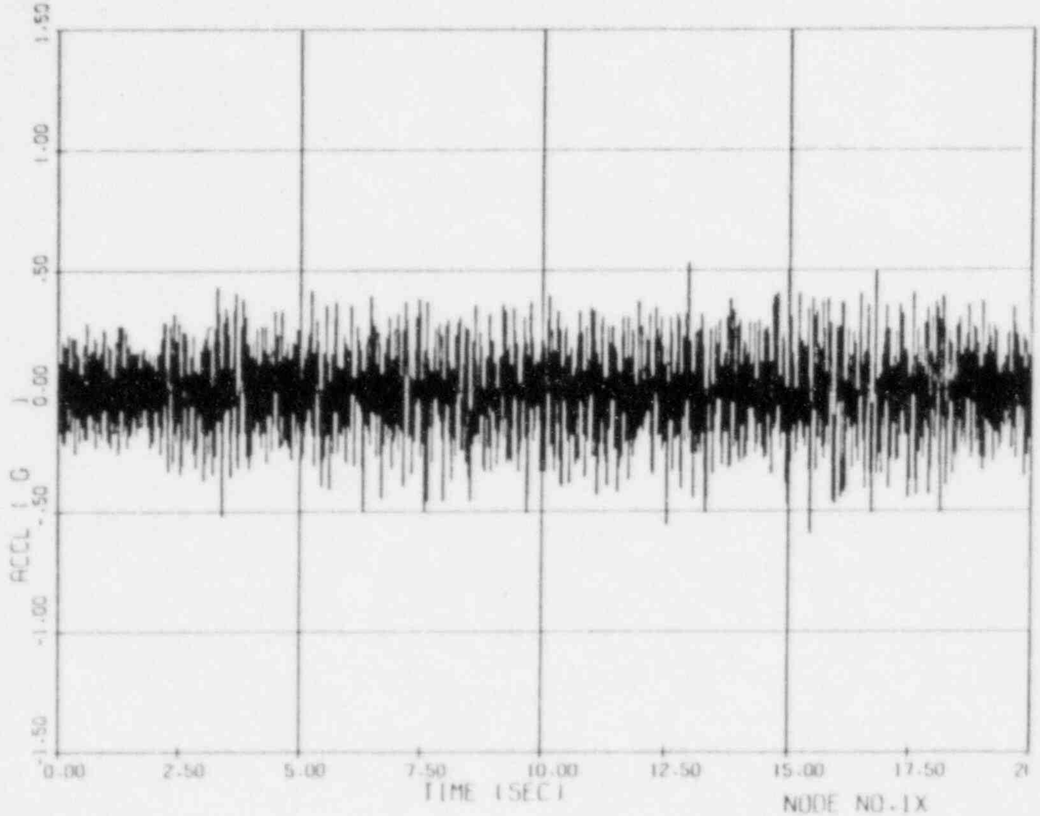
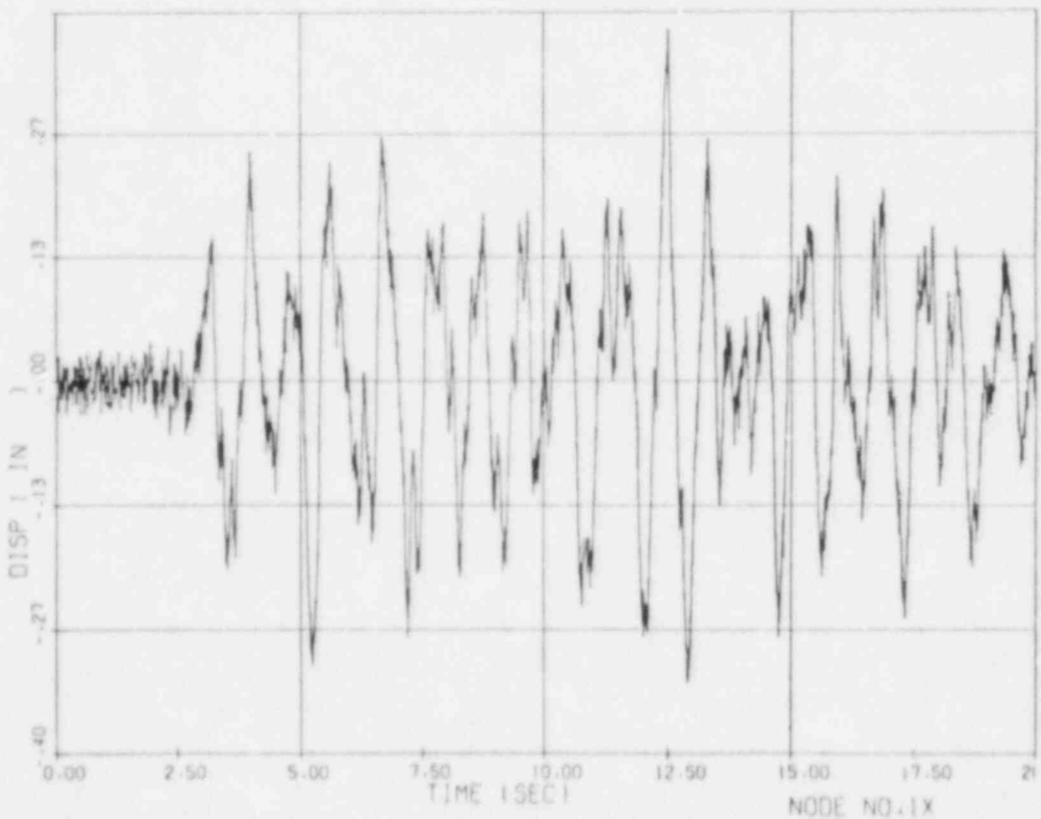


Fig. 30. Acceleration Response, Main Pipeline Node No. 62Z

Time History Records
Main Pipeline With Branches

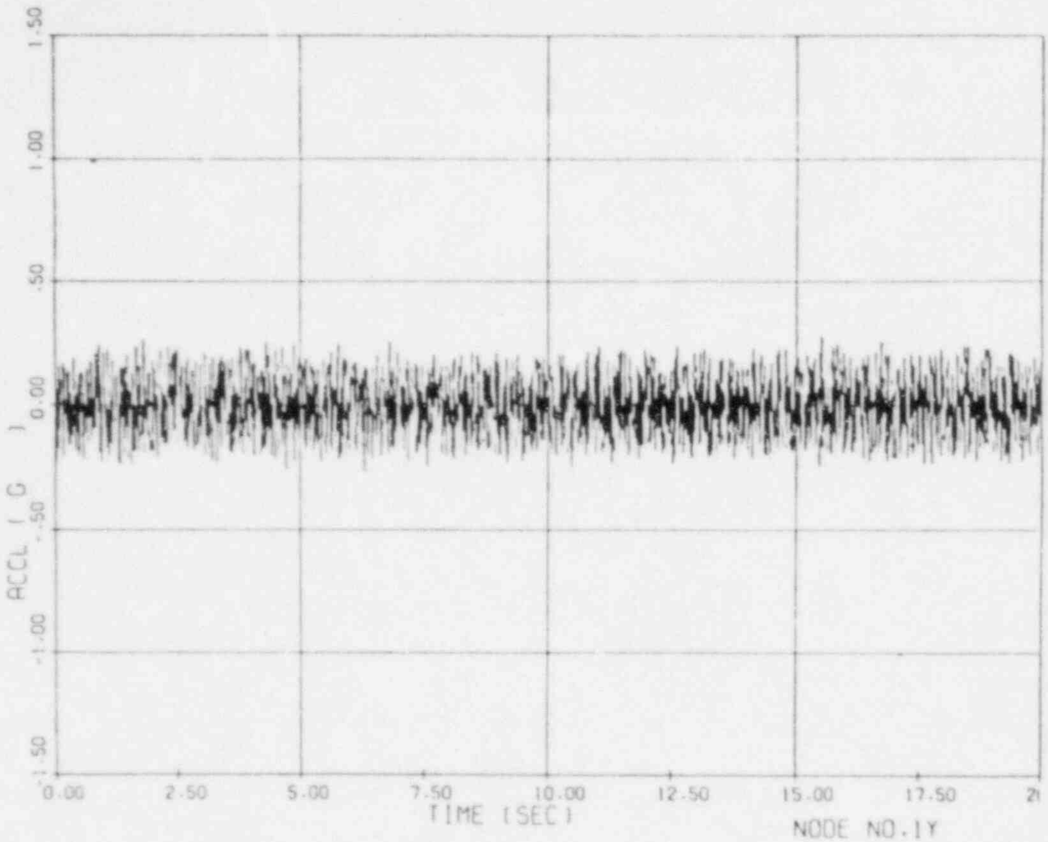


Acceleration

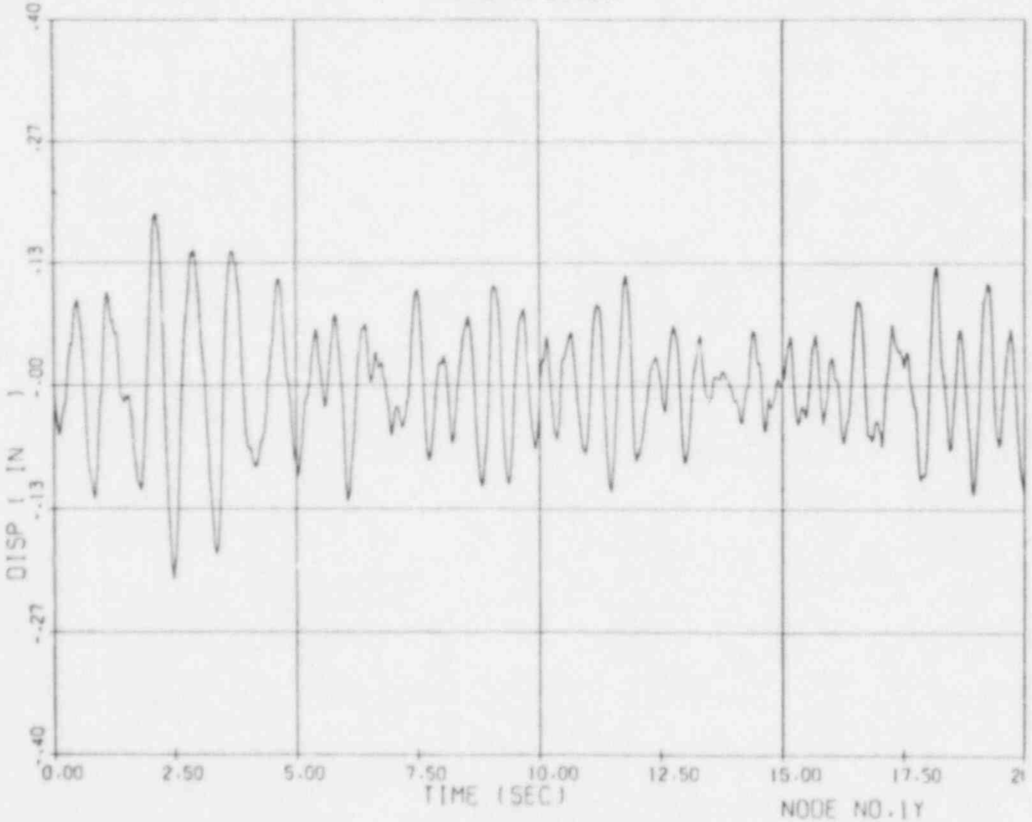


Displacement

Fig. 31. Input Main Pipeline With Branches Node No. 1X (Carriage S1)

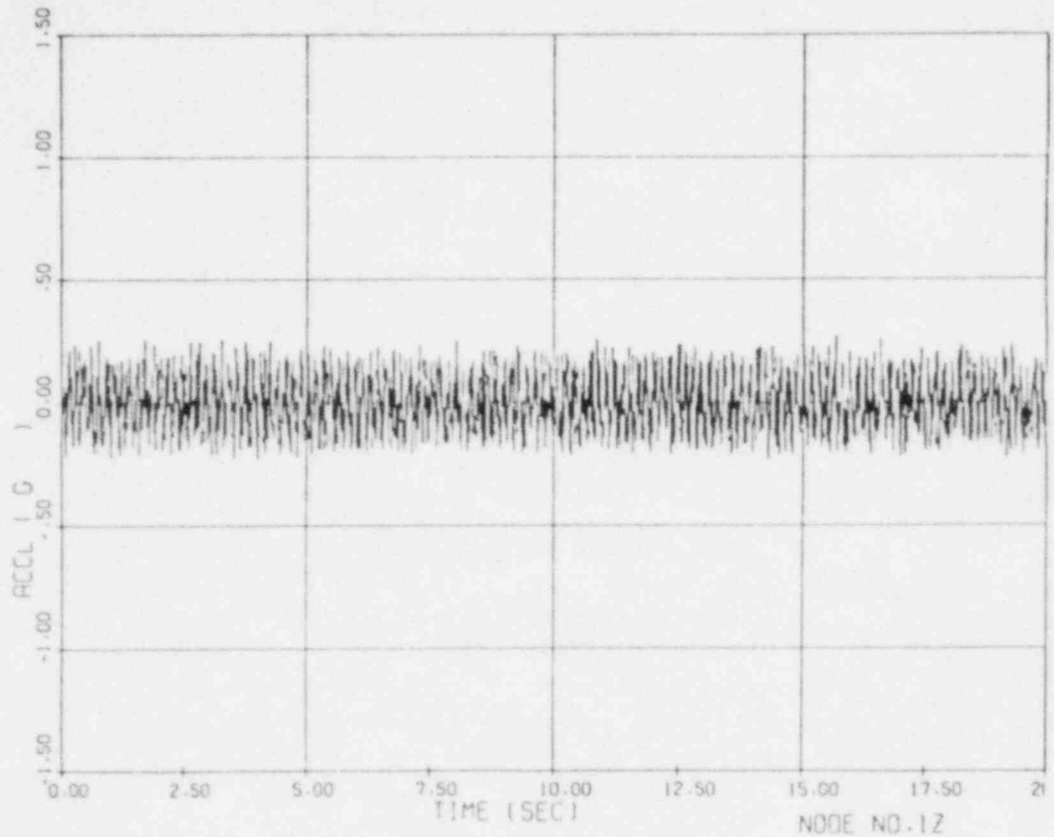


Acceleration

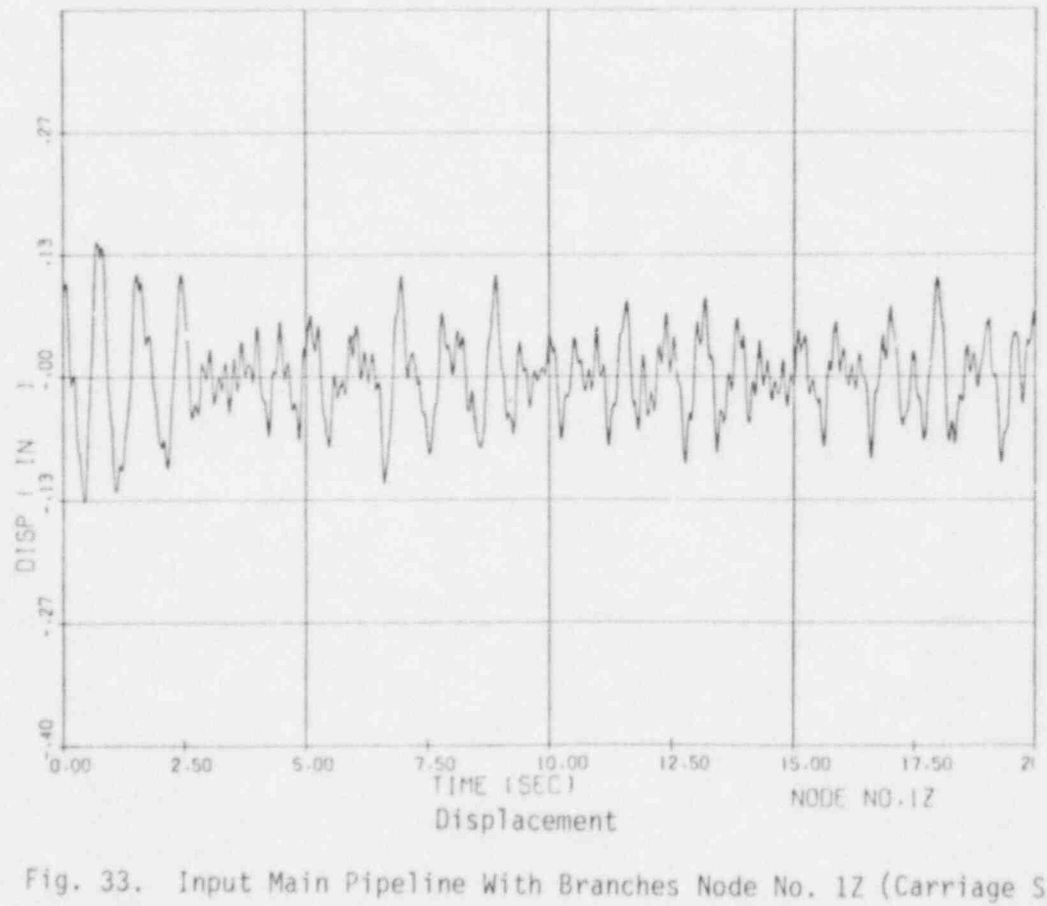


Displacement

Fig. 32. Input Main Pipeline With Branches Node No. 1Y (Carriage S1)

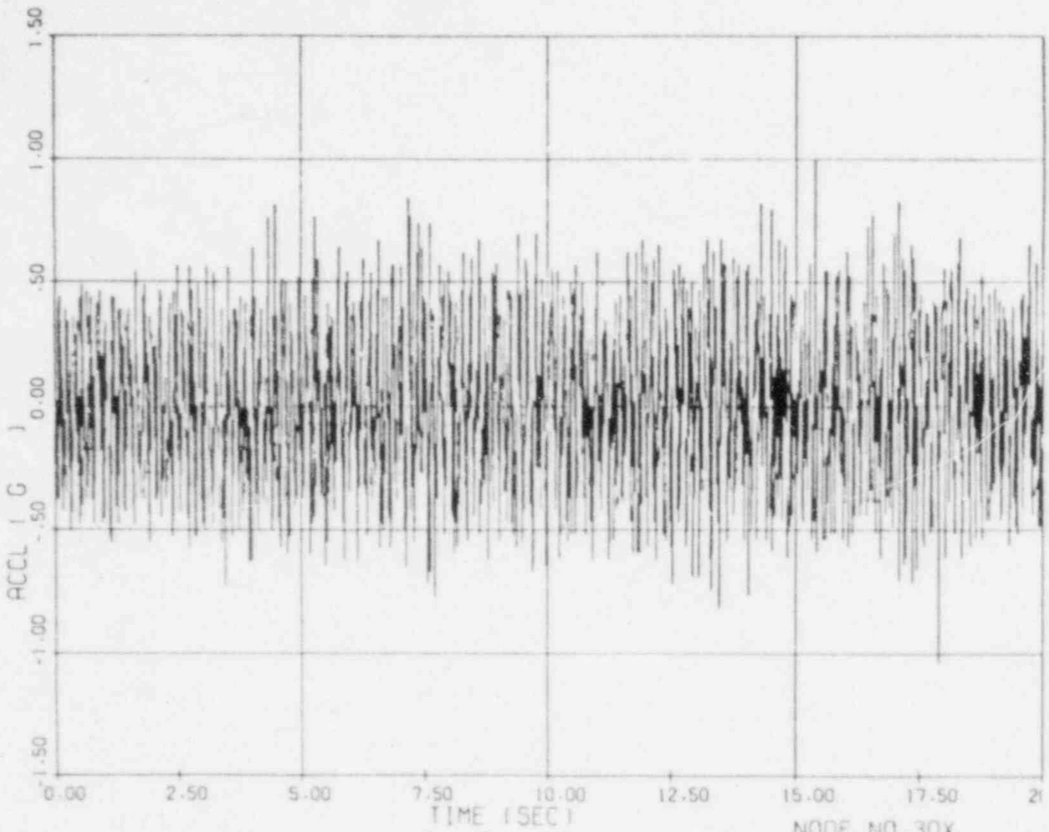


Acceleration

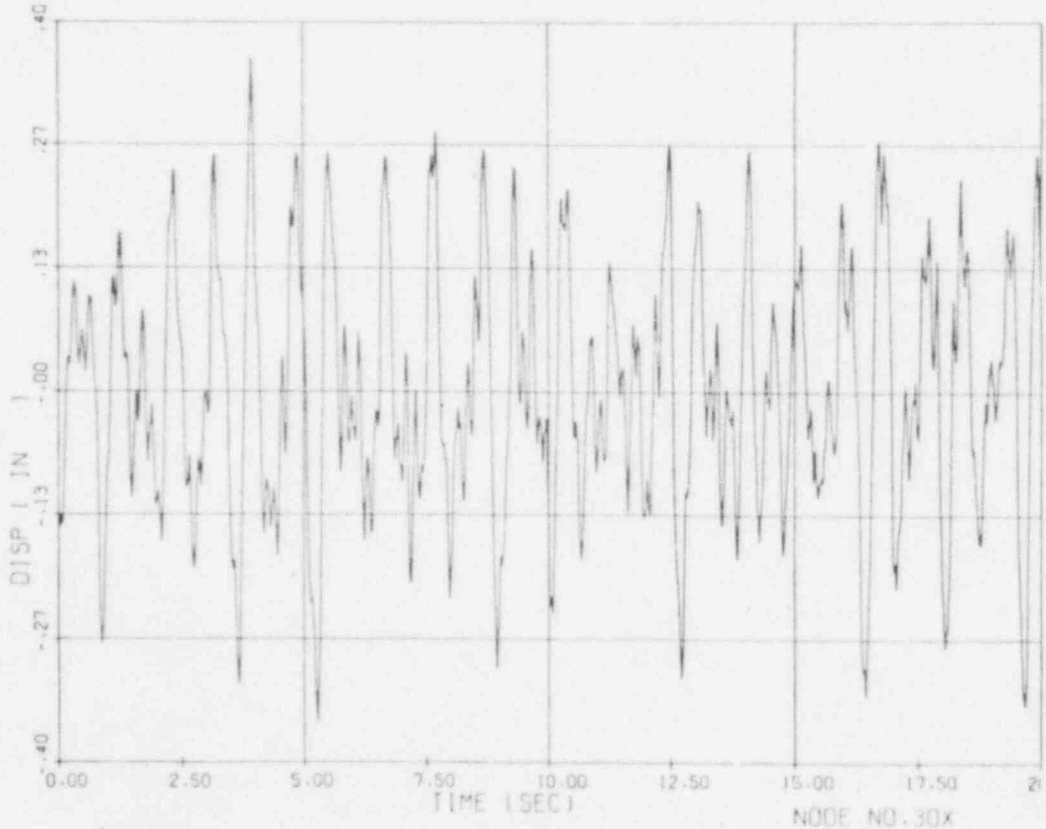


Displacement

Fig. 33. Input Main Pipeline With Branches Node No. 1Z (Carriage S1)

