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BNL PIPING RESEARCH

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Abstract

Brookhaven National Laboratory (BNL) has assisted in the development of methods to evaluate the analysis methods used by industry to qualify nuclear power piping. Through FY 1985 these efforts were conducted under the Mechanical Piping Benchmarks project while current and future efforts will be performed under the Combination Procedures for Piping project. Under these projects BNL has developed analytical benchmark problems for piping systems evaluated using uniform or independent support motion response spectrum methods, investigated the adequacy and limitations of linear piping analysis methods by comparison to test results and evaluated and developed criteria for new and alternate methods of analysis. A summary description of the status of these efforts is provided.

1. INTRODUCTION

The Structural Analysis Division of the Department of Nuclear Energy at the Brookhaven National Laboratory (BNL) has and continues to perform various research tasks relating to piping analysis for the U.S. Nuclear Regulatory Commission (USNRC). Until the current period the BNL efforts were funded under the Mechanical Piping Benchmarks Project monitored by J. O'Brien of the USNRC. The current and future efforts are funded under the project entitled, "Combination Procedures for Piping Response Spectra Analysis monitored by D. Guzy of the USNRC.

The BNL research efforts may be broadly characterized into three areas; the development of benchmark problems and solutions suitable for the verification of applicant piping analysis methods, the investigation of the adequacy of linear analysis methods by the comparison of analysis and test results for piping (Physical Benchmarking) and the evaluation of new and alternate methods for the dynamic analysis of piping systems. At present, the benchmarking efforts, both analytical and physical, have ceased, each having satisfied the funded project goals under the Mechanical Piping Benchmarks project. The investigation of new and alternate analysis methods continues under the second project. A summary description of the three research areas follows.

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2. PHYSICAL BENCHMARK PROBLEMS

The benchmark problems and solutions developed to verify applicant piping analysis methods are published in the Piping Benchmark Problems Report Series [1,2]. Although it was anticipated that there would be five volumes in the report series, only the first two volumes have been issued to date. In the current period the second volume [2] of the series entitled, "Piping Benchmark Problems, Dynamic Analysis, Independent Support Motion, Response Spectrum Method", was issued. In the report, four benchmark problems and solutions developed for verifying the adequacy of computer programs used for the dynamic analysis and design of elastic piping systems by the independent support motion (ISM), response spectrum method are presented. The dynamic loading is represented by distinct sets of support excitation spectra assumed to be induced by non-uniform excitation in three spatial directions. Complete input descriptions for each problem are provided and the solutions include predicted natural frequencies, participation factors, nodal displacements and element forces for independent support excitation and also for uniform envelope spectrum excitation. Solutions to the associated anchor point pseudo-static displacements are not included.

All solutions were developed using the finite element code PSAFE2 [3]. In each solution combination over group contributions was performed first, followed by SRSS interspatial combination, followed by SRSS intermodal combination without the consideration of closely spaced frequencies. For the ISM solutions both absolute and SRSS combination between support group contributions were considered where a support group was defined as all supports exhibiting the same motion. Figure 1 shows the finite element grid for the third benchmark problem which involved 54 pipe elements and four distinct support groups.

3. Physical Benchmarks

The basic premise of the physical benchmarking 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. In the effort a total of six evaluations were performed involving 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. 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 after the analyses were complete. After evaluation no attempts to improve the results with refined analyses was undertaken.

A description of each of the piping systems evaluated, with a summary of the key results, is provided in Table 1. Detailed descriptions of each evaluation are provided in References 4-7 while examples of typical results are shown in Figures 2-4 and Table 2.

A sketch of the Main Pipeline [7] is shown in Figure 2. The system was totally supported and excited by actuators located at positions S1 through S4. For the test simulated the actuators imposed nearly in phase, seismic like excitation of the system in the X coordinate direction. The measured and computed natural frequencies for the system are shown in Table 2. A review of this data indicates that the correspondence was good and this level of agreement for frequencies was typical in the evaluations. An example of good agreement between the predicted and measured acceleration response for an interior point is shown in Figure 3. The figure shows predicted and measured time history traces of the acceleration in the X coordinate direction of a point in the vicinity of the valve. An example of poor agreement between predicted and measured response is shown in Figure 4. These are the accelerations in the Z coordinate direction of a point located on the uppermost horizontal run. Good agreement for responses in the direction of excitation X direction, and poor agreement for responses in the unexcited directions was typical for this evaluations. The poor correspondence for the unexcited directions was attributed to the failure to monitor and therefore simulate in the analysis the input motions in the directions orthogonal to the actuators.

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.

4. Alternate Analysis Methods

Standard practice to qualify piping for dynamic events is to perform a response spectrum analysis of the system assuming uniform excitation of all supports to the envelope spectrum level coupled with a conservative estiamte of the additional responses associated with differential support point movement [8]. For systems subjected to multiple independent support motions a modified response spectrum procedure which allows the use of separate response spectra for each support group seems more appropriate. To assist the USNRC in its evaluation of the Independent Support Motion (ISM) response spectrum method BNL undertook an evaluation of ISM methods and the associated computation of anchor movement (pseudo-static) response. The evaluation was performed under the Mechanical Piping Benchmarks project and involved a consideration of systems exhibiting uniform damping only. An extension of the evaluation for systems exhibiting frequency dependent (PVRC) damping is currently being performed under the project monitored by D. Guzy.

To predict the dynamic component of response a response spectrum method which allows the use of independent spectra sets for each support or group of supports was evaluated. In this method a response parameter is predicted as a function of each support group for each mode and each direction of excitation.

To obtain the total dynamic response a combination over groups, modes and directions must be performed. In this evaluation the square root of the sum of the squares (SRSS) combination over directions and SRSS combination with clustering for closely spaced modes were accepted for the combination over directions and modes. For the combination over groups algebraic (methods 1 and 2), SRSS (Methods 3-8) and absolute (methods 9-14) combination were considered. Further all sequences of performing these combinations were considered. In all fourteen different combination strategies, methods 1-14 were evaluated for the computation of the dynamic component of response.

To predict the SAM component of response five procedures were evaluated. Four of these were based on the use of absolute peak support displacement data. These methods differed in the manner in which the supports were grouped to account for the unknown phasing between supports. The grouping assumptions considered were random phasing (method 2), grouping by global direction (method 3), grouping by attachment point (method 4) and grouping by elevation (method 5). Within each group support effects were summed algebraically. Between groups both SRSS and absolute summation were considered. The remaining method evaluated (method 1) was based on sampling the support point displacement time history records. Since in this method support point phasing information is retained, no grouping assumptions were made.

To compute the total component of response, both SRSS and absolute combination between the dynamic and SAM components were considered. The response parameters computed included pipe displacements, accelerations, support forces and resultant moments. At each stage the predicted response estimates were compared to response estimates developed using ISM time history methods which were assumed to represent the true response. The relative approach of each predicted value to the time history result was expressed as a degree of exceedance given by Predicted-TH/TH (TH = time history).

The evaluations were performed for five different piping-structure problems. The salient characteristics for each problem are summarized in Table 3. To provide a statistical basis to the study the evaluations for two of the problems, the AFW model and the RHR model, were performed for thirty-three different seismic events. For these the time history results were provided by an alternate NRC contractor.

All study results are summarized in tabular form. Each table lists the time history estimate as well as the response estimate for each calculational option and parameter studied. For the two problems involving thirty-three seismic events the pertinent results are summarized in figure form. Figures 3 and 4 show these results for resultant moments in the RHR problem. Figure 3 corresponds to the dynamic component while Figure 4 corresponds to the SAM component. Each figure shows the mean (data point) ± one standard deviation (line extent) for the parameter over the thirty-three seismic events. The figures show the results only for those elements which establish the lower bound of degree of exceedance (define the minimum level of conservatism). A comprehensive presentation of the results is provided in Reference 9.

At the completion of the study the following recommendations were advanced:

Dynamic Component of Response

The independent support motion response spectrum method should be certified as acceptable for the evaluation of the dynamic component of response.