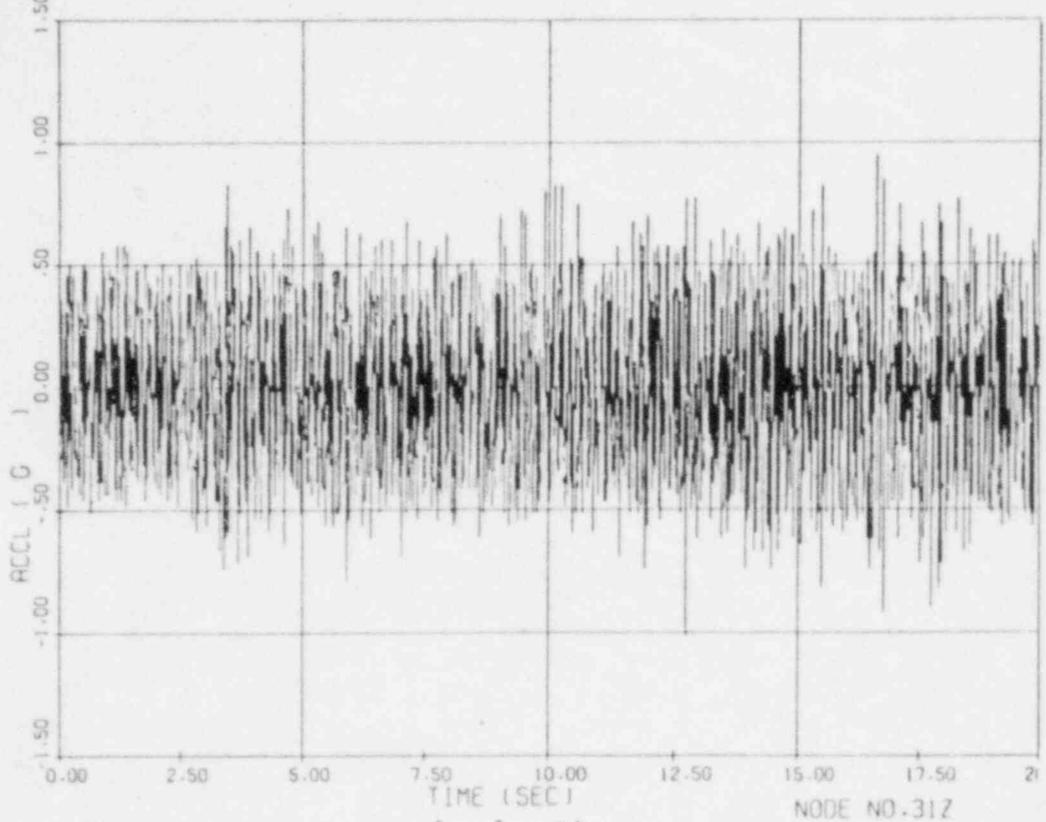


Acceleration

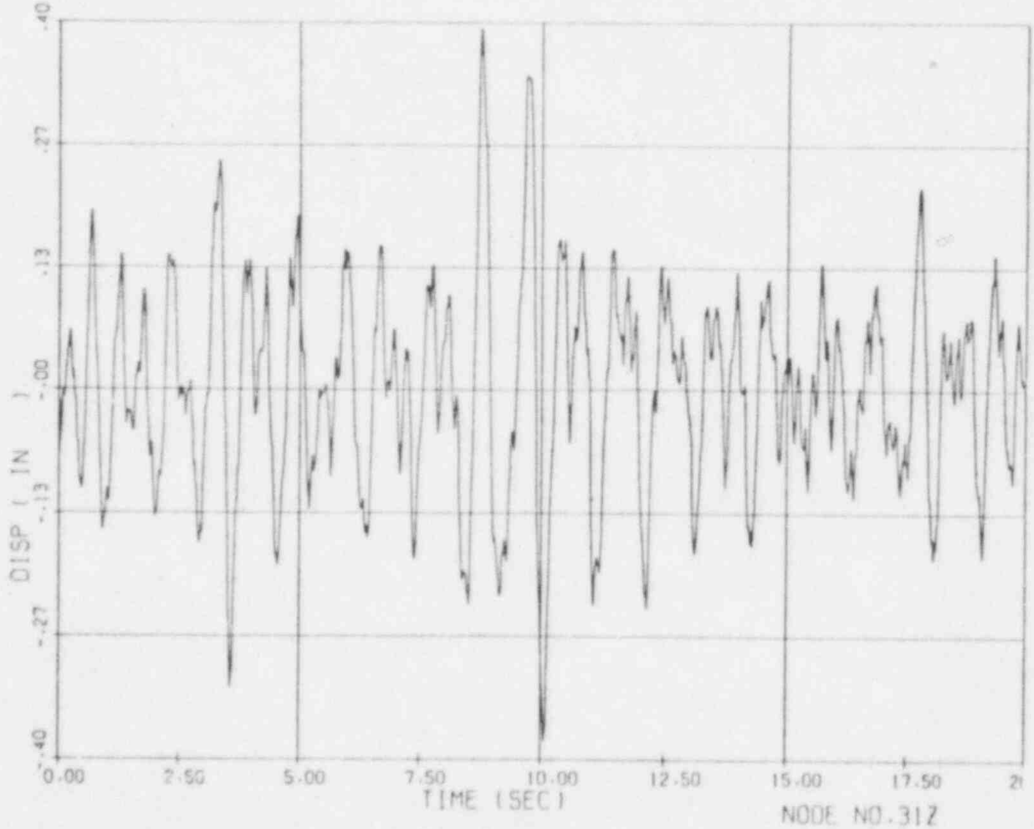


Displacement

Fig. 34. Input Main Pipeline With Branches Node No. 30X



Acceleration



Displacement

Fig. 35. Input Main Pipeline With Branches Node No. 31Z

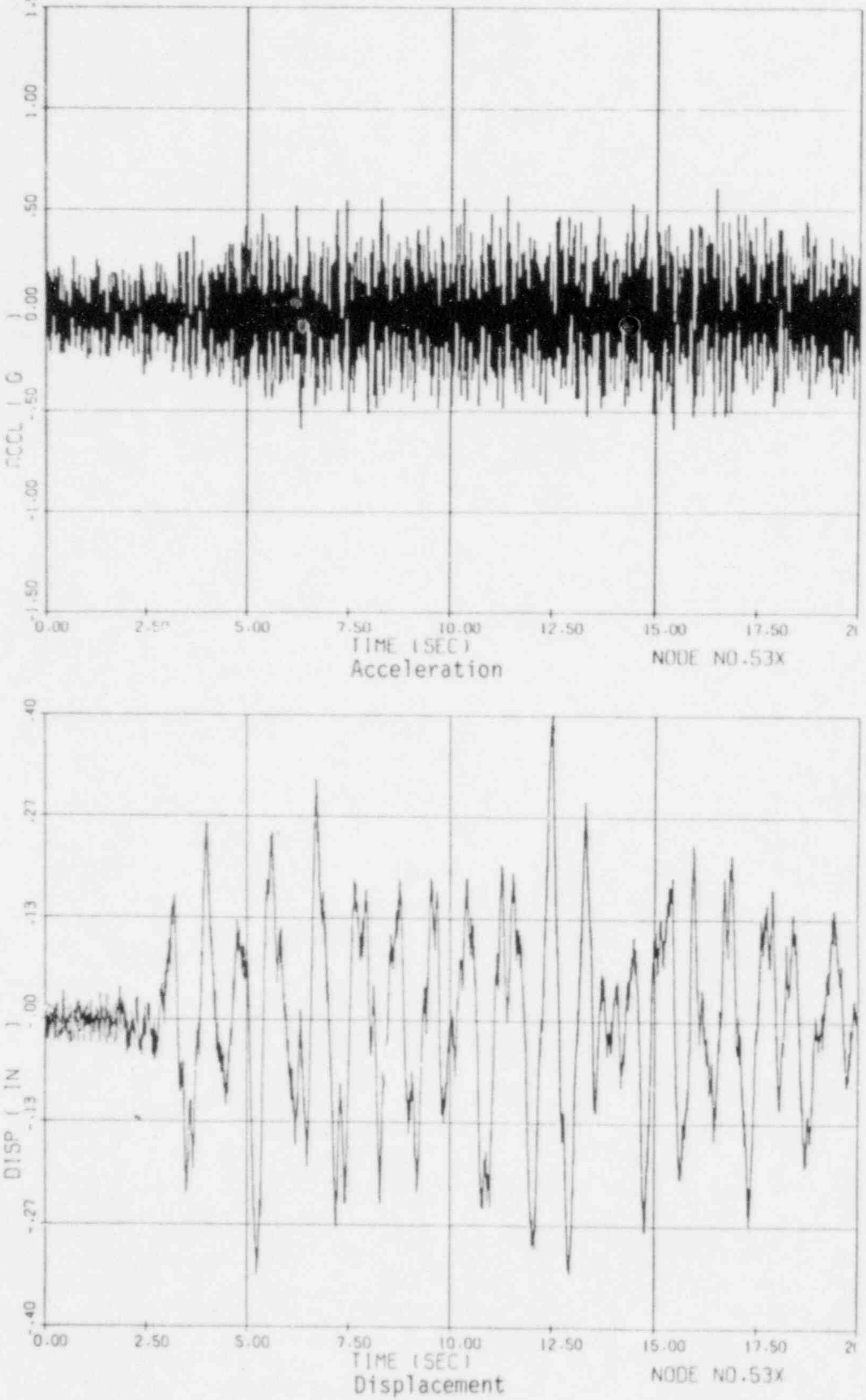
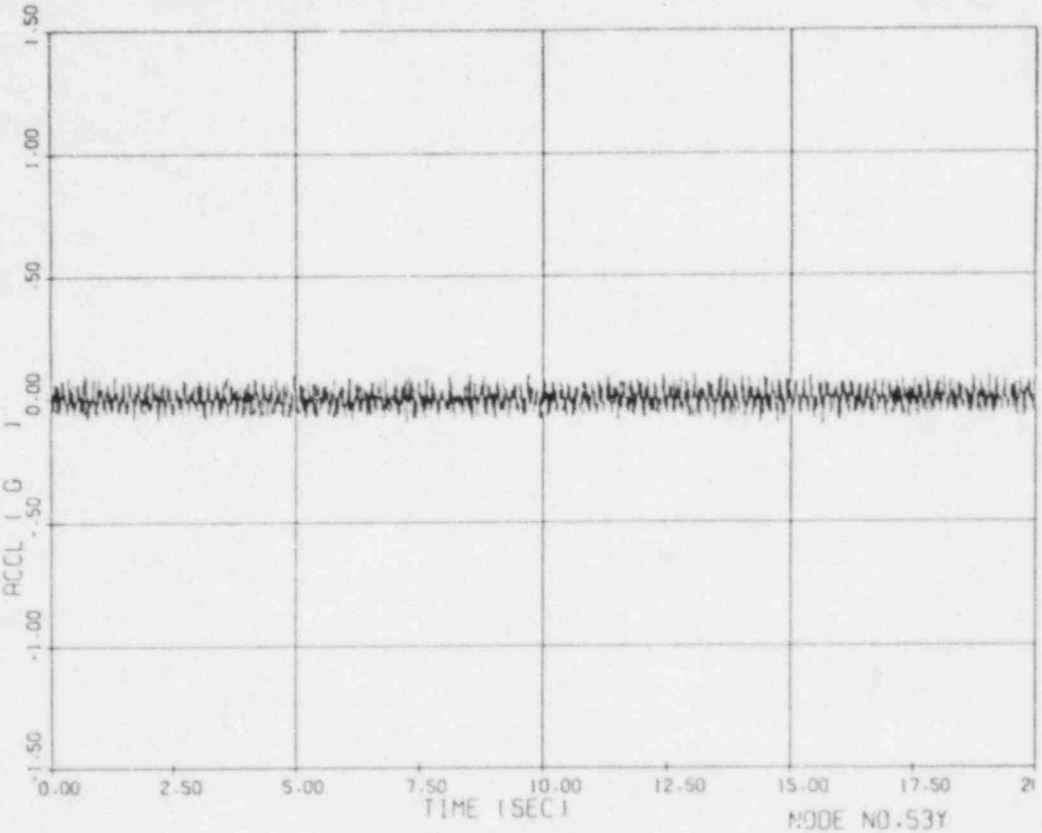
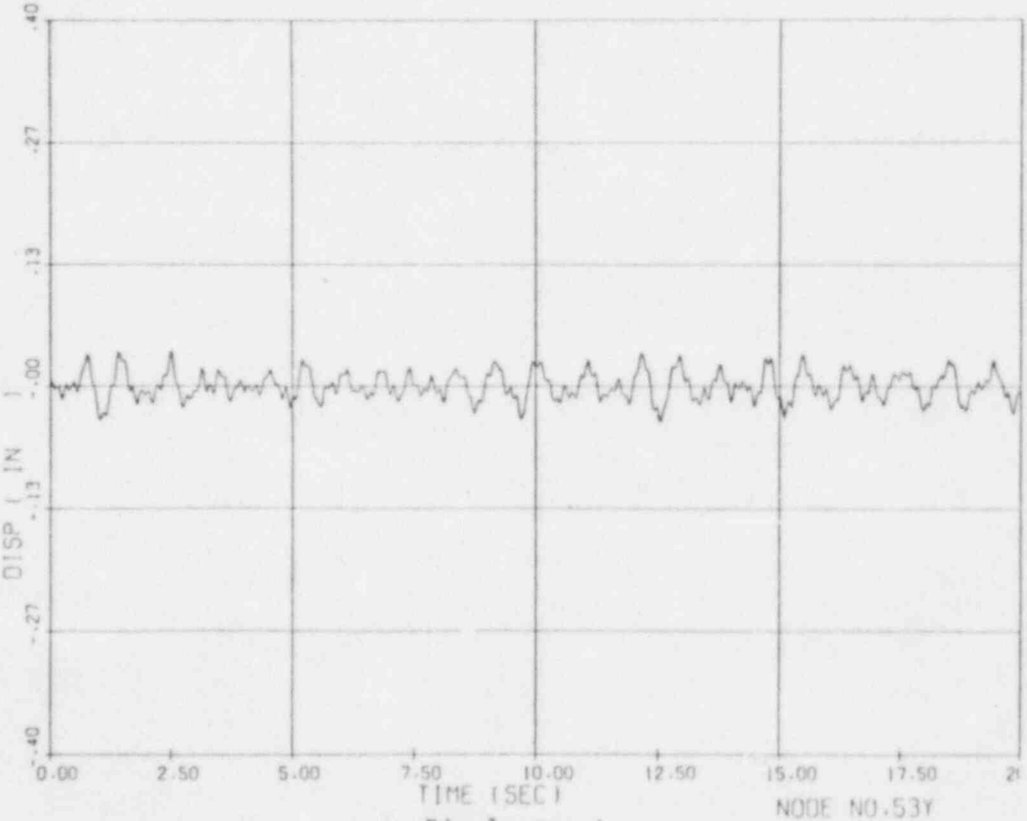