SRSS combination between support group contributions should be adopted in the independent support motion response spectrum analysis.

Pseudo-Static Component of Response

For displacements, pipe moments and support forces:

Method 5 (grouping by elevations) with absolute combination between groups should be used for preliminary design.

Method 4 (grouping by attachment points) with absolute combination between groups should be used for final design.

For accelerations:

Absolute combination between support groups should be adopted.

Combined Response

SRSS combination between the dynamic and static components of the response should be adopted.

As mentioned, BNL is currently extending the evaluation of ISM methods to consider the effect of PVRC damping. Pending tasks also include the evaluation of proposed modal combination methods accounting for closely spaced modes, frequency dependent effects and an investigation of the impact of correlation between inputs on the combination rules recommended for the ISM method.

5. REFERENCES

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Table 1
Physical Benchmark Evaluations

System	System Description	Input Excitation	Comments and Results
Z Bend	Planar configuration of 4" pipe supported from and excited by three hydraulic actuators	Laboratory tested with independent seismic excitations of each actuator	Results good except in vicinity of central actuator. Poor results here attributed to existence of a clearance gap at central actuator
Indian Point Rigid Strut Configuration	Segment of boiler feed system of shutdown Indian Pt. Unit 1 power plant. 8 in, sch 80 pipe approx. 100 ft. long supported with rigid struts	In situ, snap back test	Results poor. Correlation good for maximum responses, poor everywhere else. Poor results attributed to the approximations used to model supports
HDR-URL Piping	Recirculation loop of shutdown Heissdampfreactor. 450 and 350 mm piping with two pumps and four valves	In situ explosive, 5 Kg blast in near field	Results poor. Correlation good for peak responses. Poor results attributed to the use of linear analysis methods to model a system with strongly nonlinear support elements
Extended Z Bend	Z Bend configuration redesigned to eliminate all clearance gaps	Laboratory tested with independent seismic excitations of each actuator	Results fair. Estimates of displacements good. Estimates of accelerations ranged from good to poor.

Table 1 (Cont'd)
Physical Benchmark Evaluations

System	System Description	Input Excitation	Comments and Results
Main Pipeline	Three-dimensional configuration of 8" and 6" pipe supported from 4 hydraulic actuators located at ends and two interior points	Laboratory tested with independent seismic excitations of each actuator	Results fair. Better for displacements and accelerations in direction of excitation. Peak responses underestimated. Deviations attributed to boundary element effects.
Main Pipeline with Branches	As above with two 3" lines branched from main line. Supported from 4 end point and one interior point hydraulic actuators.	Laboratory tested with independent seismic excitations of each actuator	Results fair/poor. Correlation for response in directions orthogonal to excitation poor. Peak responses underestimated. Poor correlation attributed to failure to monitor and therefore simulate dominant inputs.