Fig. 36. Input Main Pipeline With Branches Node No. 53X

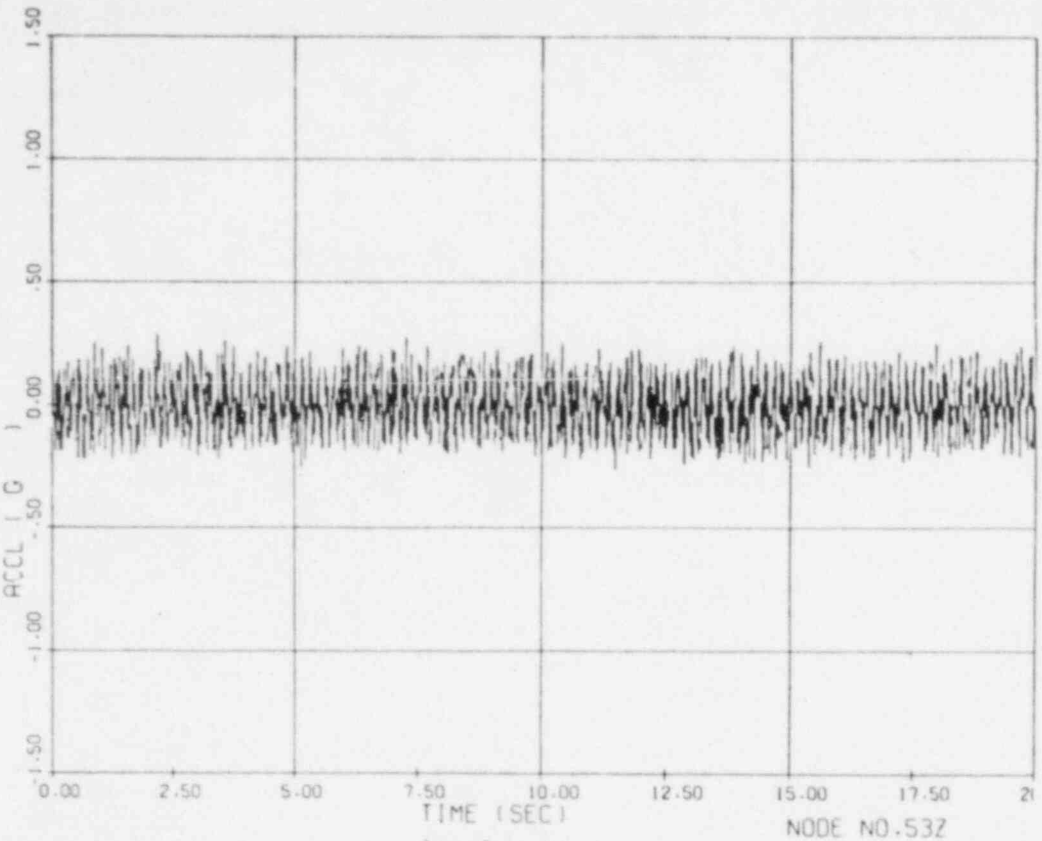


Acceleration

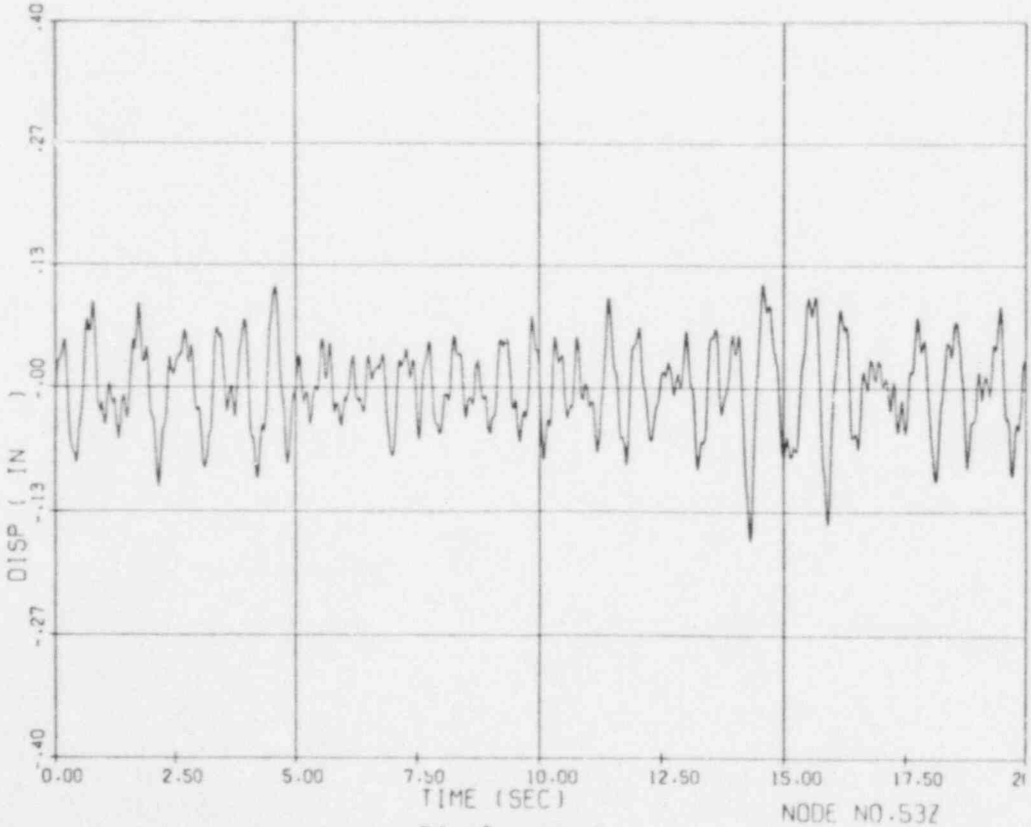


Displacement

Fig. 37. Input Main Pipeline With Branches Node No. 53Y

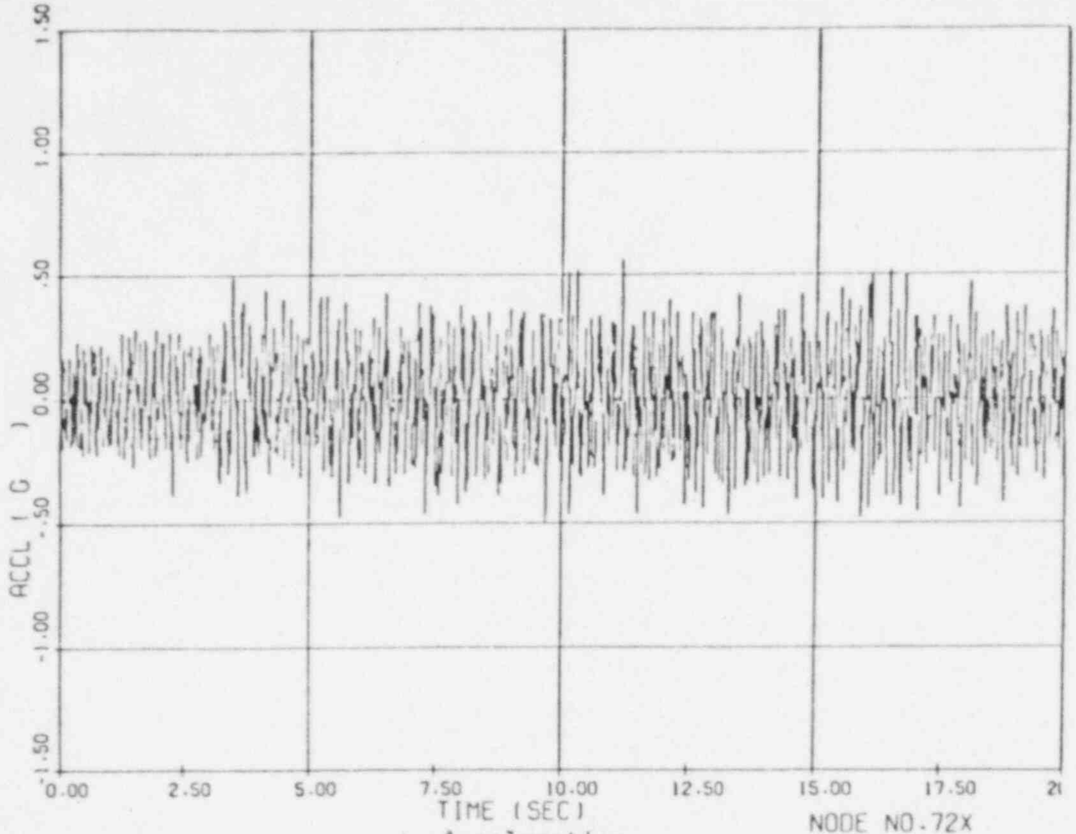


Acceleration

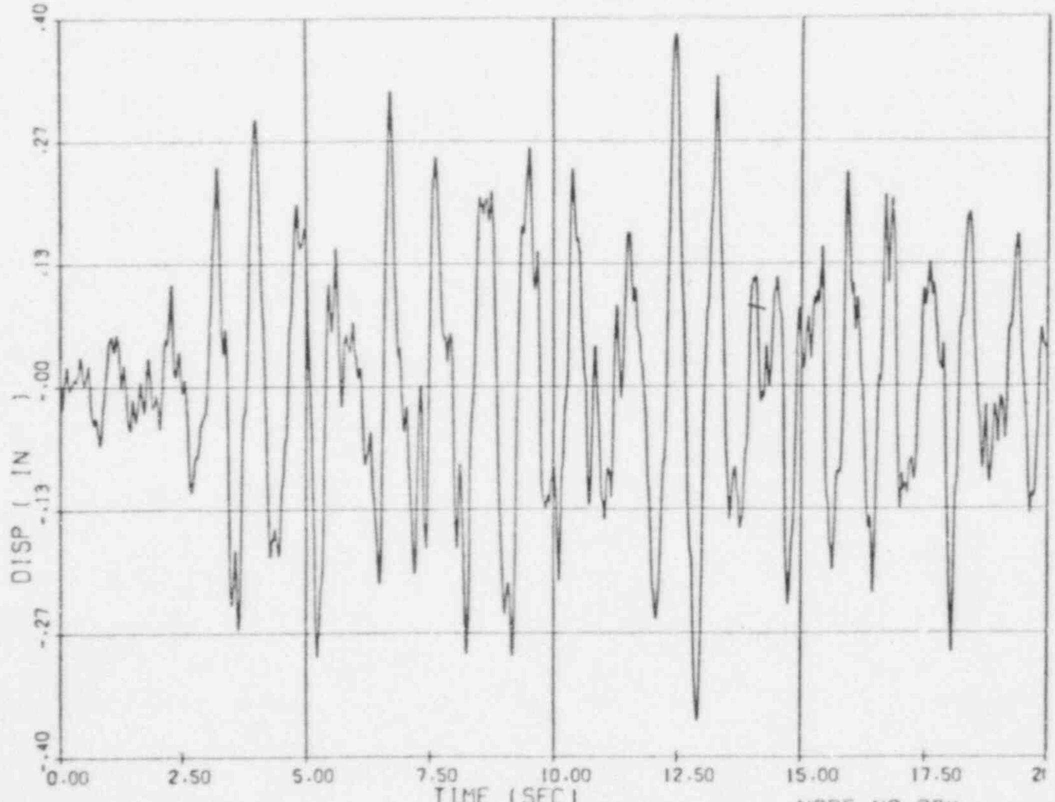


Displacement

Fig. 38. Input Main Pipeline With Branches Node No. 53Z

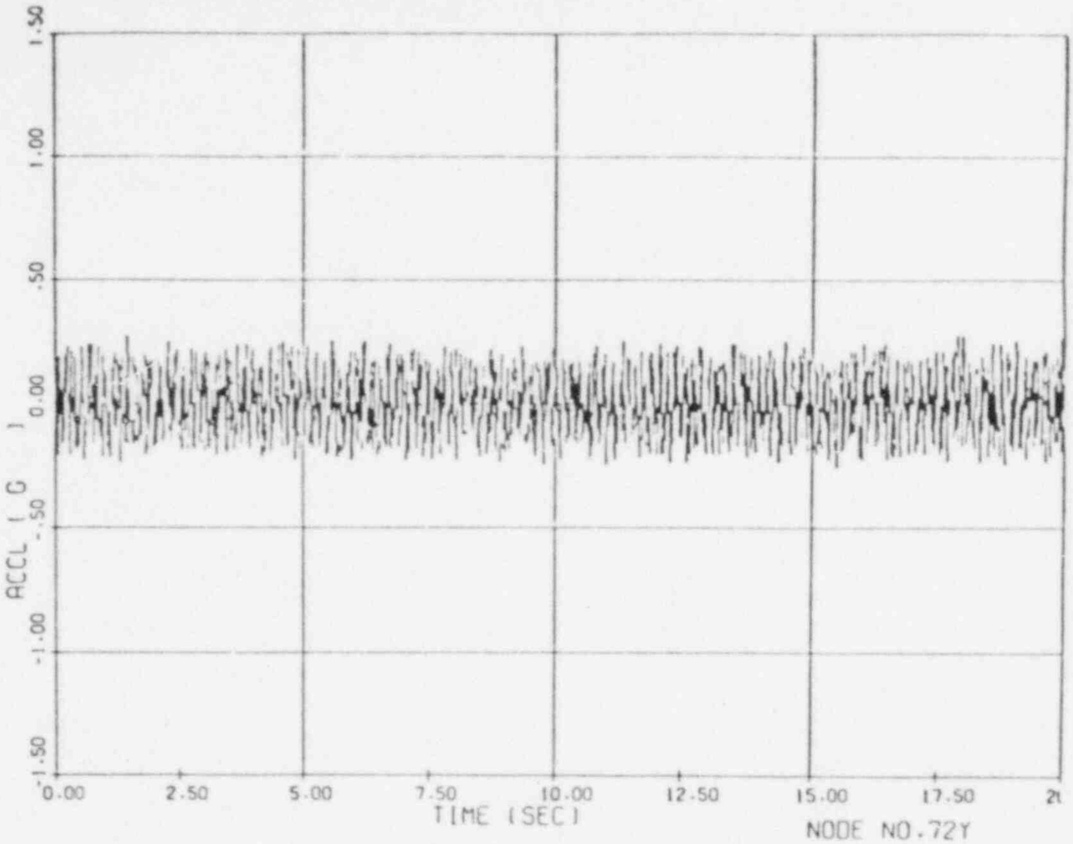


Acceleration

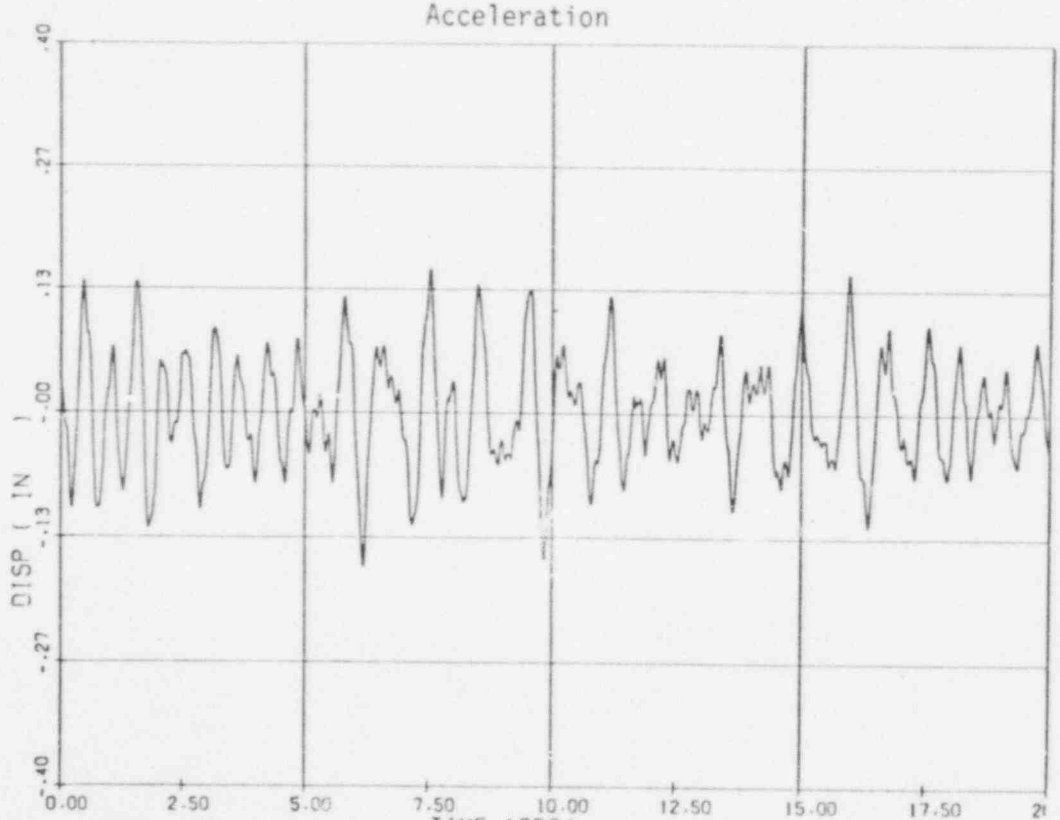


Displacement

Fig. 39. Input Main Pipeline With Branches Node No. 72X

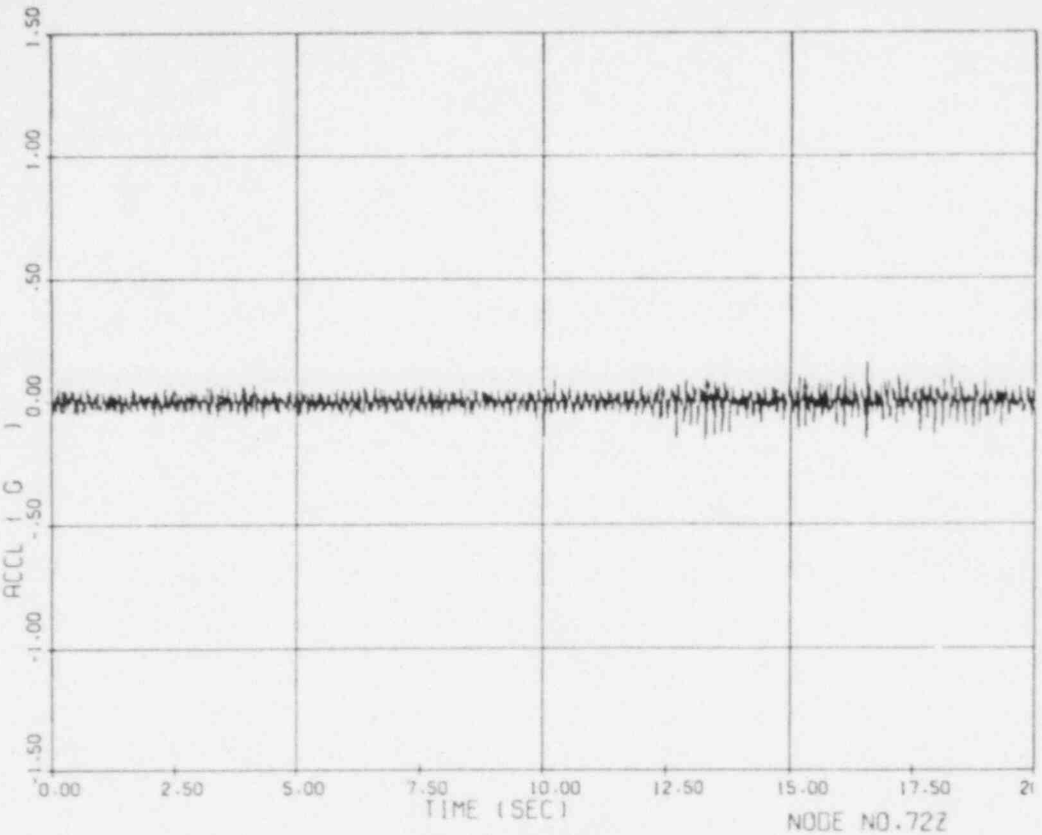


Acceleration

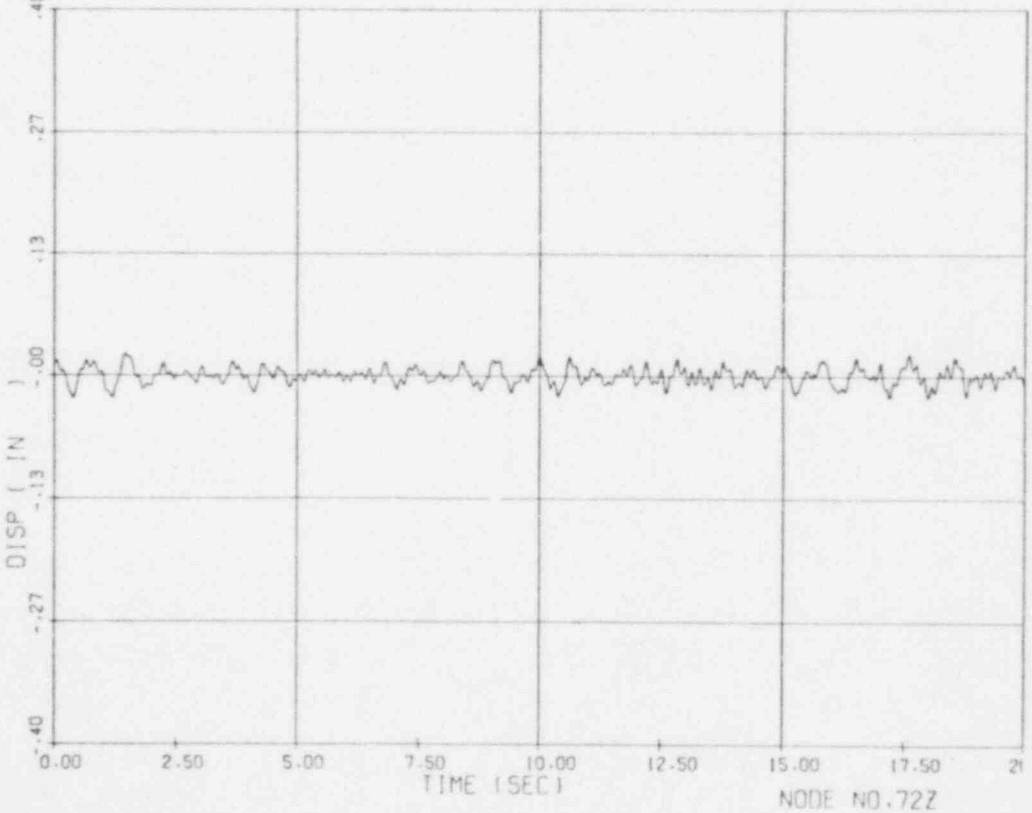


Displacement

Fig. 40. Input Main Pipeline With Branches Node No. 72Y

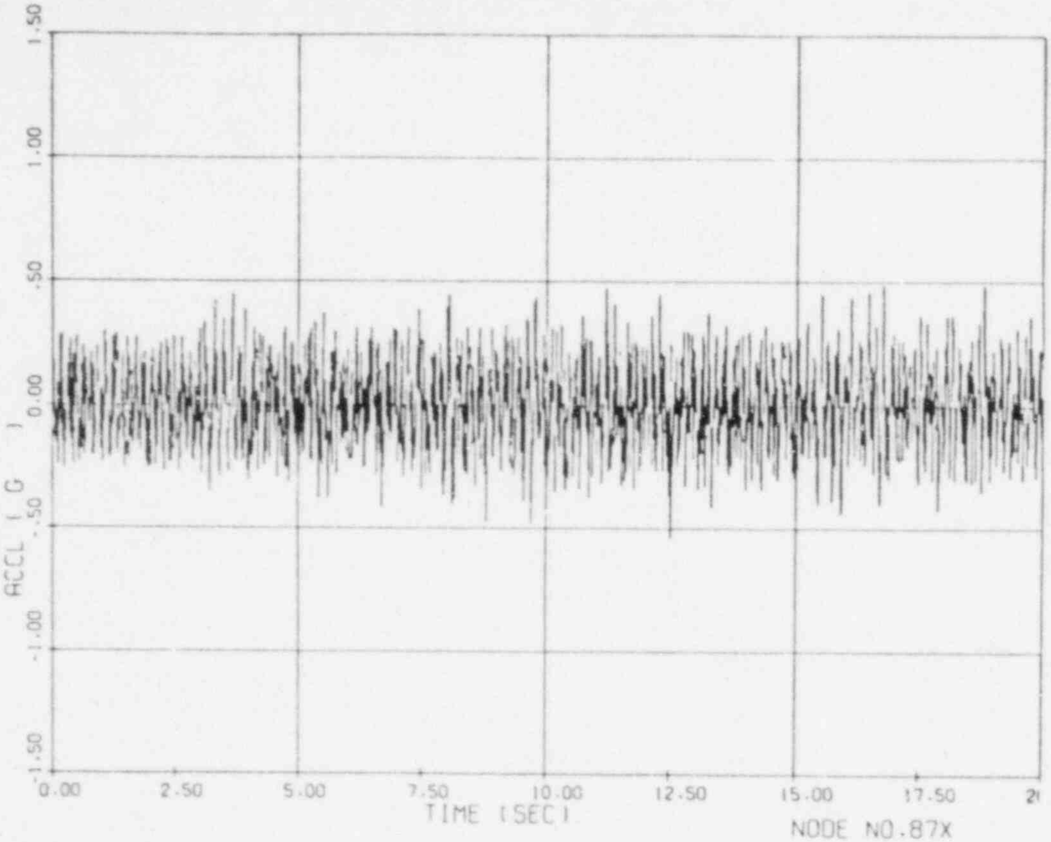


Acceleration

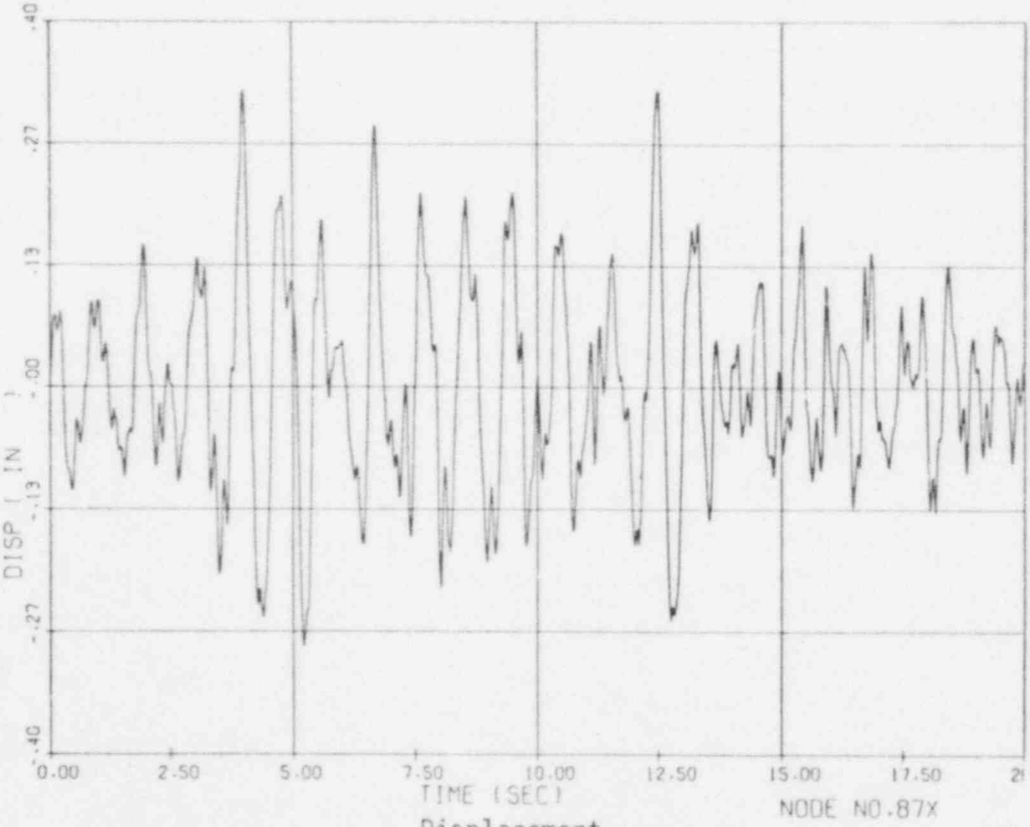


Displacement

Fig. 41. Input Main Pipeline With Branches Node No. 72Z

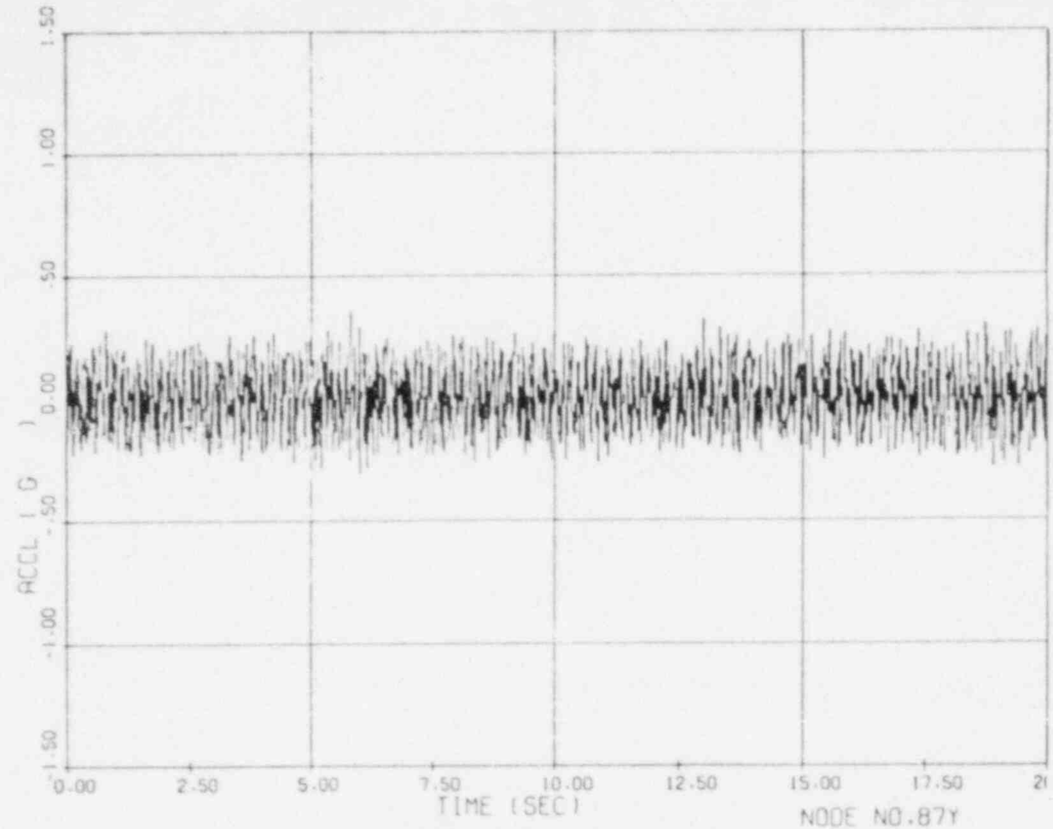


Acceleration

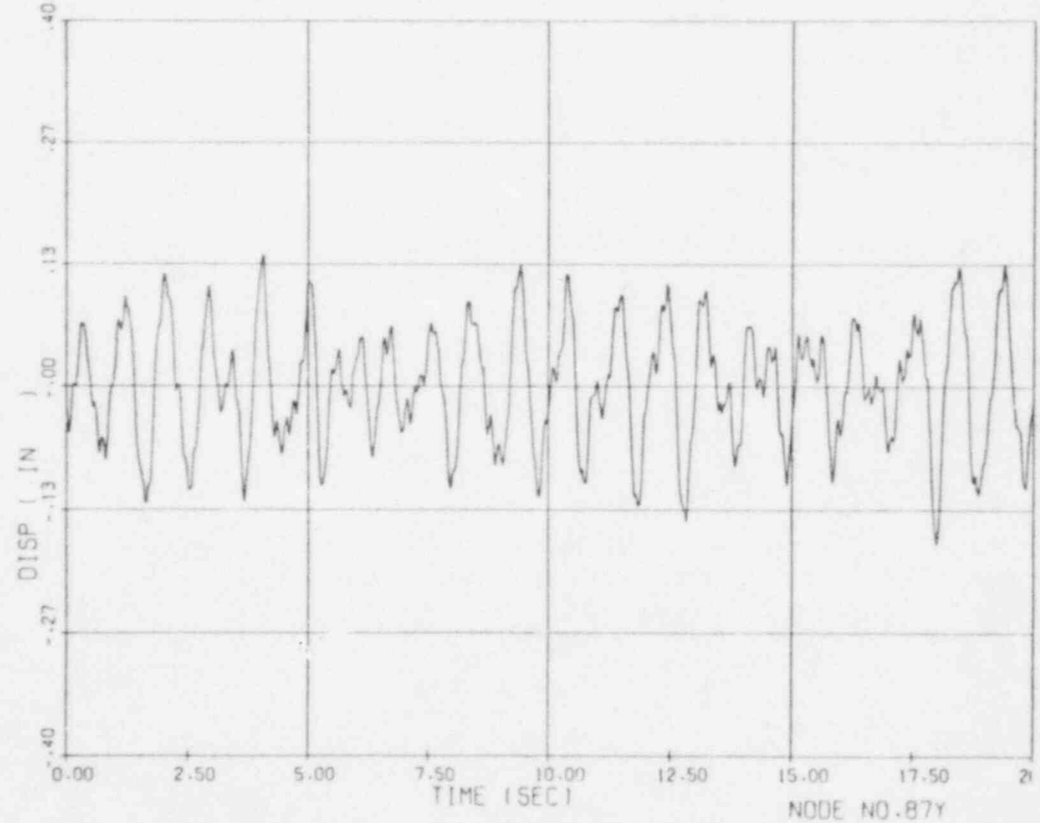


Displacement

Fig. 42. Input Main Pipeline With Branches Node No. 87X

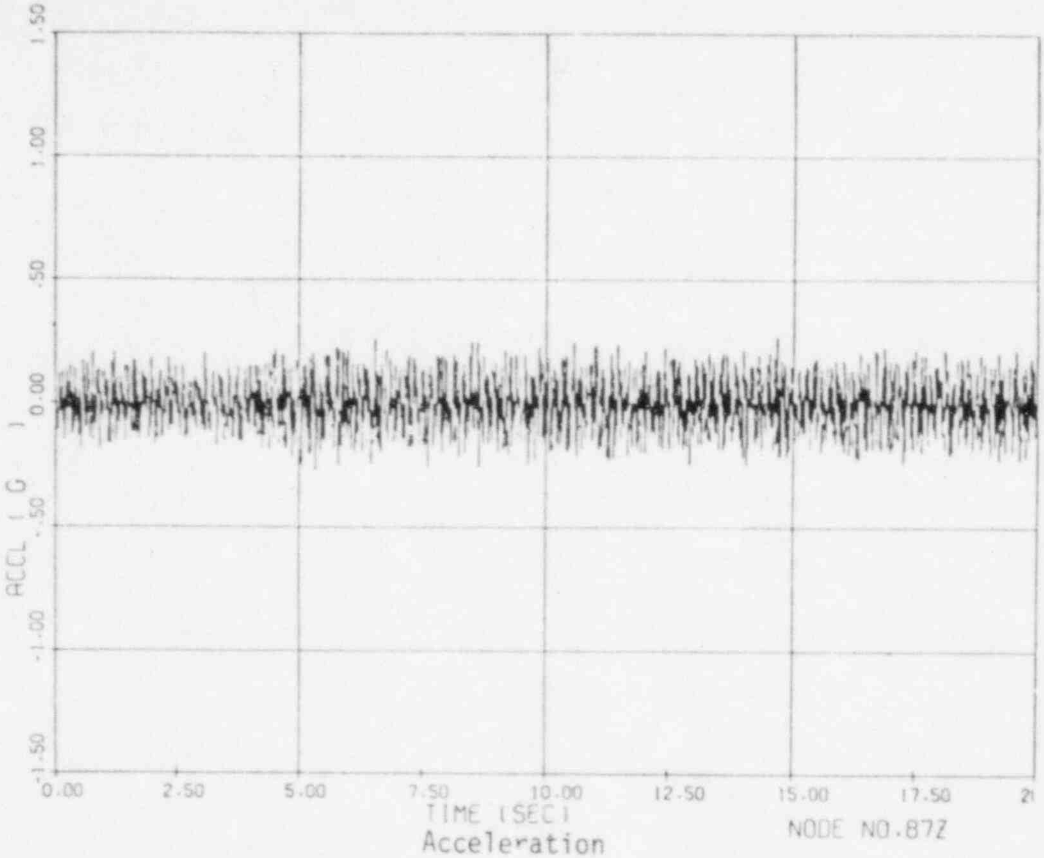


Acceleration



Displacement

Fig. 43. Input Main Pipeline With Branches Node No. 87Y



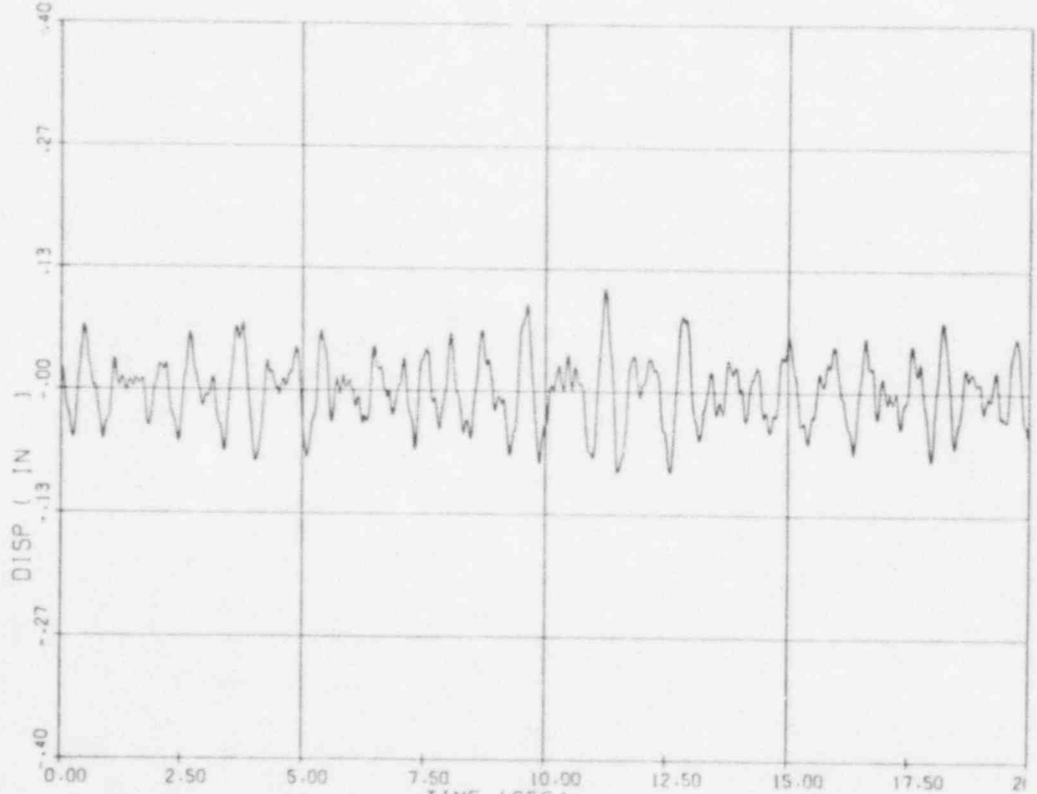
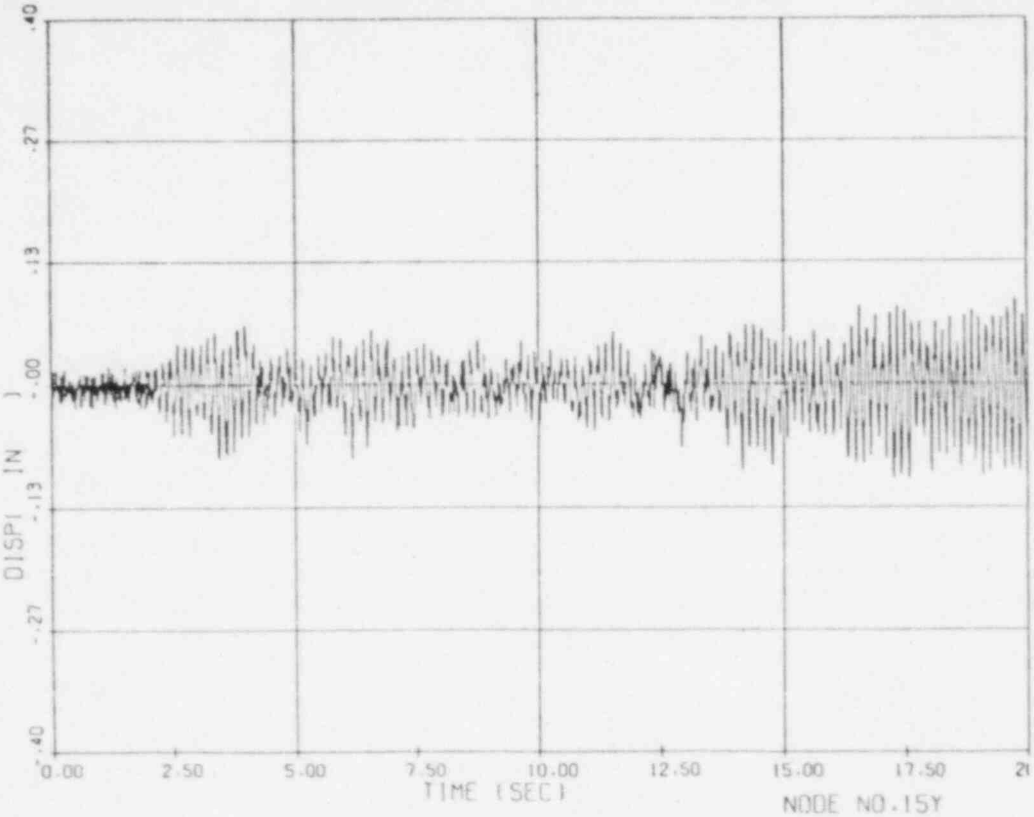
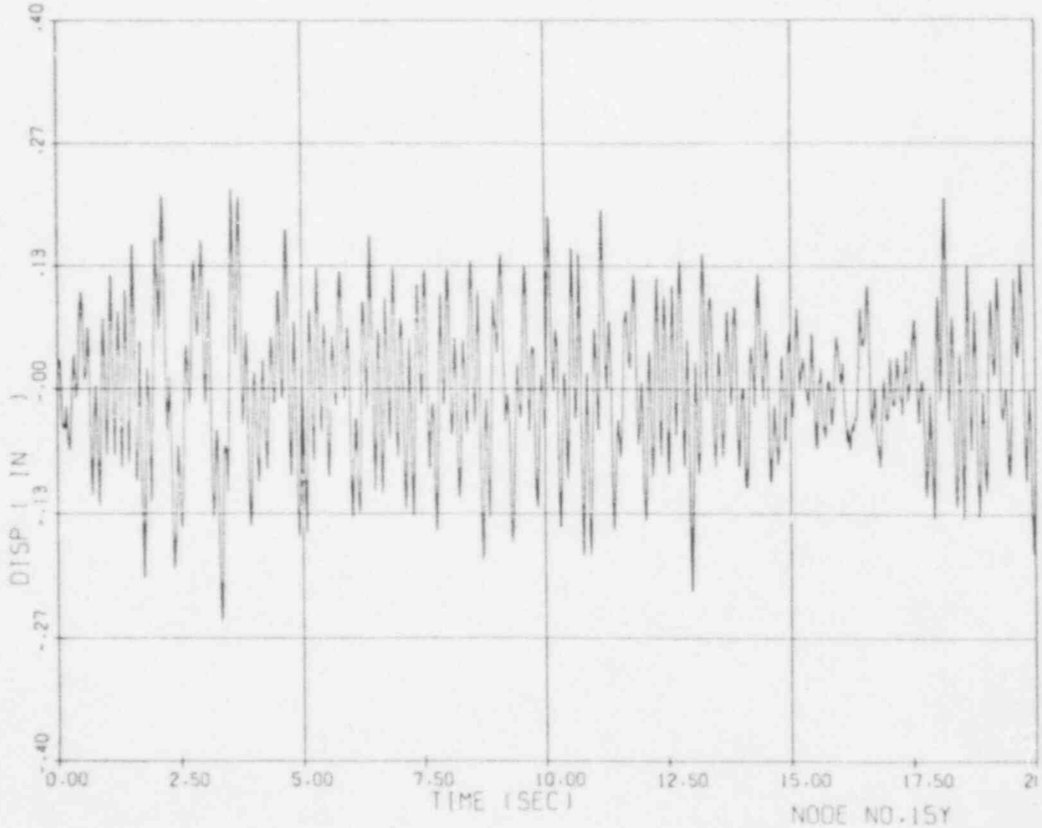