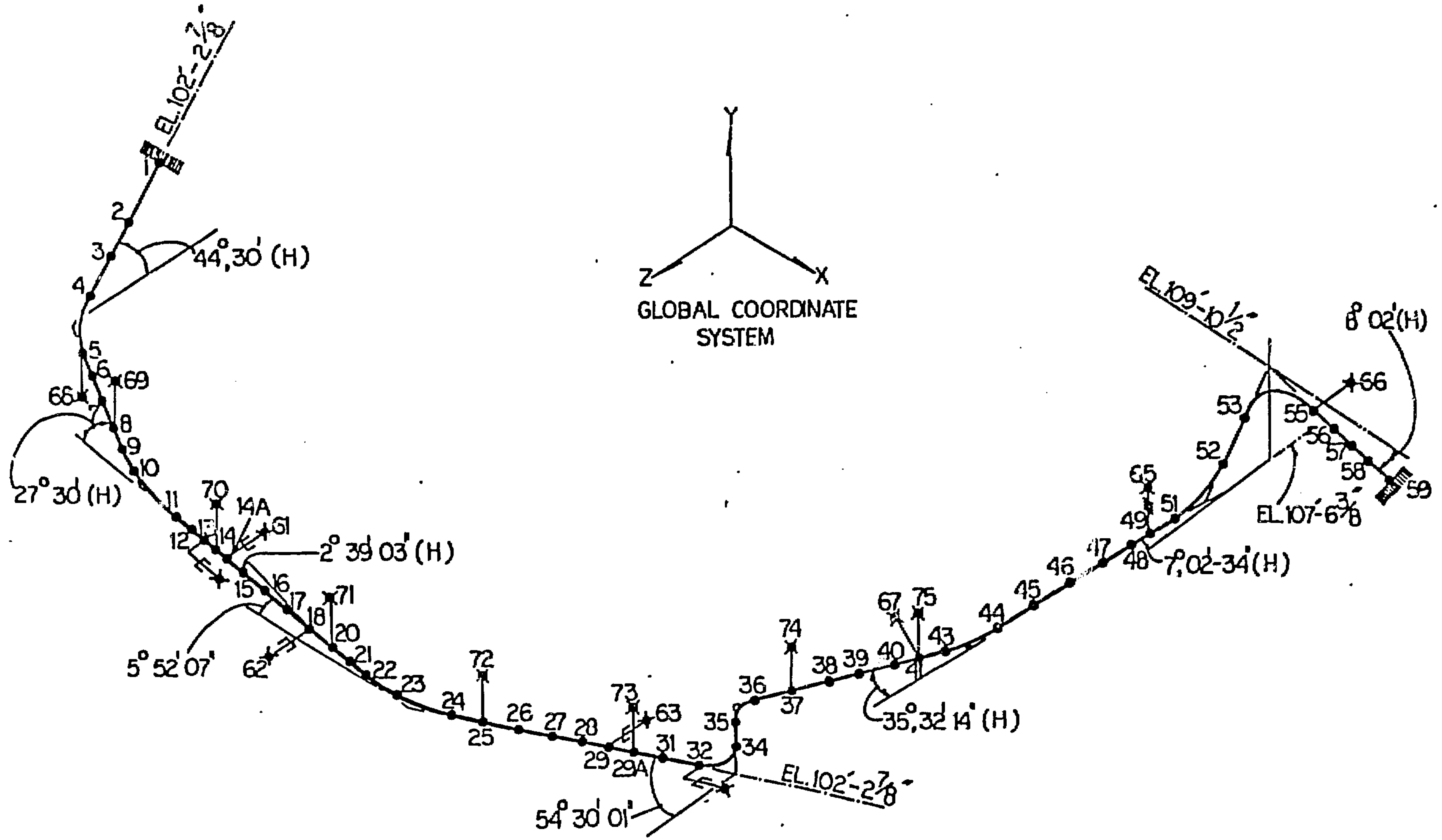
TABLE 2

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

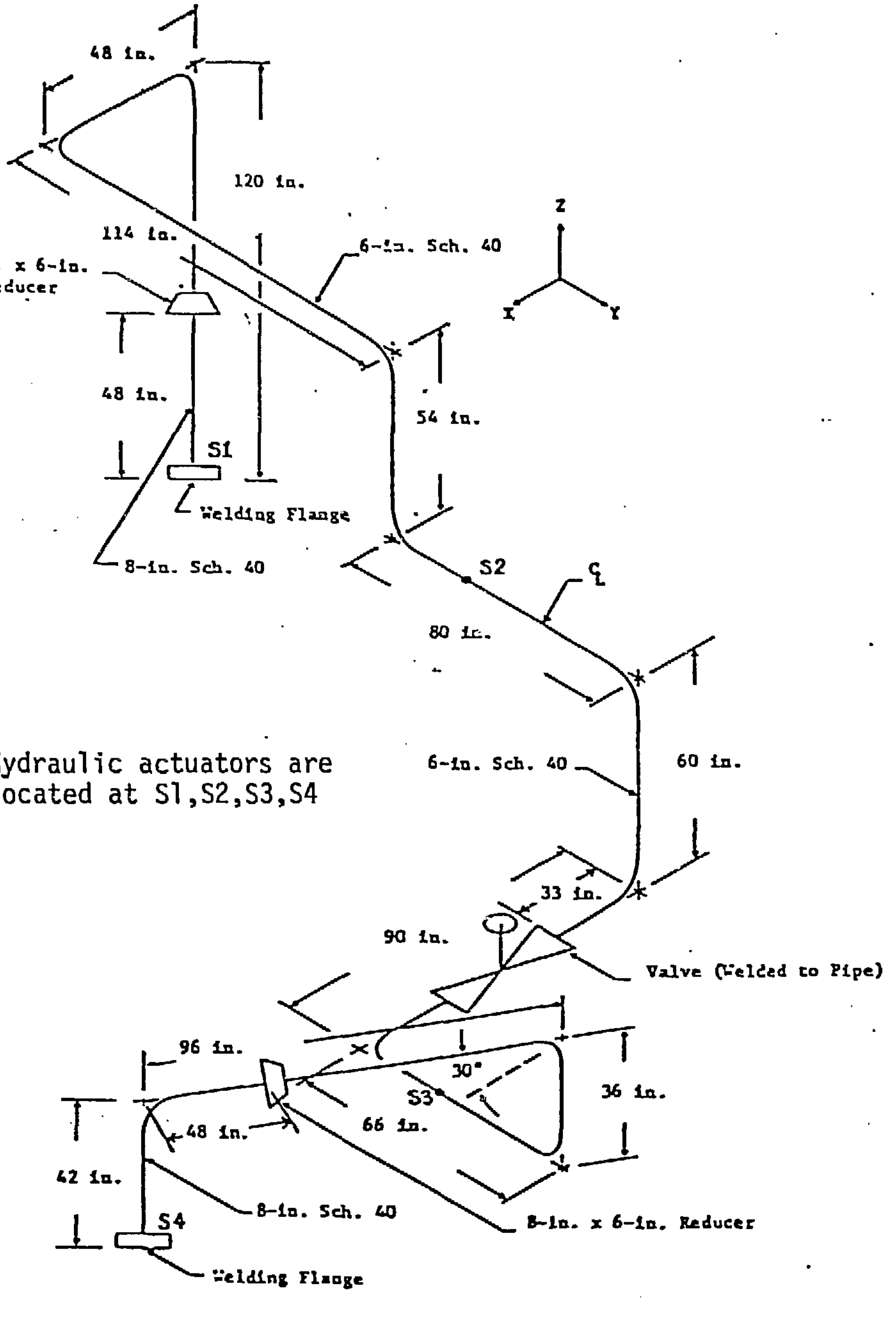
Table 3 Model Parameters

Model	Structure	No. of Equations	Pipe Size	Pipes Frequencies 1st, 2nd	No. of Support Groups	No. of Seismic Events	No. of Modes Used	No. of Moments	No. of Support Forces	No. of Disp./Accel. Parameters
RHR	Zion (3D)	423	8", 12"	3.86, 8.11	9	33	18	22	15	17 x 3
AFW	Zion (3D)	945	3", 16"	2.86, 3.76	15	33	37	23	28	21 x 3
Z-Bend	ANCO Test (3D)	204	4"	8.67, 17.42	3	1	10	39	16	34 x 3
BM 1	PWR (3D)	336	2", 6"	5.05, 14.63	5	1	15	55	32	56 x 3
BM 2	BWR (Stick)	336	2", 6"	5.05, 14.63	4	1	15	55	32	56 x 3
BM 3	Test Reactor	228	3", 4", 8"	2.91, 4.39	2	1	23	37	30	38 x 3