Fig. 44. Input Main Pipeline With Branches Node No. 87Z

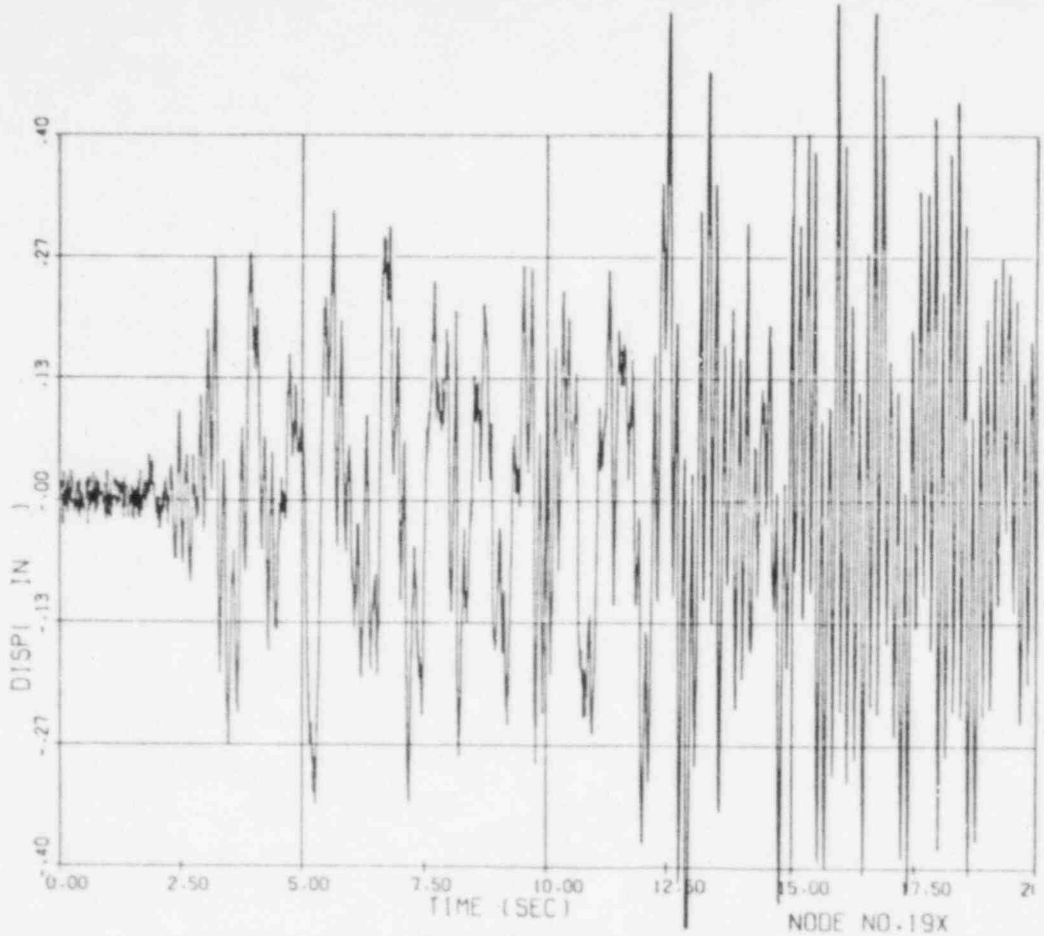


Experimental

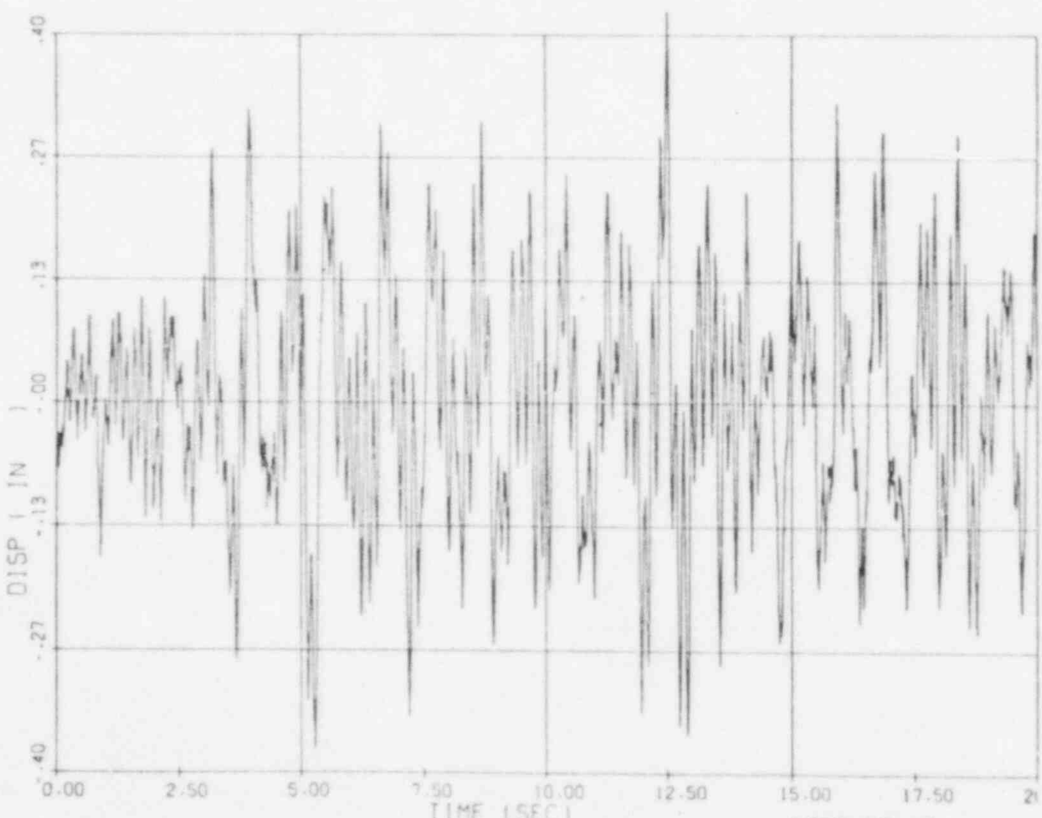


Analytical

Fig. 45. Displacement Response, Main Pipeline With Branches Node No. 15Y

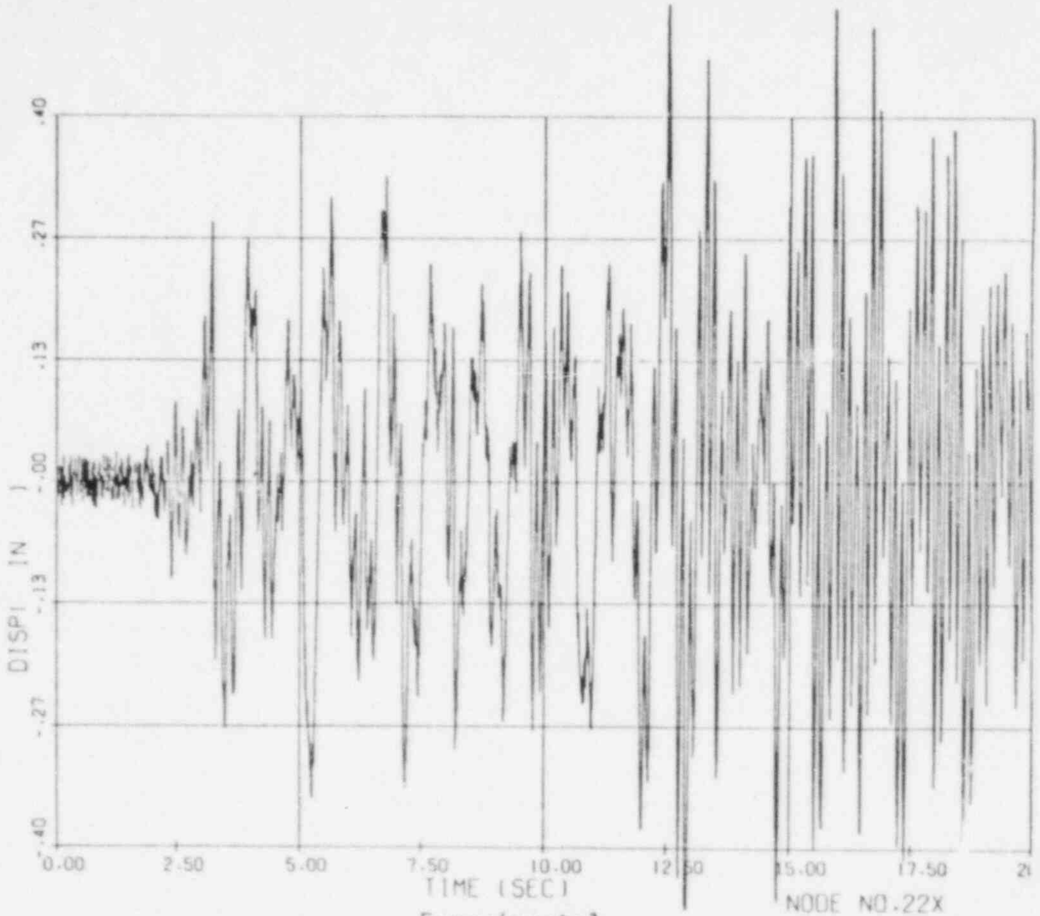


Experimental

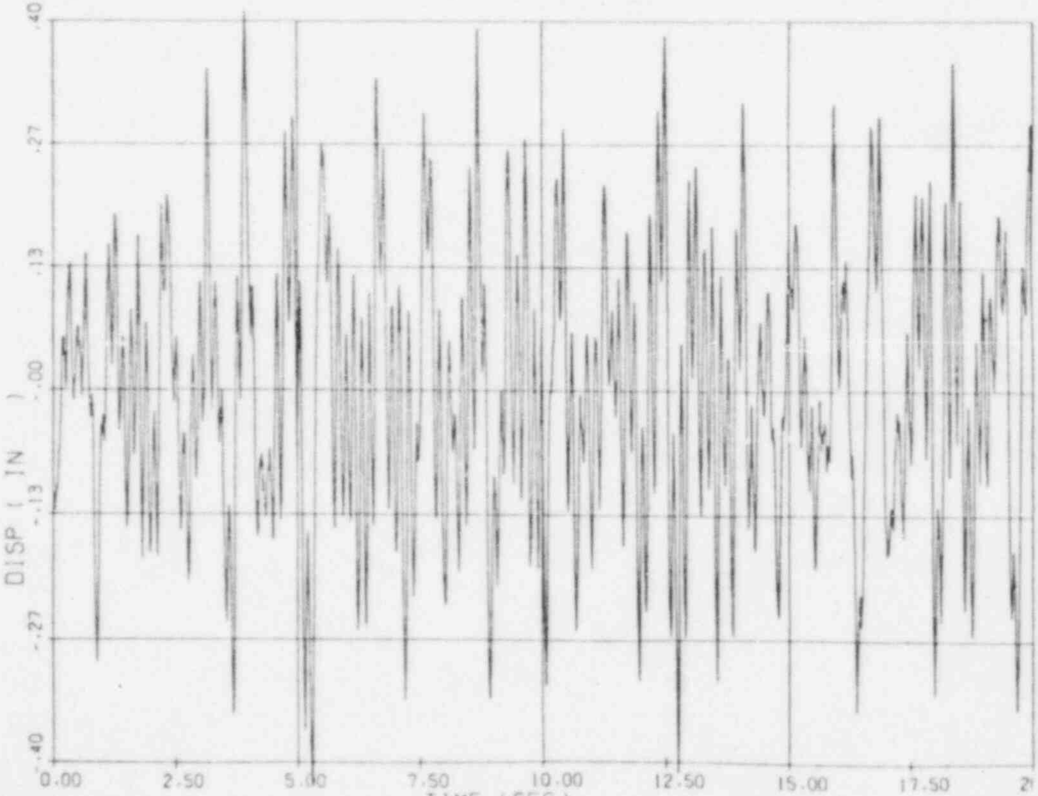


Acceleration

Fig. 46. Displacement Response, Main Pipeline With Branches Node No. 19X

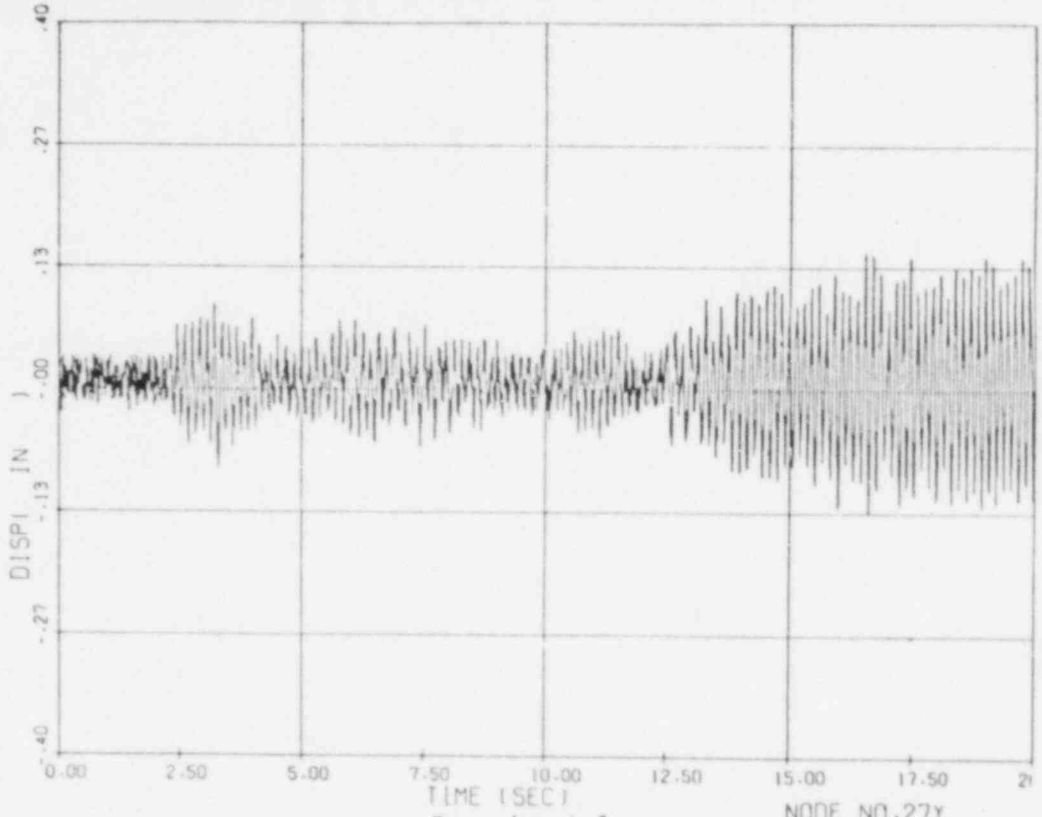


Experimental

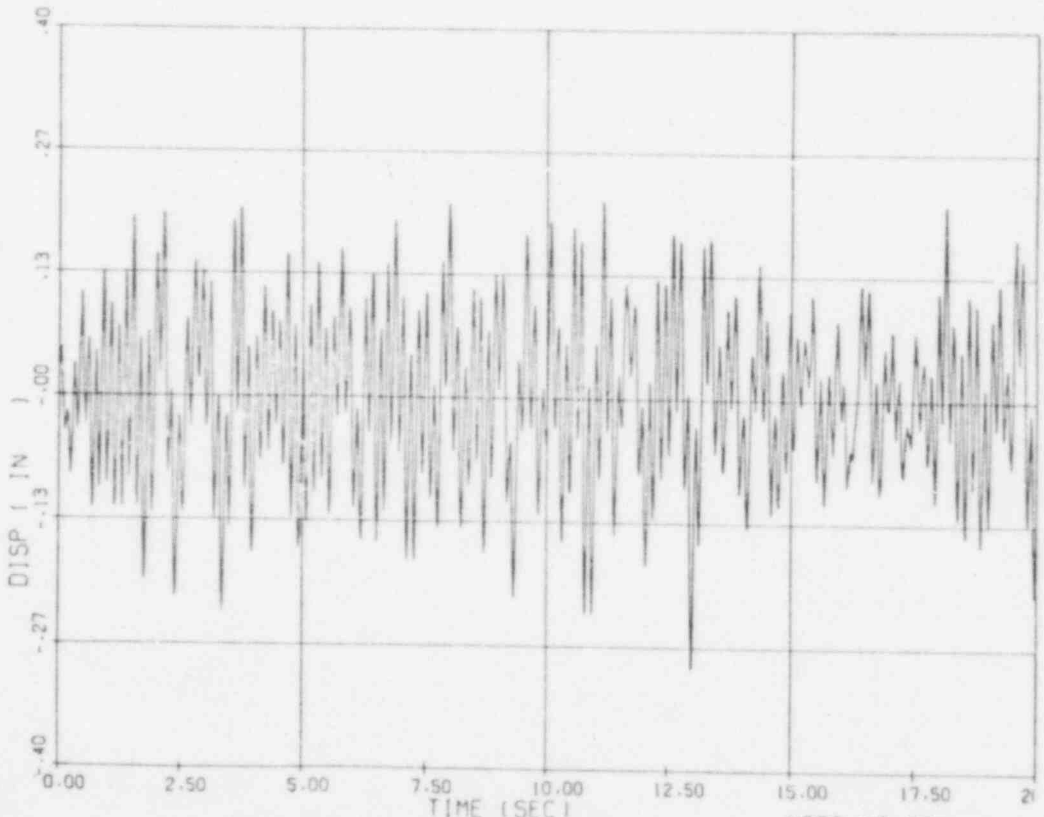


Acceleration

Fig. 47. Displacement Response, Main Pipeline With Branches Node No. 22X

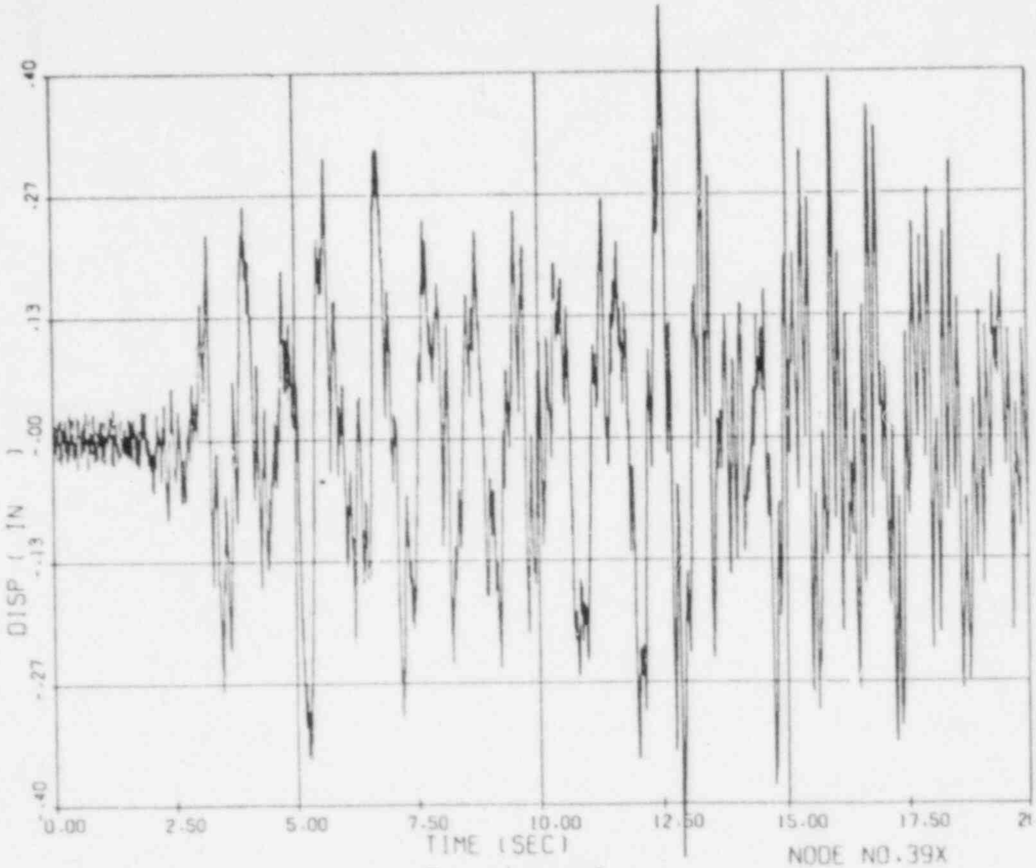


Experimental

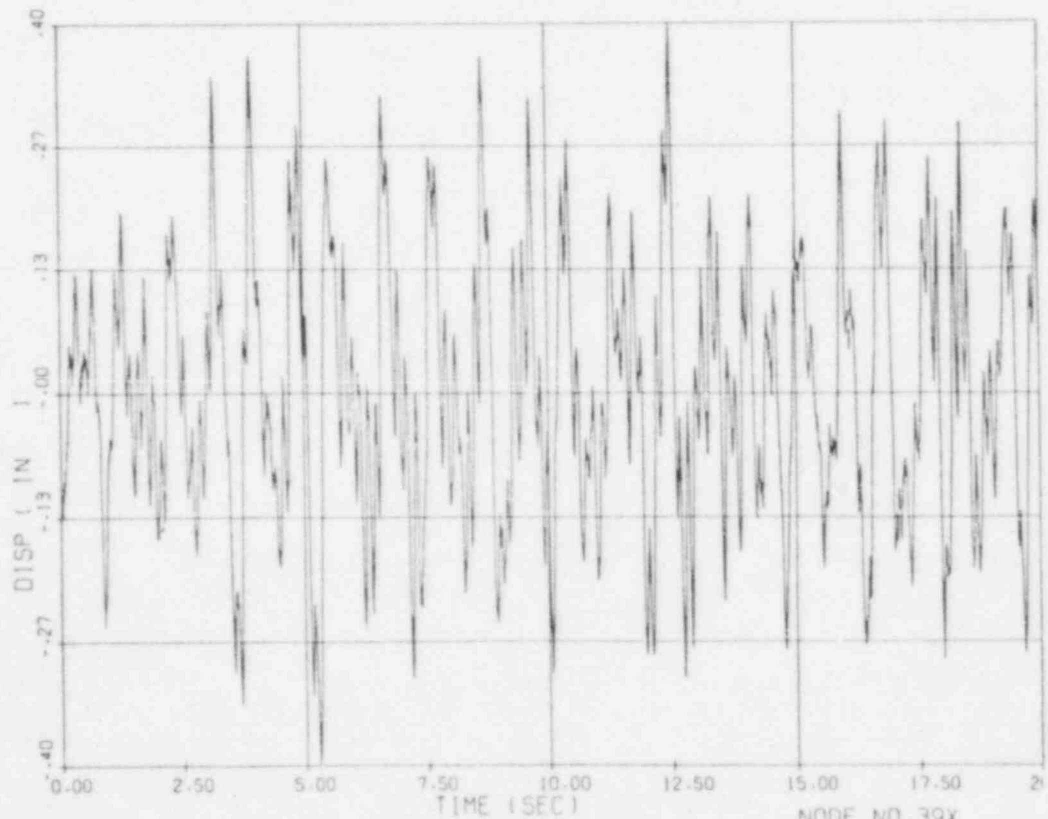


Acceleration

Fig. 48. Displacement Response, Main Pipeline With Branches Node No. 27Y

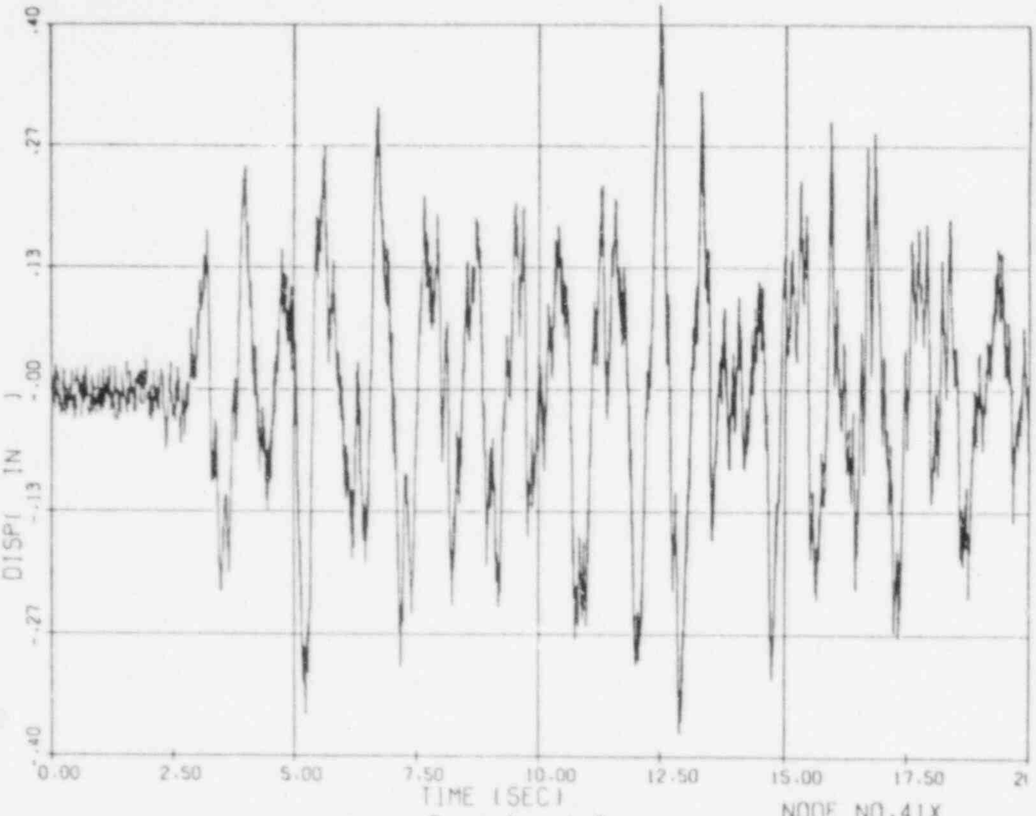


Experimental

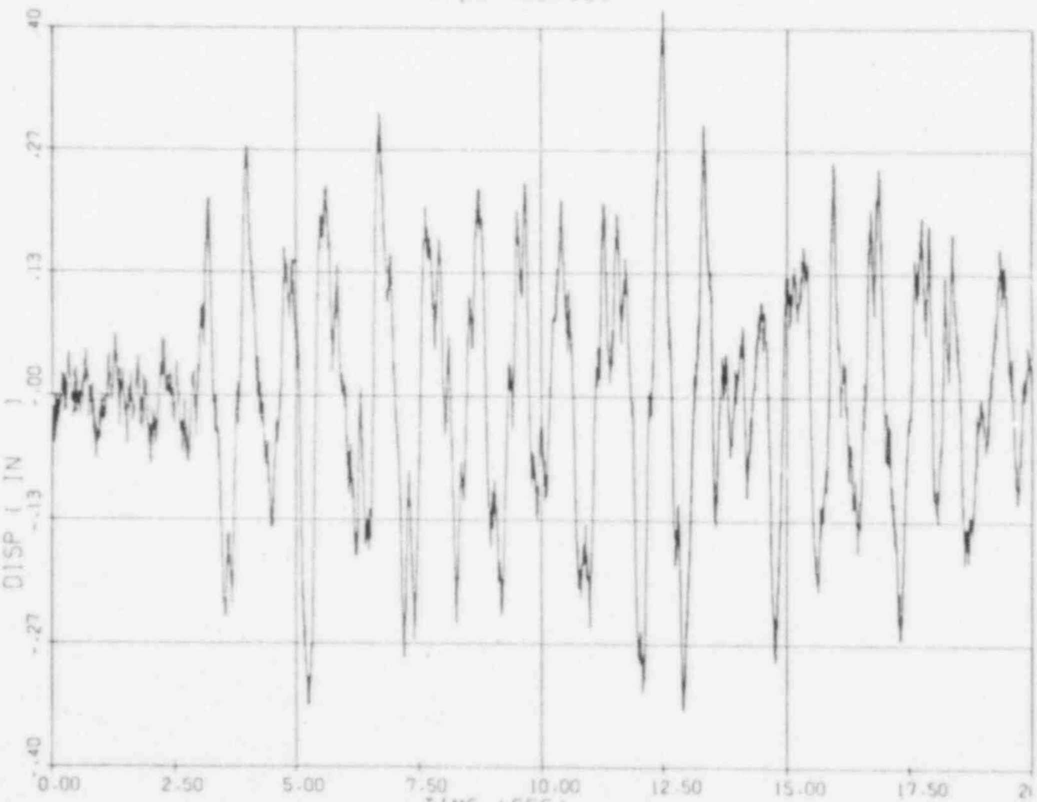


Acceleration

Fig. 49. Displacement Response, Main Pipeline With Branches Node No. 39X

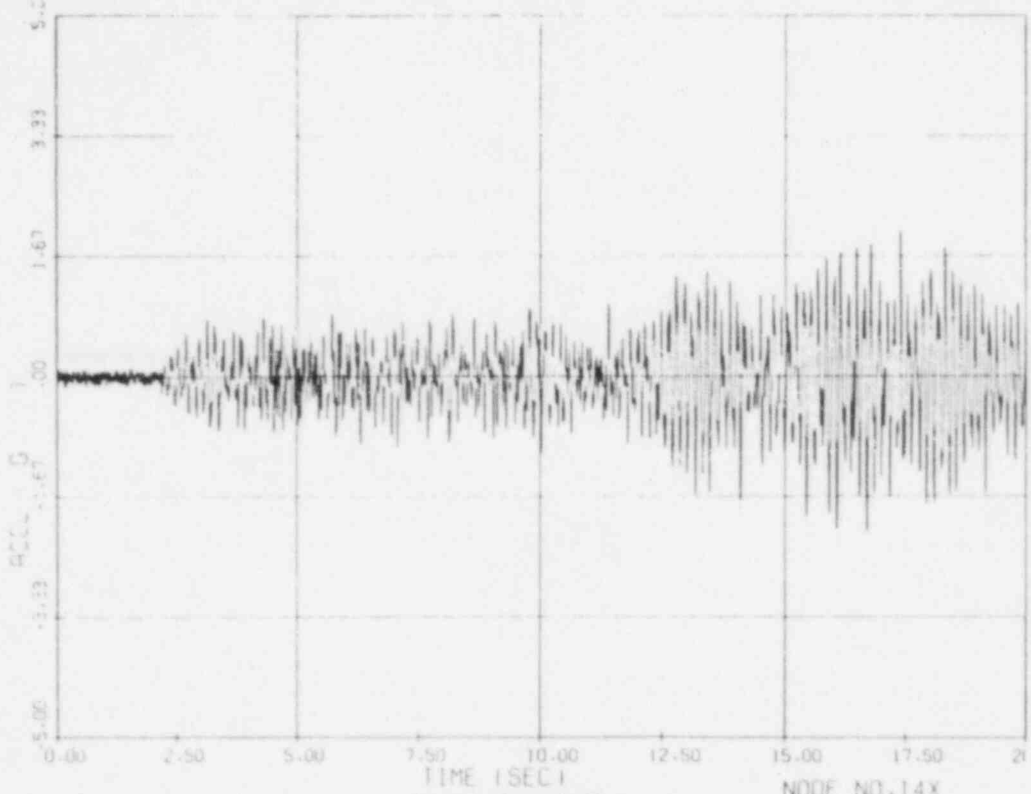


Experimental

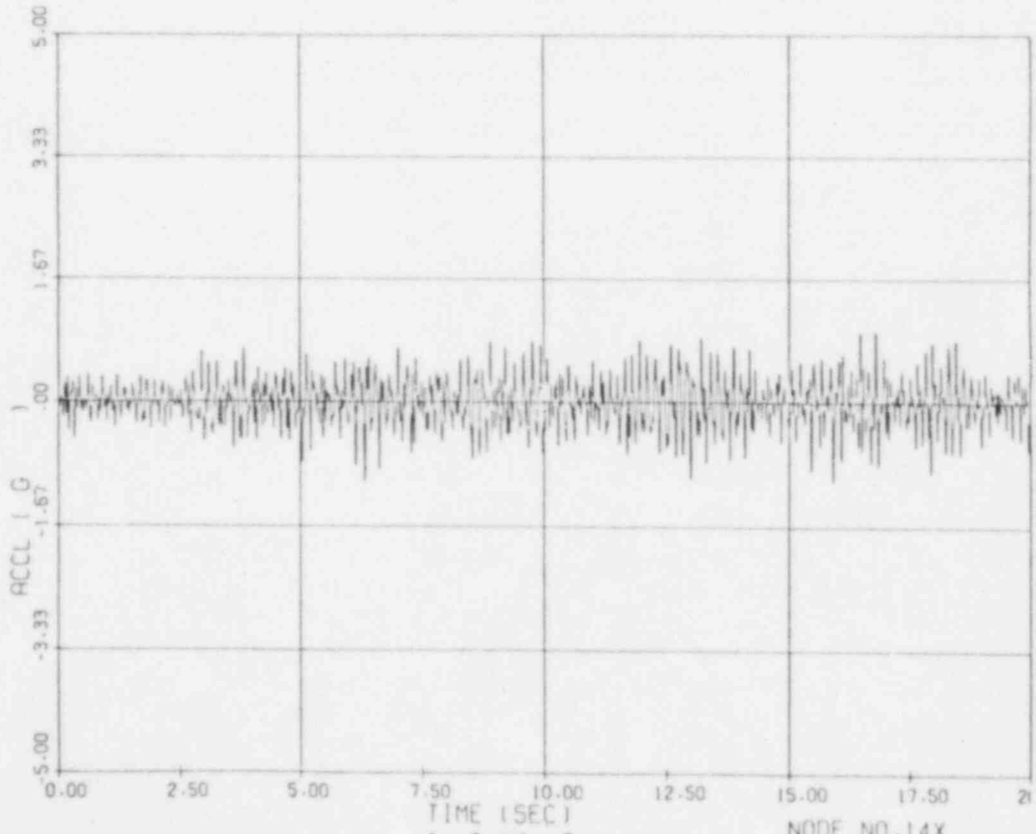