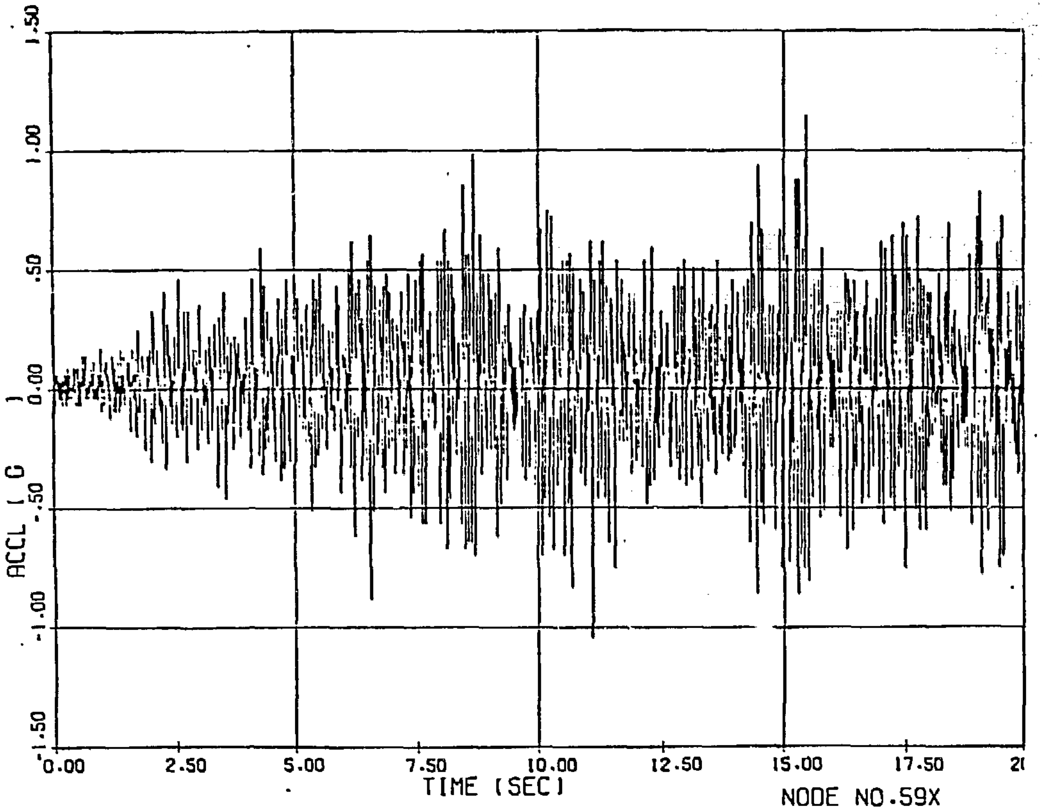
BENCHMARK PROBLEM NO. 3

Figure 1

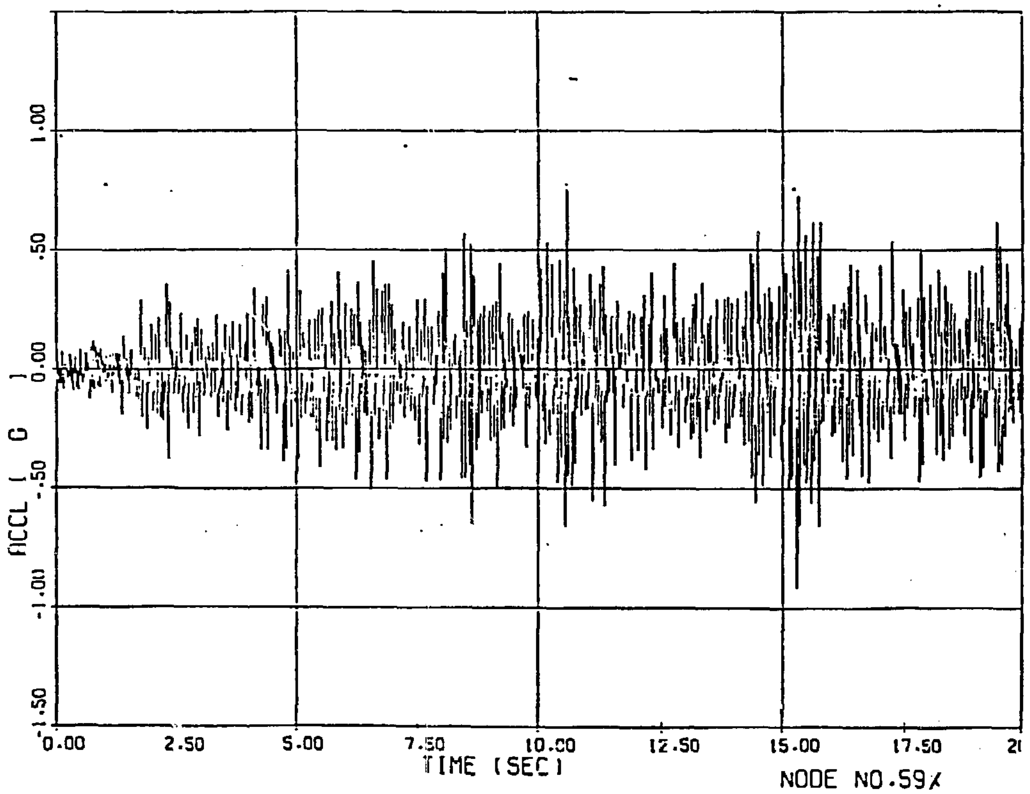