Acceleration

Fig. 50. Displacement Response, Main Pipeline With Branches
Node No. 41X

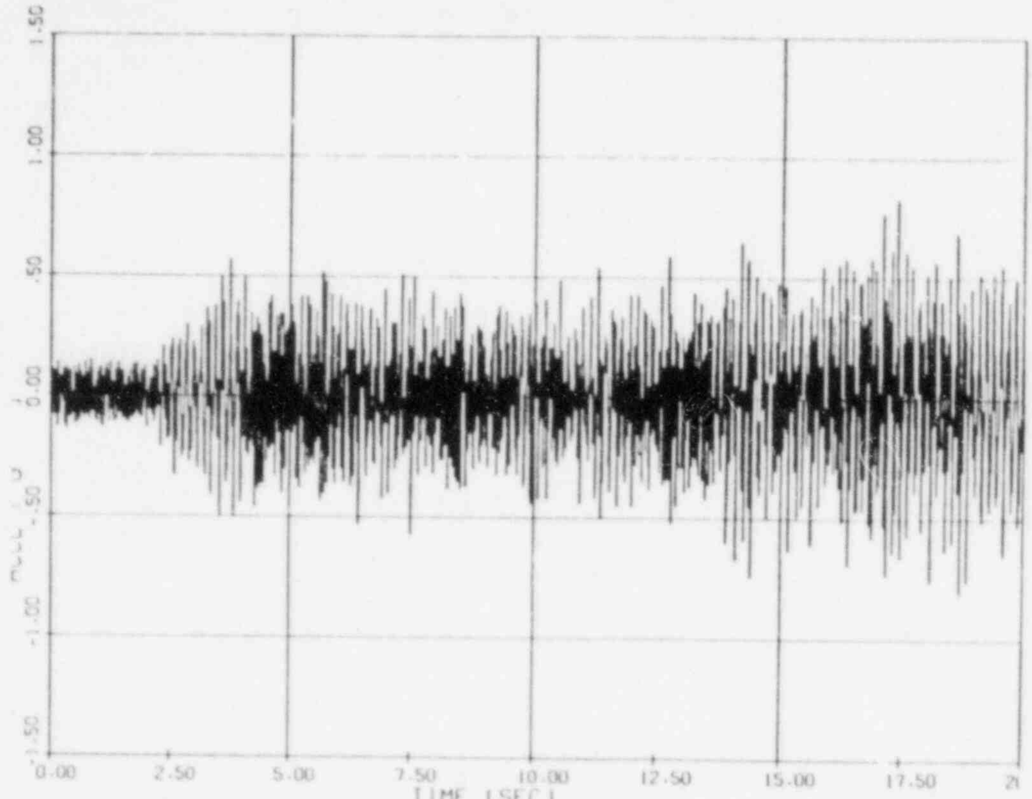


Experimental

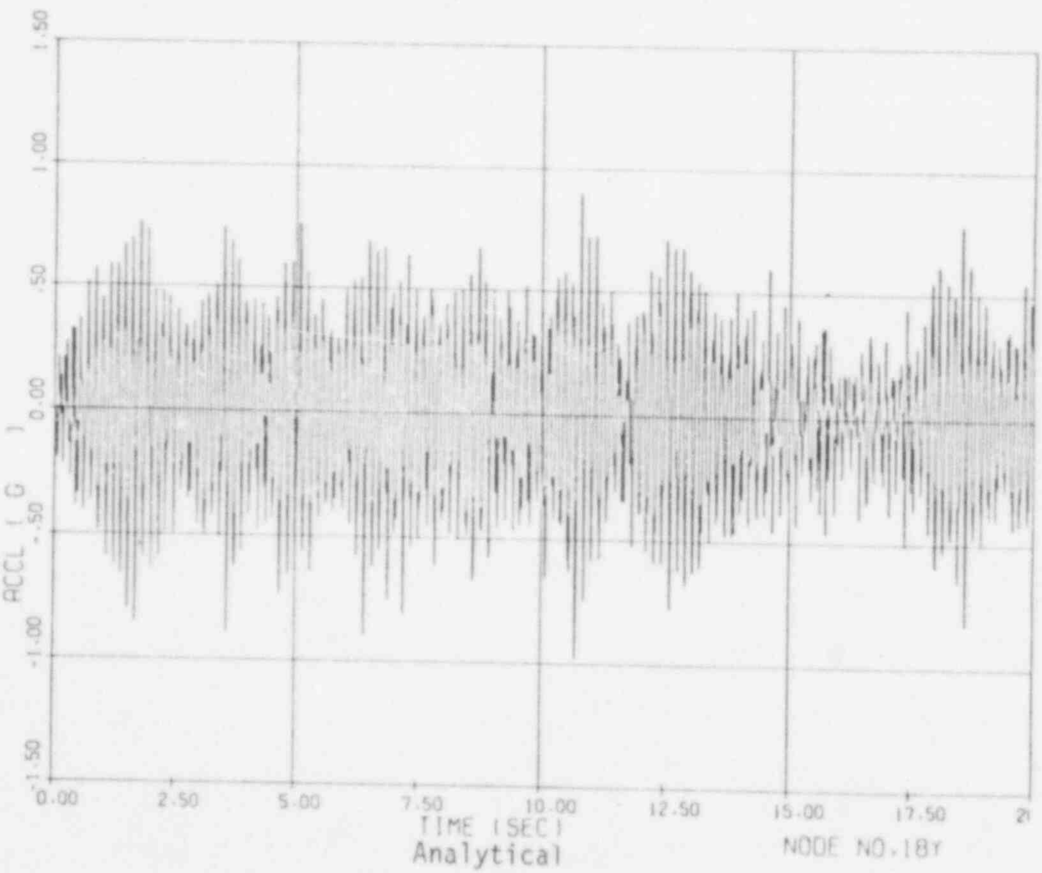


Analytical

Fig. 51. Acceleration Response, Main Pipeline With Branches Node No. 14X

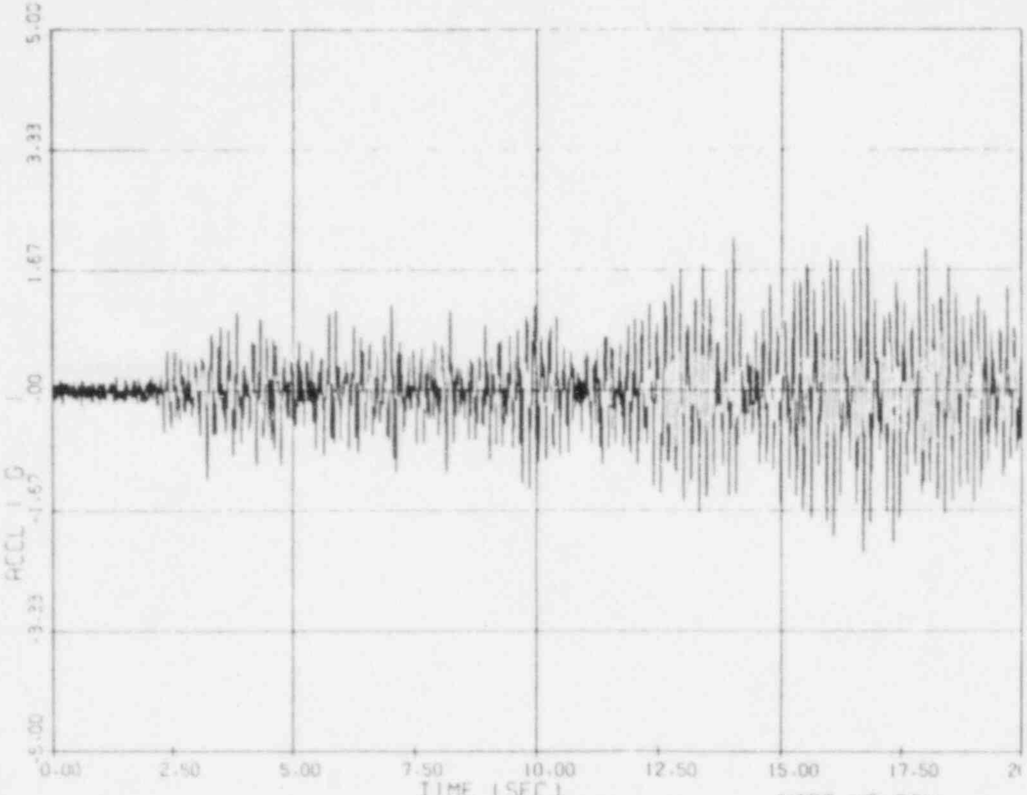


Experimental

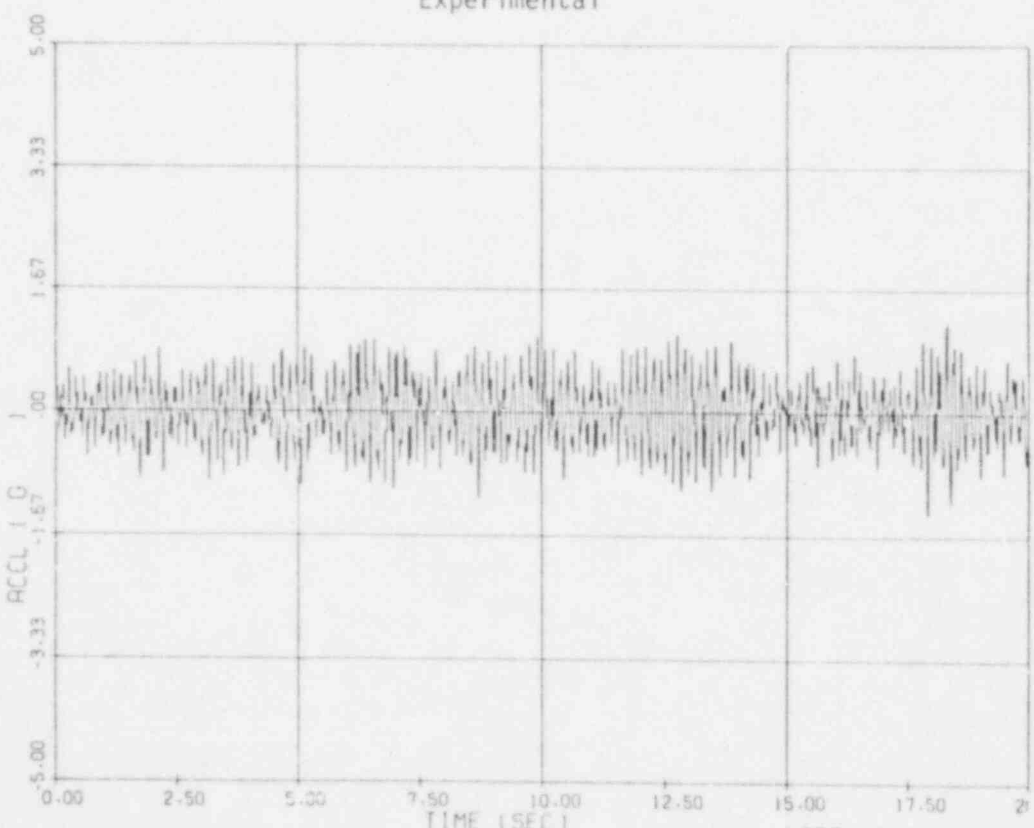


Analytical

Fig. 52. Acceleration Response, Main Pipeline With Branches Node No. 18Y

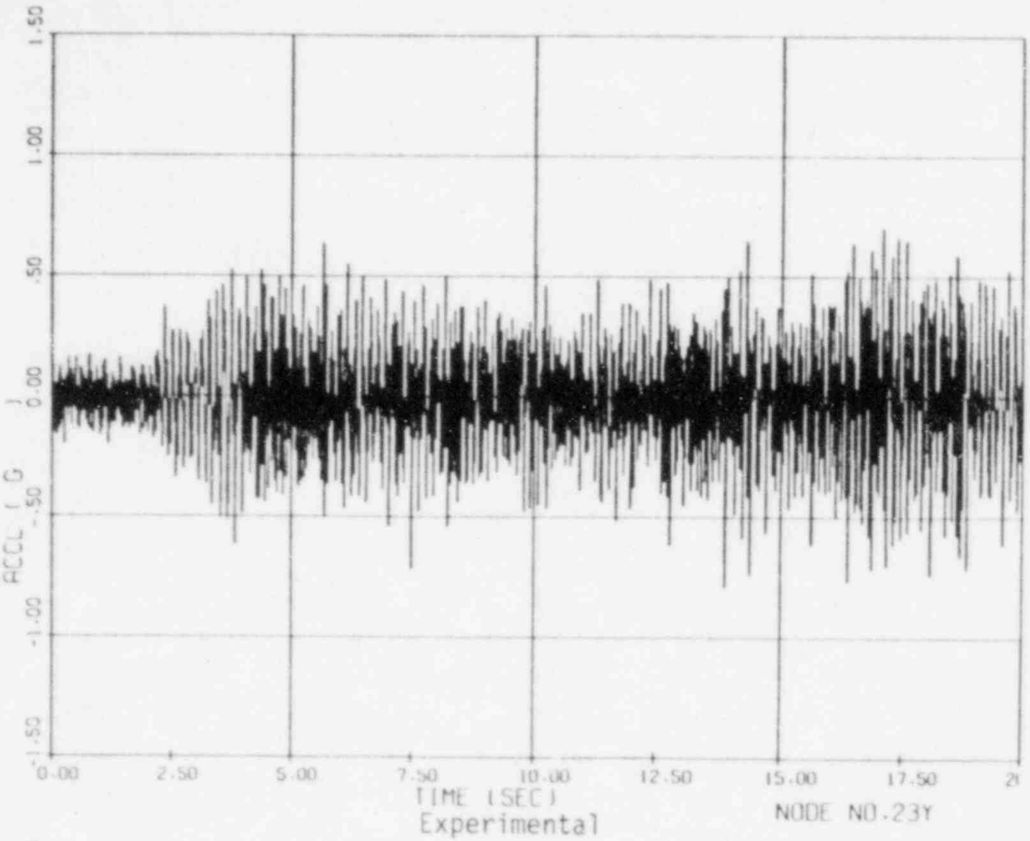


Experimental

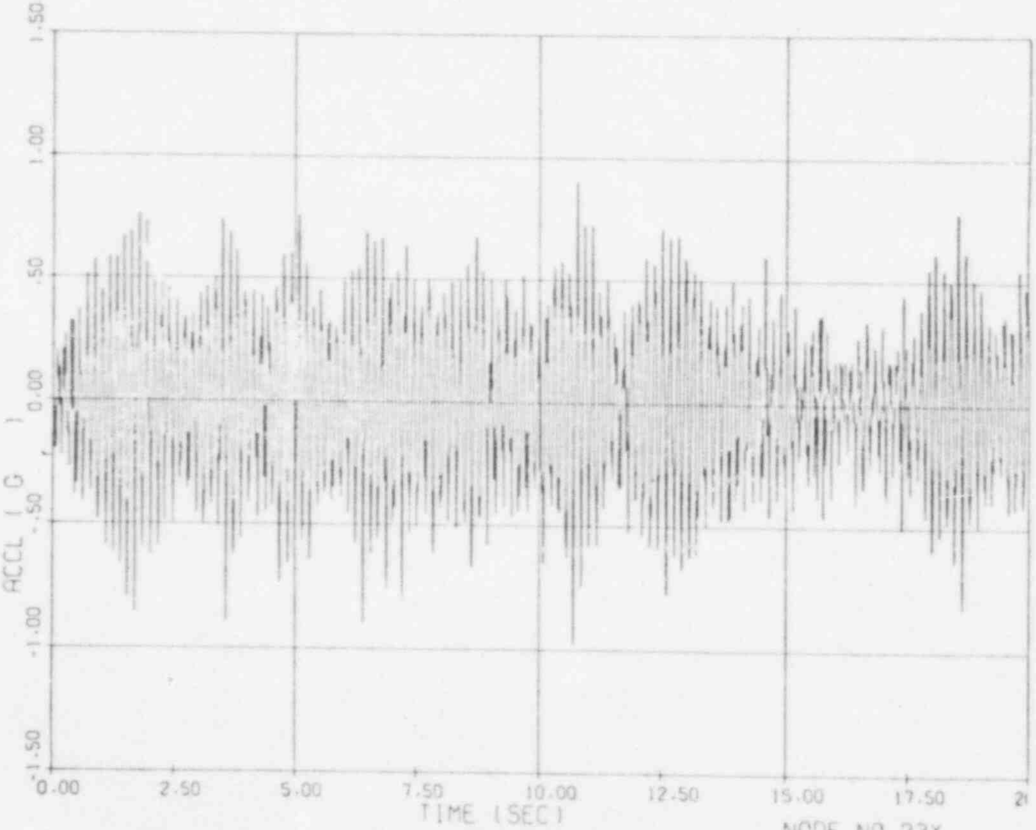


Analytical

Fig. 53. Acceleration Response, Main Pipeline With Branches Node No. 23X

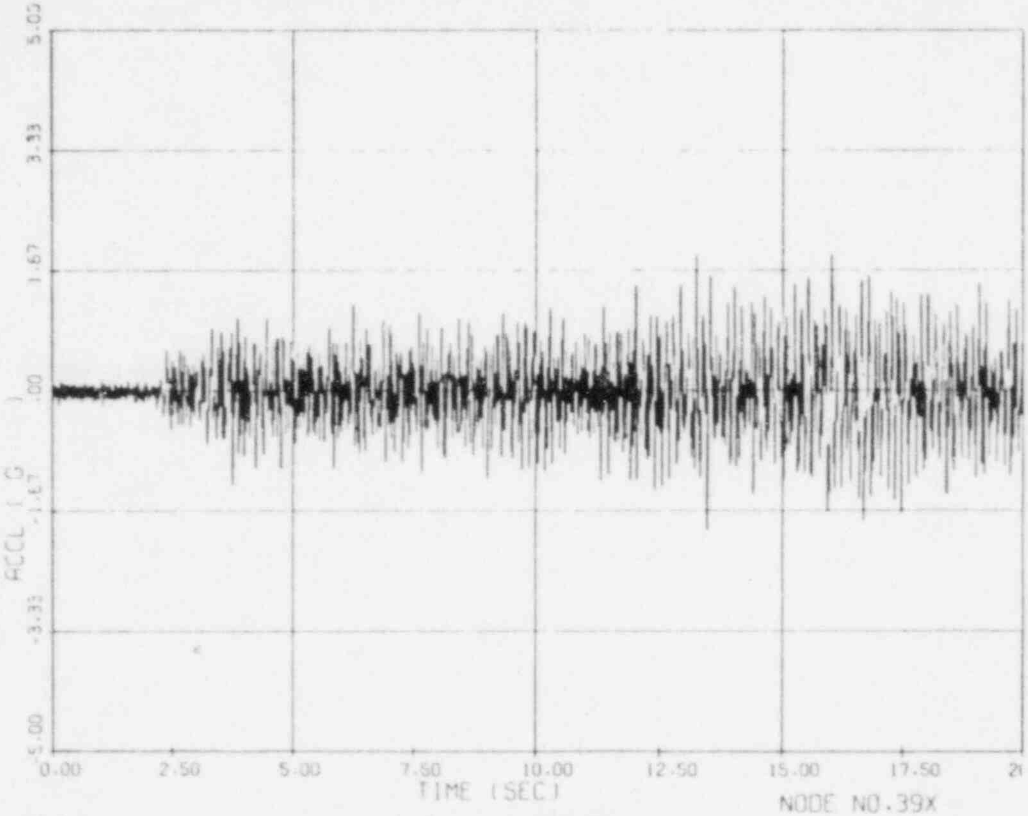


Experimental

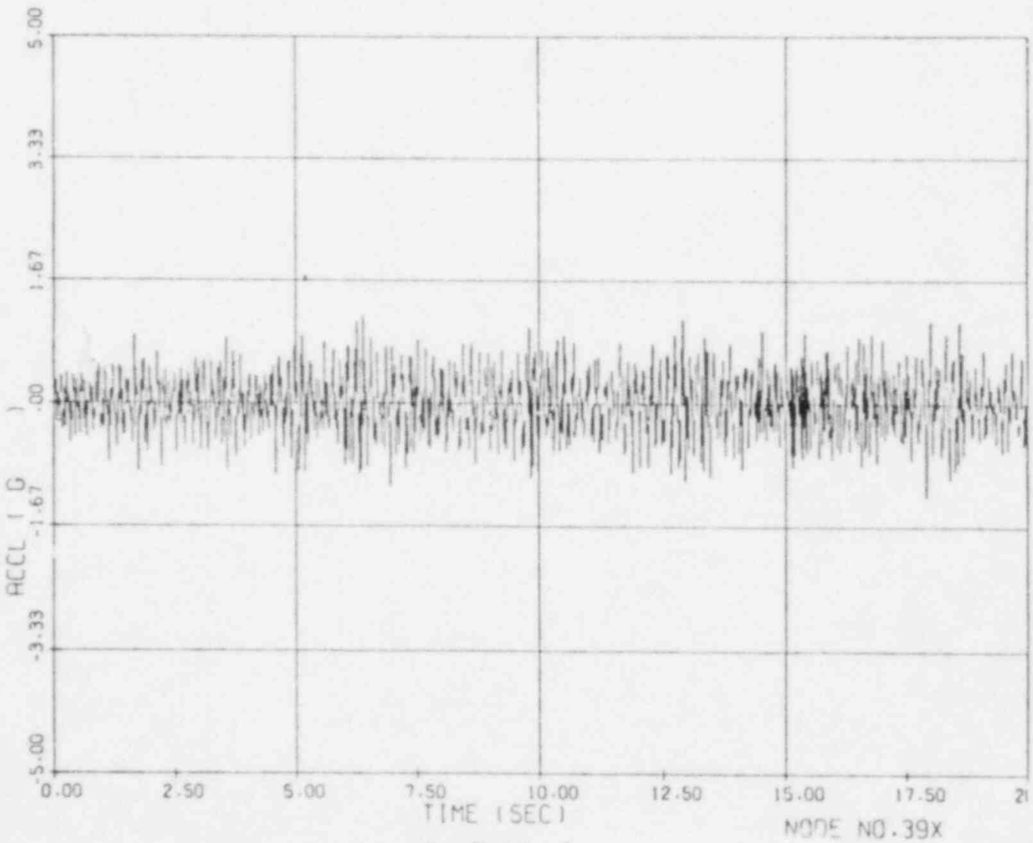


Analytical

Fig. 54. Acceleration Response, Main Pipeline With Branches Node No. 23Y



Experimental



Analytical

Fig. 55. Acceleration Response, Main Pipeline With Branches Node No. 39X

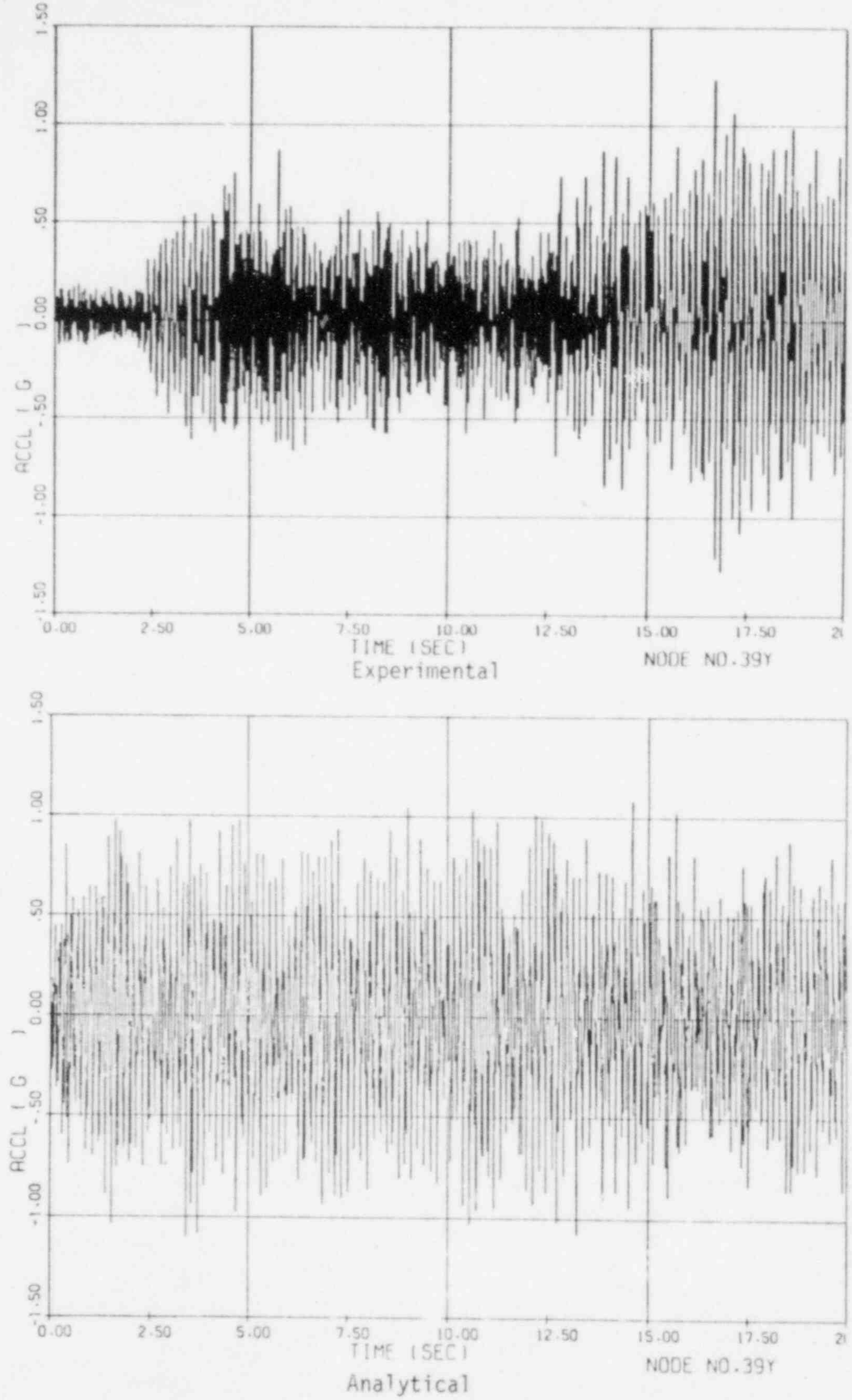
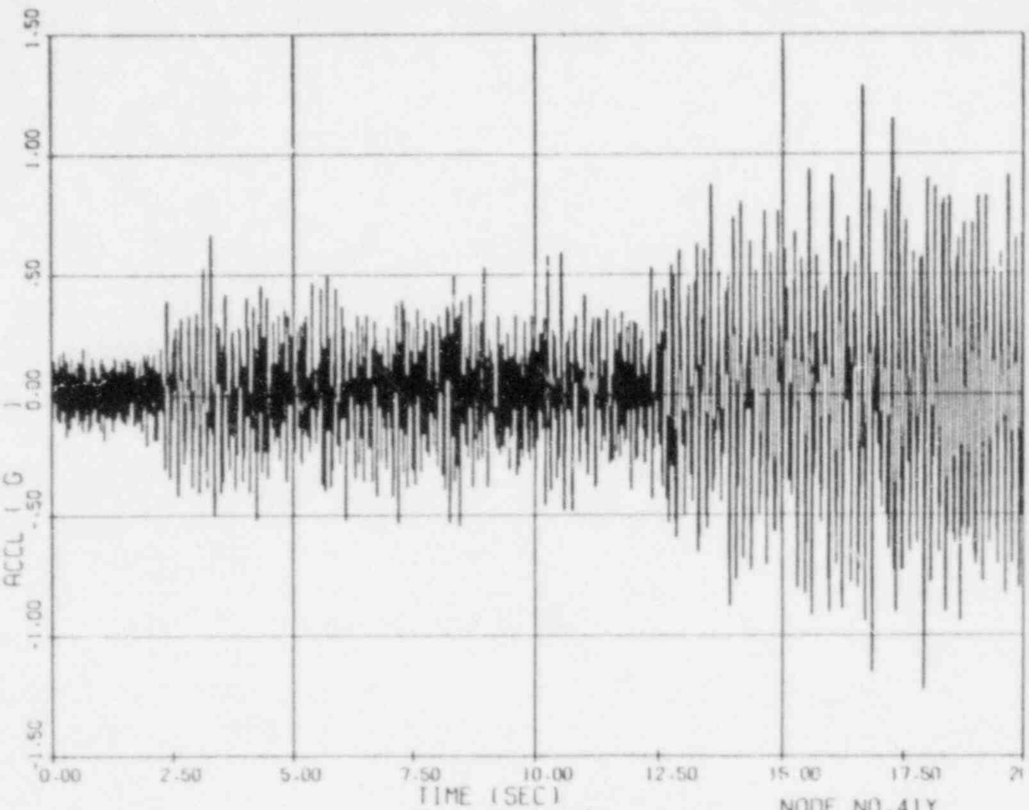
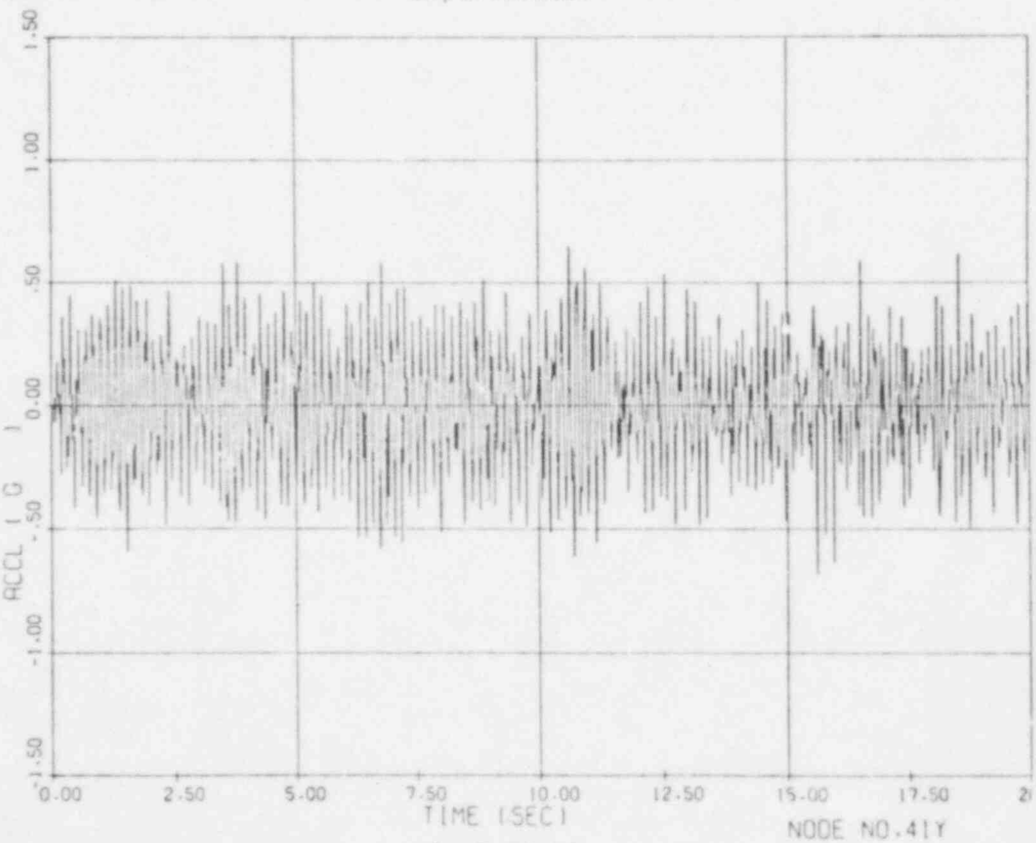


Fig. 56. Acceleration Response, Main Pipeline With Branches Node No. 39Y

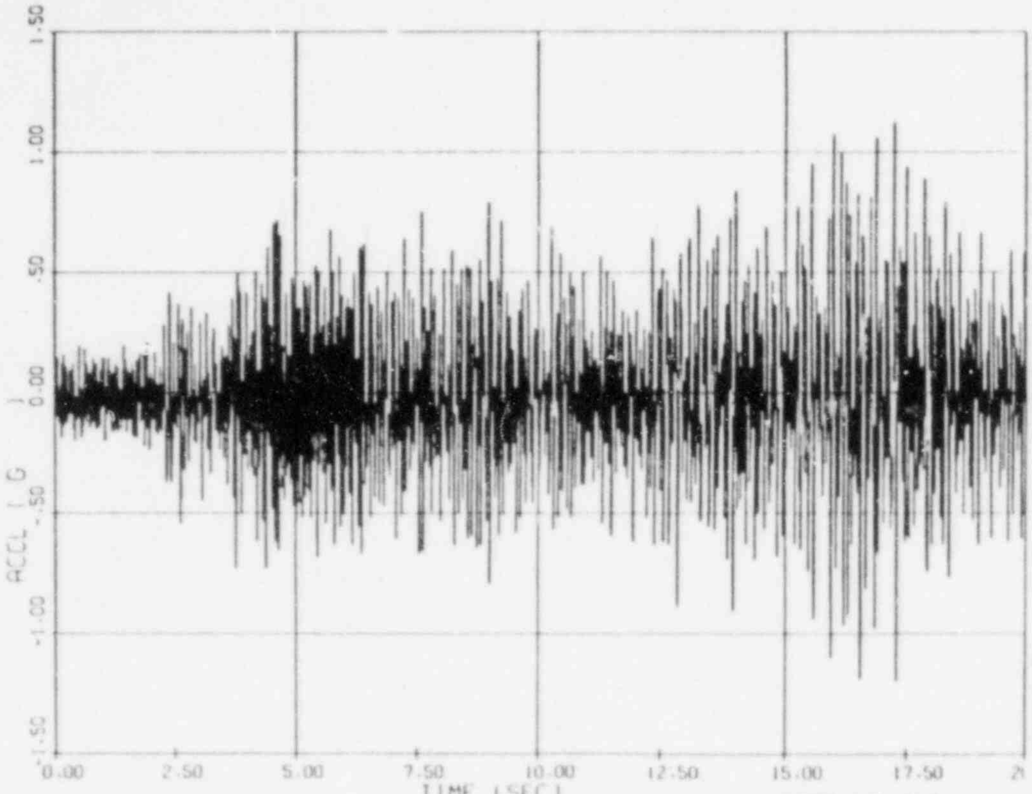


Experimental

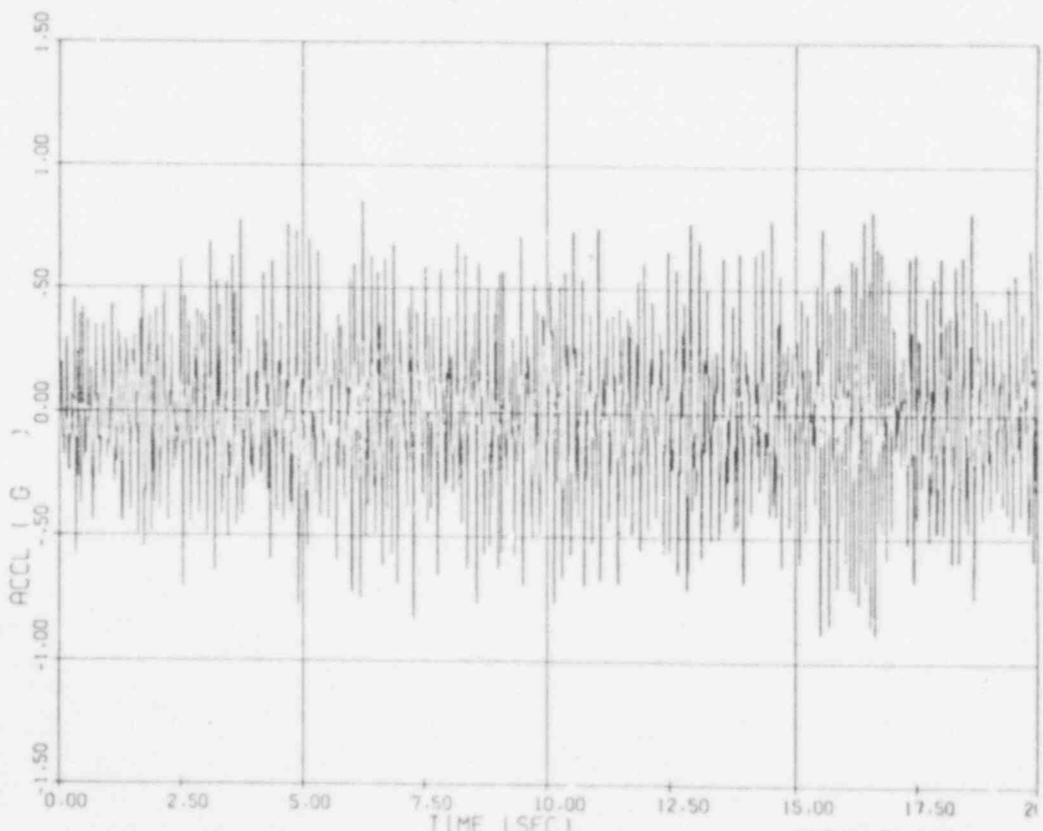


Analytical

Fig. 57. Acceleration Response, Main Pipeline With Branches Node No. 41Y

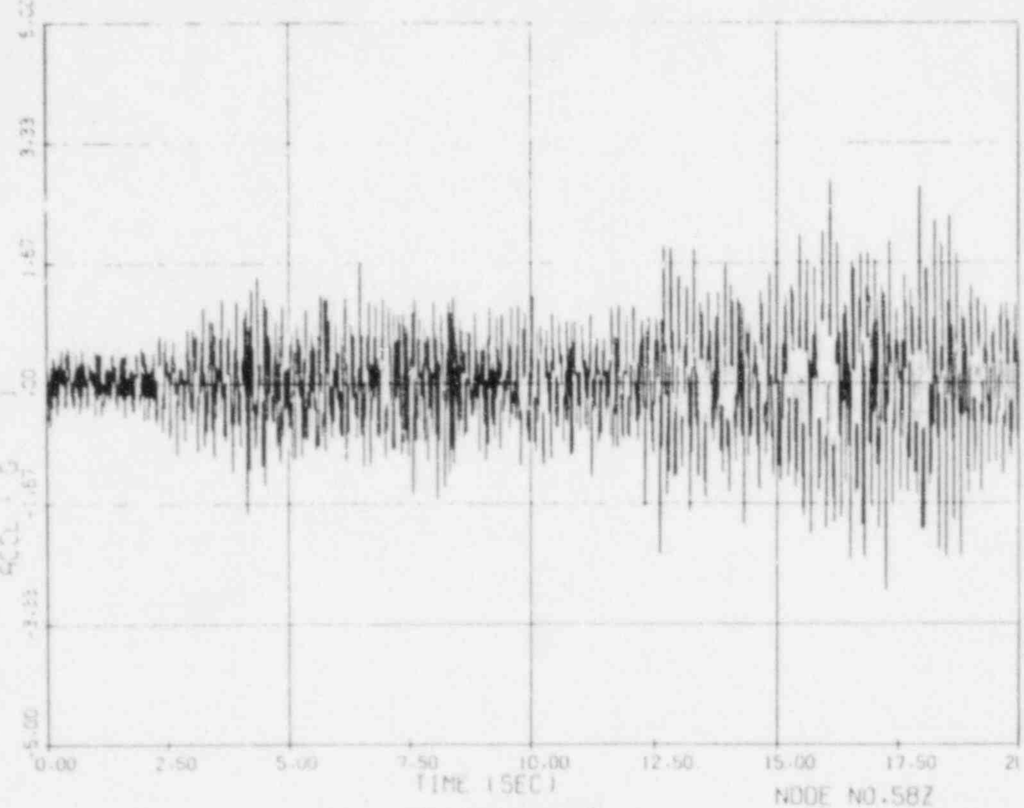


Experimental

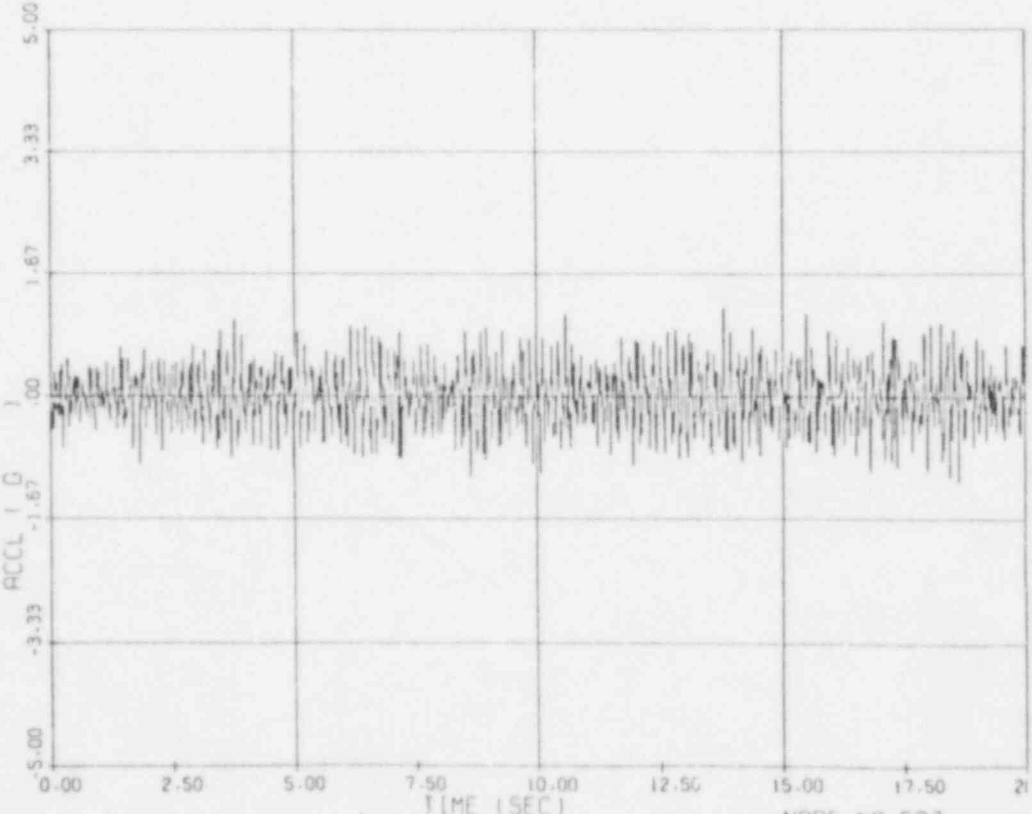


Analytical

Fig. 58. Acceleration Response, Main Pipeline With Branches Node No. 41Z

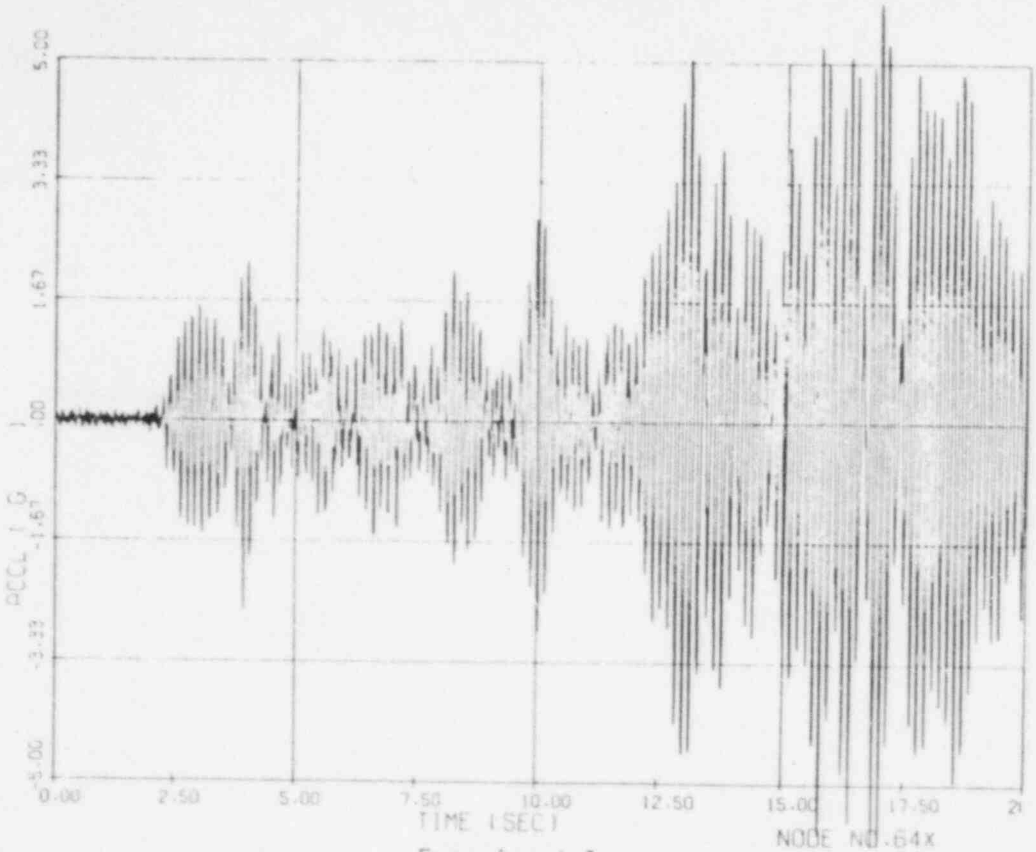


Experimental

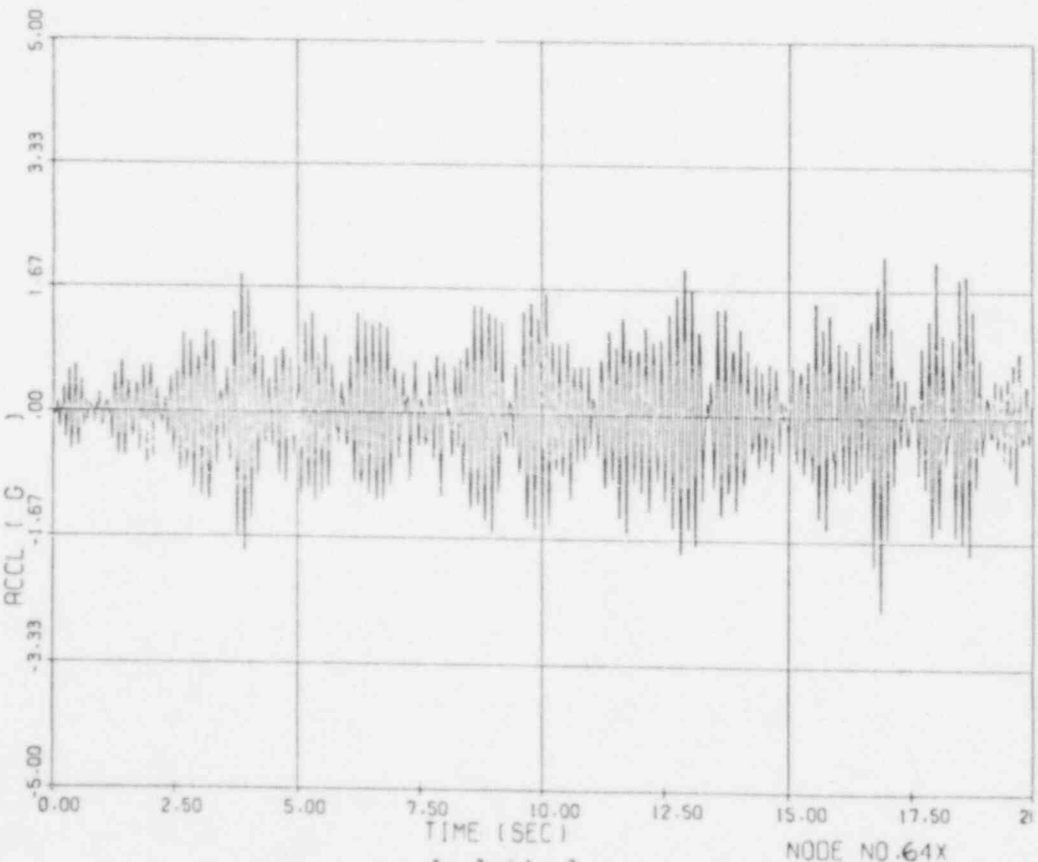


Analytical

Fig. 59. Acceleration Response, Main Pipeline With Branches Node No. 58Z



Experimental



Analytical

Fig. 60. Acceleration Response, Main Pipeline With Branches
Node No. 64X

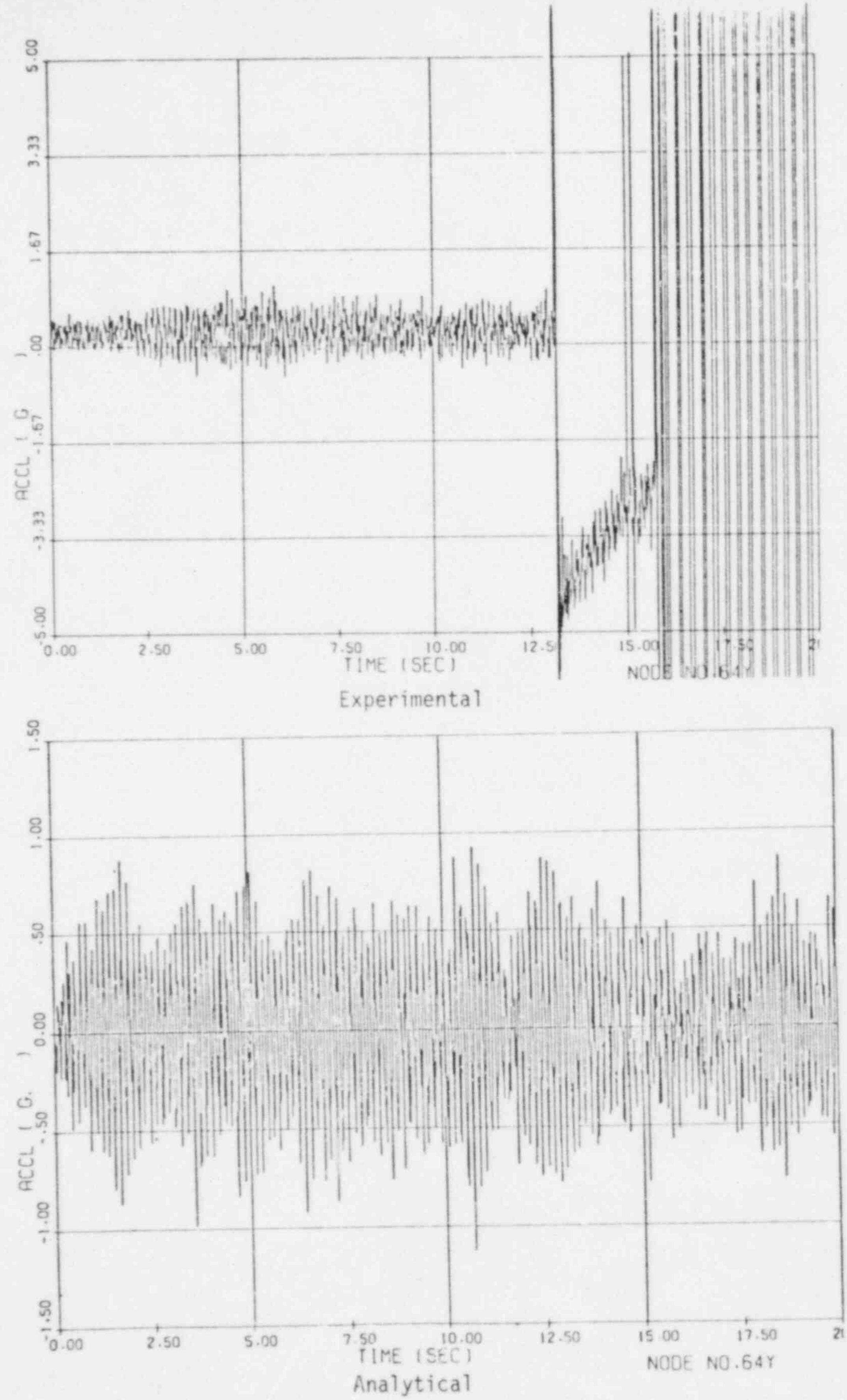
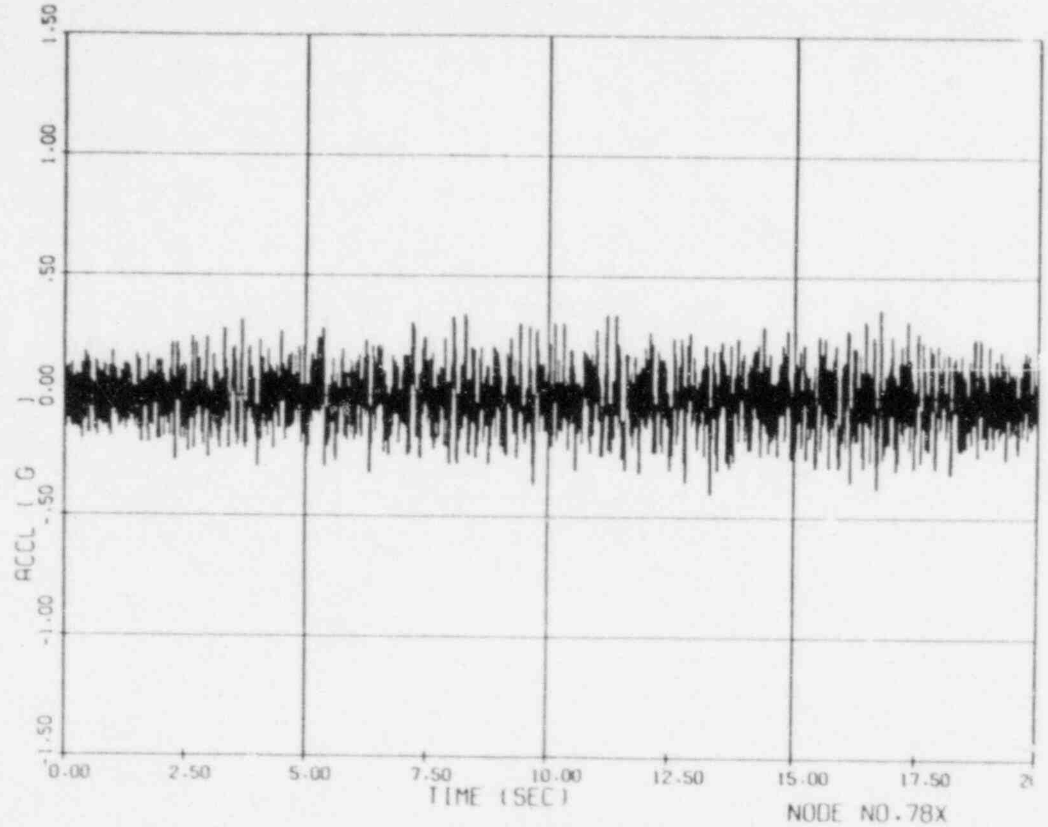
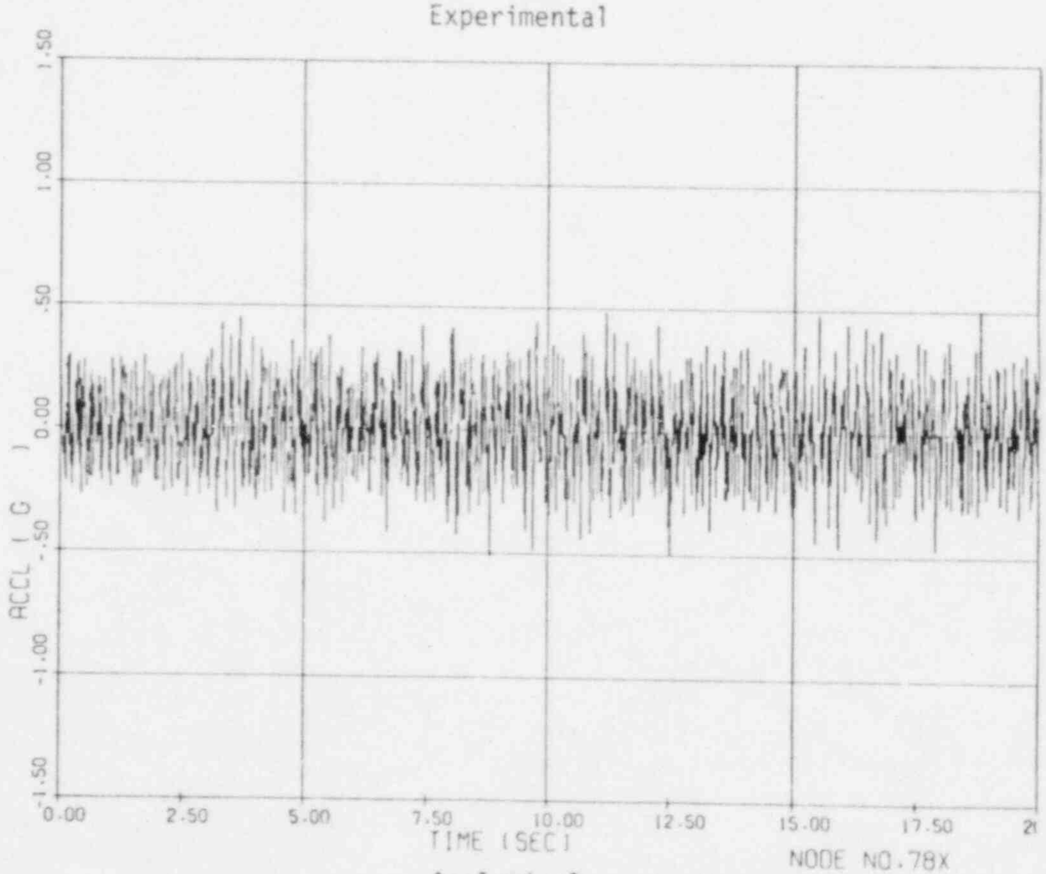


Fig. 61. Acceleration Response, Main Pipeline With Branches Node No. 64Y

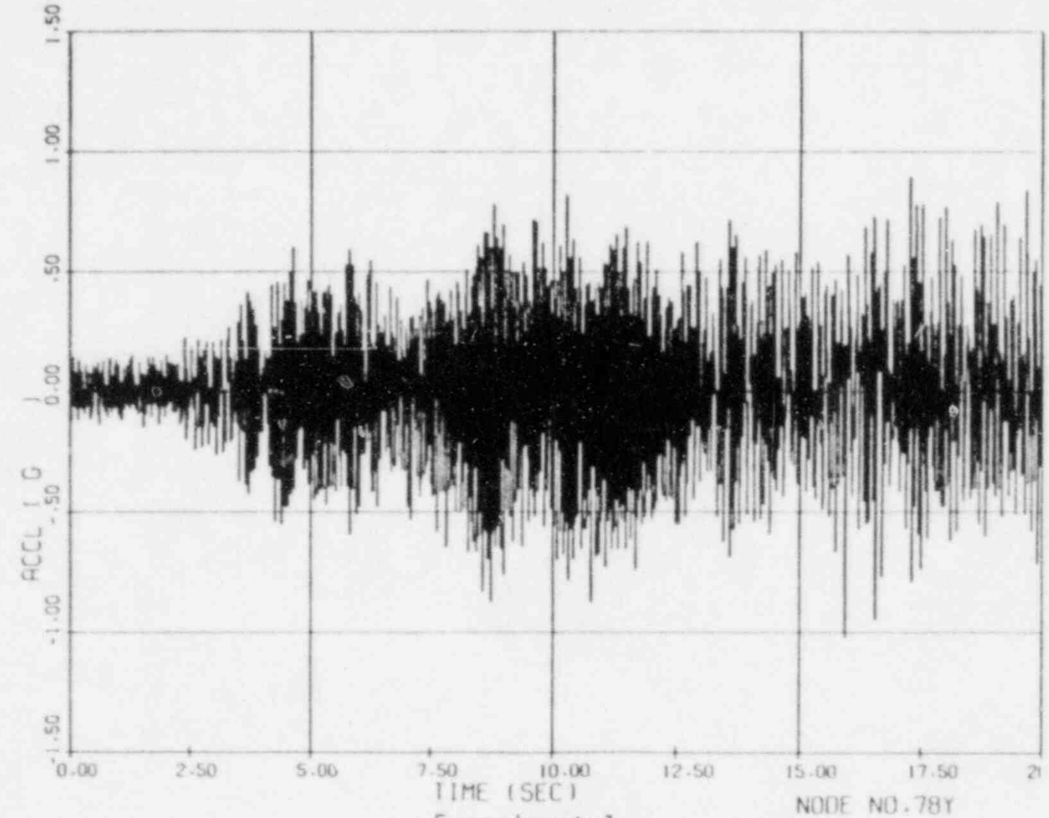


Experimental

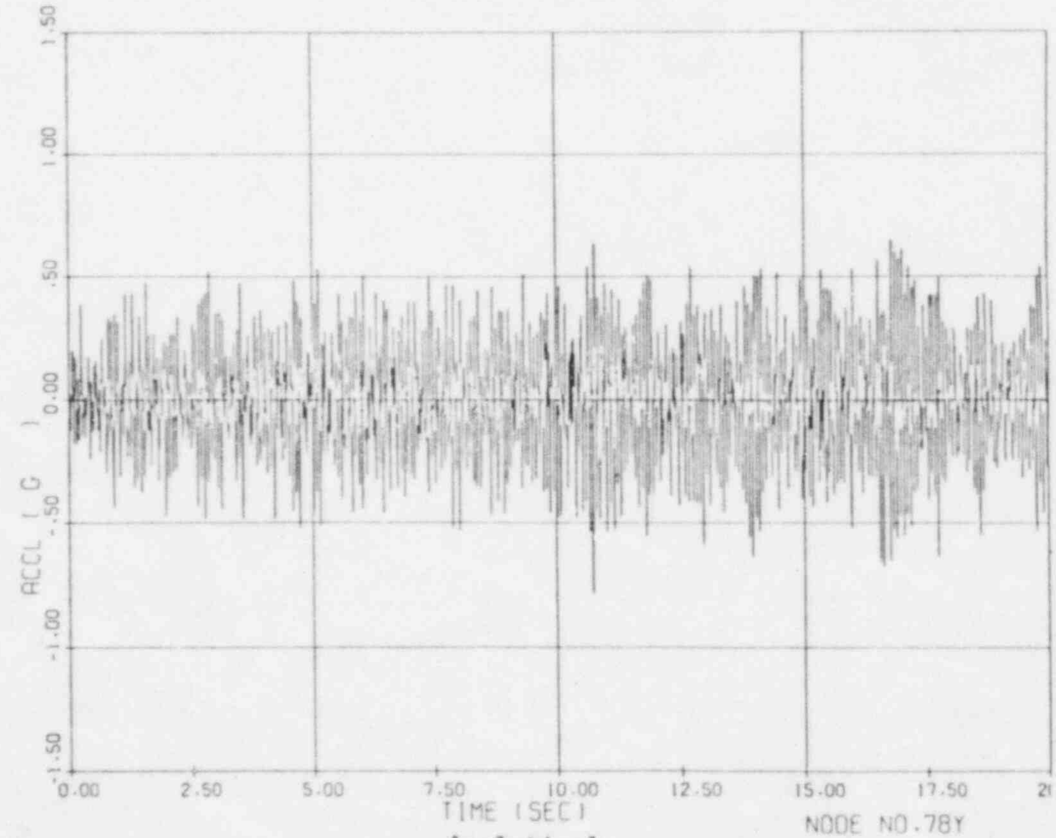


Analytical

Fig. 62. Acceleration Response, Main Pipeline With Branches Node No. 78X



Experimental



Analytical

Fig. 63. Acceleration Response, Main Pipeline With Branches Node No. 78Y

REFERENCES

1. ANCO Engineers Inc., "Laboratory Studies: Dynamic Response of Protoypical Piping Systems", NUREG/CR-3893, August 1984.

2. Trifunac, M.D. and Lee, V.W., Automatic Digitization and Processing of Strong Motion Accelerograms, Dept. of Civil Engineering, Report No. 79-15, University of Southern California, Los Angeles, Dec. 1979.

3. Subudhi, M. and Bezler, P., "PSAFE 2-Piping analysis Program: User's Manual - Version 1981", an Informal Report, May 1981.

4. Bezler, P., Subudhi, M. and Shteyngart, S., "In Situ and Laboratory Benchmarking of Computer Codes Used for Dynamic Response Predictions of Nuclear Reactor Piping", NUREG/CR-3340, May 1983.

5. Thinnes, G.L., Rahl, R.G., "Experimental and Analytical Results of Blast Induced Seismic Studies at HDR", NUREG/CR-2463, EGG-2158, November 1981.

6. Bezler, P. and Subudhi, M., "Corroboration of Heissdampfreaktor Reactor Recirculation Loop Piping Investigations", BNL-NUREG-31732, August 1982.

7. Bezler, P., Subudhi, M. and Shteyngart, S., "Physical Benchmark Evaluation, Extended Z-Bend", BNL-NUREG-34354, February 1984.

Appendix A

COMPARISONS OF BROOKHAVEN NATIONAL LABORATORY PREDICTED PIPING RESPONSE TO ANCO TEST XEQ1C1 DATA

A. G. Ware
EG&G Idaho, Inc.
Idaho National Engineering Laboratory

This letter report certifies that EG&G Idaho has compared computer generated predictions by Brookhaven National Laboratory (BNL) of test XEQ1C1 (conducted by ANCO Engineers) to the experimental data, and judges the adequacy of the computer predictions to be "fair". The general shape of the time-history motion was matched well, but the predictions for both displacement and acceleration magnitudes were underestimated on over 70% of the corresponding points examined. Thus the calculated stresses which would be compared to allowable values would more than likely be unconservative, and the design margins overestimated.

INTRODUCTION

Under sponsorship of the U.S. Nuclear Regulatory Commission (NRC) and the Electric Power Research Institute (EPRI), a series of vibration tests was performed on a 6-inch laboratory piping system at the ANCO Engineers' test facility in Culver City, California. On one of the tests XEQ1C1, a lower level earthquake simulation in the elastic range, BNL performed a blind prediction of piping system response using their structural computer code. For input, this time-history analysis used the recorded input test data for the supports of the piping system, where the seismic type force was applied, as supplied by ANCO Engineers. The resulting BNL predicted piping responses at intermediate points have been compared by EG&G Idaho to the corresponding ANCO displacement and acceleration measured test data. Results of the evaluation of predicted vs. actual responses are discussed below.

BASIS FOR COMPARISON

The BNL and ANCO data were first compared to ensure that the input data were applied correctly. It was verified that the BNL and ANCO displacements and accelerations were equal at the piping system ends (locations S1 and S4 of Figure 1; BNL nodes 1 and 87). Data for two intermediate supports (locations S2 and S3 of Figure 1; BNL nodes 37 and 67) were not comparable since the test data were for relative motions while the BNL predictions were for absolute motions. For the remaining points (pipe nodes) of measured data, comparisons of the maximum positive and negative responses, the times of occurrence of maximum response, and the five maximum positive and five maximum negative data peaks for each measurement location were made.

COMPARISON OF MAXIMUM RESPONSES

The magnitudes of the maximum displacements and accelerations for corresponding node points, without regard to the time of occurrences, were evaluated. For displacements, the motion was underpredicted 90% of the time and overpredicted 10% of the time. These maximum displacements were within 0 to 10% on forty percent of the comparisons, within 10 to 20% on ten percent of the comparisons, and within 20 to 30% on fifty percent of the comparisons. The average difference was 17%.

For accelerations, the motion was underpredicted 76% of the time, exactly predicted 5% of the time, and overpredicted 19% of the time. The maximum accelerations were within 0 to 10% on ten percent of the comparisons, within 10 to 20% on ten percent of the comparisons, within 20 to 30% on nineteen percent of the comparisons, within 30 to 40% on fourteen percent of the comparisons, and were greater than 40% on forty-seven percent of the comparisons.

The times of maximum response for the BNL and ANCO data were within 0.25 second on 56% of the comparisons.

COMPARISONS OF FIVE CORRESPONDING MAXIMUM PEAKS

The five maximum magnitudes at each measurement location, both positive and negative, on the ANCO experimental plots were compared to the corresponding peaks in the BNL predictions. This eliminated time from consideration, and gives an overall indication of the variance on a peak-to-peak basis. For displacements, the motion was underpredicted on 72% of the comparisons, exactly predicted 12% of the time, and overpredicted 16% of the time. The peaks were within 0 to 10% on twenty-eight percent of the comparisons, within 10 to 20% in eight percent of the comparisons, within 20 to 30% on twenty-four percent of the comparisons, with 30 to 40% on eighteen percent of the comparisons, and over 40% on twenty-two percent of the comparisons. The average underestimate was 30% while the average overestimate was 22%. Overall, the average percent deviation was 25%.

For accelerations, motions were underpredicted 82% of the time, exactly predicted 4% of the time, and overpredicted 14% of the time. The peaks were within 0 to 10% on sixteen percent of the comparisons, within 10 to 20% on ten percent of the comparisons, within 20 to 30% on sixteen percent of the comparisons, within 30 to 40% on twelve percent of the comparisons, and over 40% on forty-six percent of the comparisons. The average underestimate was 43% while the average overestimate is 49%. The average overall percentage difference was 42%.

Histograms of the percentage differences are shown in Figure 2 for both displacements and accelerations. The deviations of the five maximum peaks of the measured data are shown by circles on the histograms.

EVALUATION

To give more of a quantitative perspective to the numbers compared, the maximum absolute data values are discussed below, with the locations of these maxima shown in Figure 1. The maximum experimentally measured displacement was 0.29 inch (at 15.10 s) whereas the maximum predicted displacement was 0.21 inch (at 6.85 and 11.65 s). The corresponding predicted displacement at the equivalent time of the maximum measurement (15.10 s) was 0.16 inch (vs. 0.29 inch experimental). Similarly, the maximum measured acceleration was 1.53 g's (at 15.05 s) while the maximum predicted acceleration was 1.37 g's (at 15.25 s). However, for the time (15.05 s) and location (see Figure 1) corresponding to the maximum measurement, the BNL prediction was only 0.36 g's.

Some general observations and conclusions to this evaluation are:

1. The shapes of the corresponding plots are similar, but magnitudes are different. Frequency response comparisons, such as power spectral densities (PSD) or Fourier transforms, were not made because digitized BNL motions were not supplied.

2. In general, the displacement case comparisons are much closer than the acceleration comparisons.

3. Overall, experimental values range higher than the BNL values for both cases, exemplified by the high percentage underestimates by BNL.

4. The five peak evaluations give a clearer picture because this eliminates the time variable and enables point-by-point comparisons.

5. Based primarily on the overall underestimates of the peak response magnitudes, the BNL predictions are judged to be a "fair" estimate of the ANCO test data.

The variation in predicted and measured values may not necessarily be entirely due to the computer results. The tolerance on the reported experimental data is not known. In addition, the structural damping used for the analysis may have been higher than the actual damping present in the piping system. Since the computer code used a linear method of analysis, the small but inevitable nonlinearities inherent in any piping system could also make a contribution to the overall deviations in predicted and measured responses. The BNL predictions probably represent the state-of-the-art in computer predictions for piping system response today; thus it is recommended that an assessment be made as to why the motions were underestimated since this affects the design margins that would be present in a piping stress analysis.

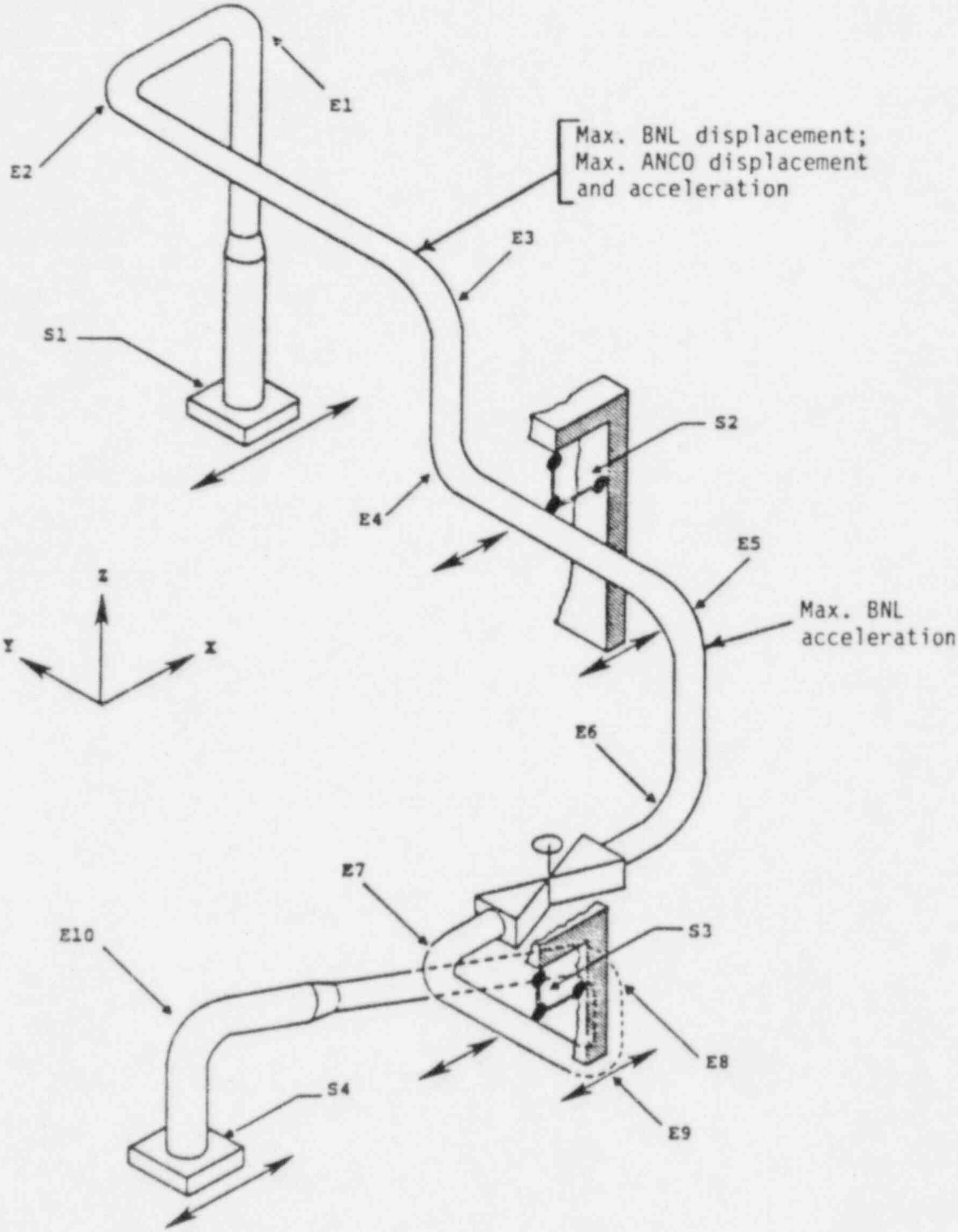
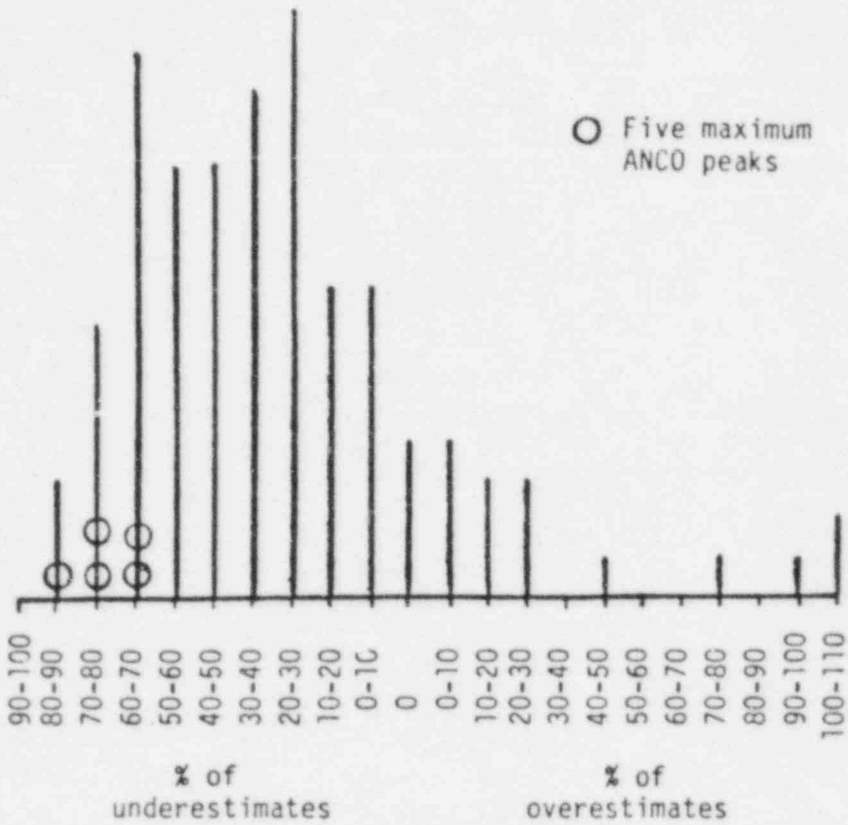
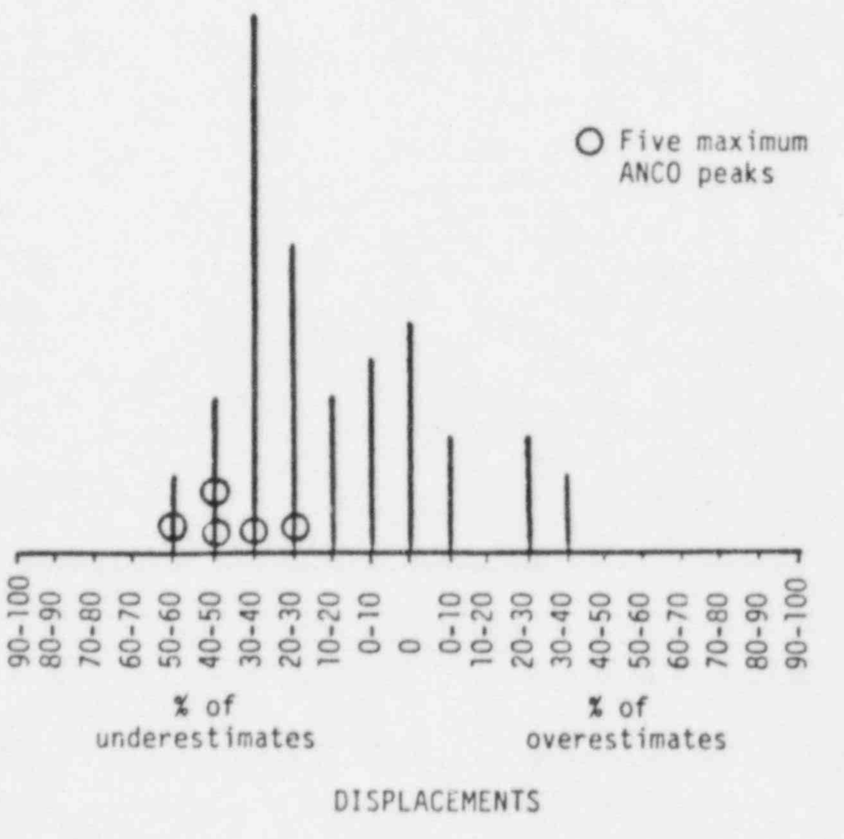


Figure 1. Locations of maximum motions.



ACCELERATIONS



DISPLACEMENTS

Figure 2. Histograms of percent deviations.

NRC FORM 335 (2-84) NRCM 1102, 3201, 3202

U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

SEE INSTRUCTIONS ON THE REVERSE

1. REPORT NUMBER (Assigned by TIDC, add Vol. No., if any)
NUREG/CR-4291
BNL-NUREG-51897

2. TITLE AND SUBTITLE
Conclusion & Summary Report on Physical Benchmarking of Piping Systems

3. LEAVE BLANK

4. DATE REPORT COMPLETED
MONTH: May YEAR: 1985

5. AUTHOR(S)
P. Bezler, M. Subudhi, S. Shteyngart & Y.K. Wang

6. DATE REPORT ISSUED
MONTH: June YEAR: 1985

7. PERFORMING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code)
Structural Analysis Division
Department of Nuclear Energy
Brookhaven National Laboratory
Upton, NY 11973

8. PROJECT/TASK/WORK UNIT NUMBER

9. FIN OR GRANT NUMBER
A-3225

10. SPONSORING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code)
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555

11a. TYPE OF REPORT
Technical Report

b. PERIOD COVERED (Inclusive dates)

12. SUPPLEMENTARY NOTES
NA

13. ABSTRACT (200 words or less)

Physical benchmark evaluations were used to assess the accuracy and adequacy of the analysis methods and assumptions used in typical piping qualification evaluations. Physical benchmark evaluations have been completed for six systems involving both laboratory and in situ tested piping. In each evaluation elastic finite element methods were used to predict the time history response of a system for which physical test results were available. In the analytical simulations the measured support excitations and the measured damping properties were used as input and the acceleration and displacement response of piping interior points were predicted as output. The linear analysis methods were found to provide reasonable estimates of system response. For a near linear system and using conservative estimates for system damping, a good correlation of response traces and acceptable estimates of response peaks can be expected. Using realistic estimates of uniform system damping, large underestimates of peak response components were observed and deviations of 100% or greater should be expected.

14. DOCUMENT ANALYSIS – a. KEYWORDS/DESCRIPTORS
PIPING SYSTEM
PHYSICAL BENCHMARKS
TEXT SIMULATION

b. IDENTIFIERS/OPEN-ENDED TERMS

15. AVAILABILITY STATEMENT

16. SECURITY CLASSIFICATION
(This page) unclassified
(This report) unclassified

17. NUMBER OF PAGES

18. PRICE

120555078877 1 1ANIRM
US NRC
ADM-DIV OF TIDC
POLICY & PUB MGT BR-PDR NUREG
W-501
WASHINGTON DC 20555