Hydraulic actuators are located at S1,S2,S3,S4

Fig. 2 Main Pipeline

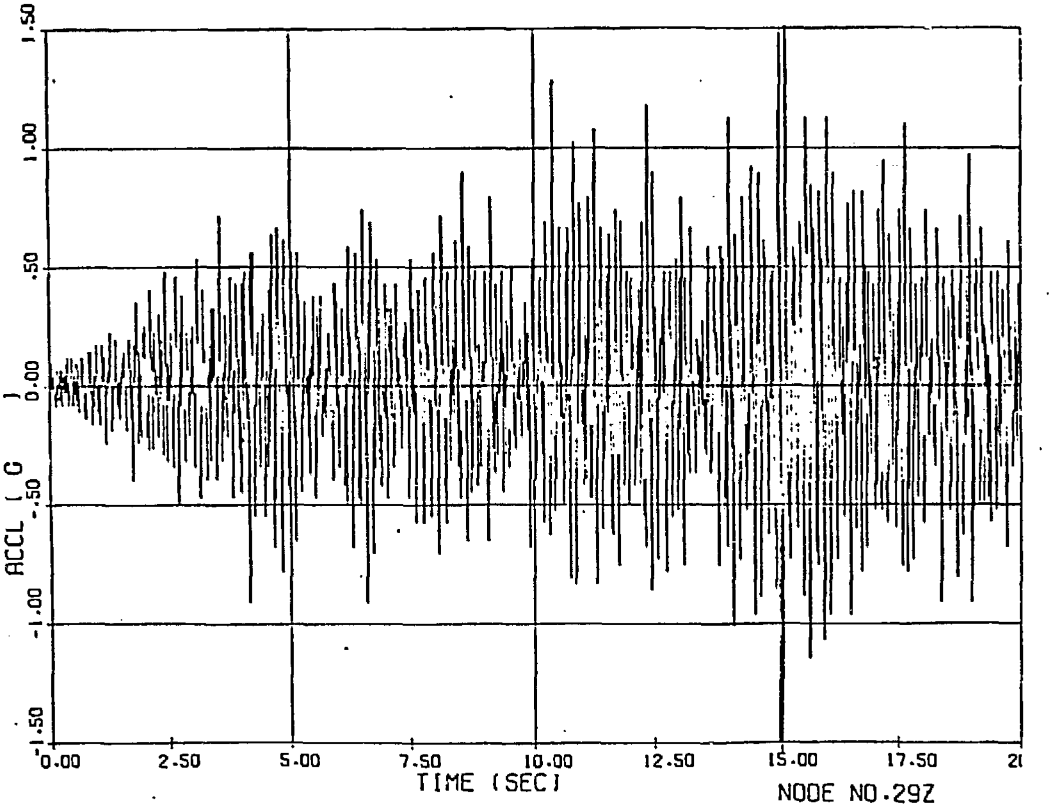


Experimental

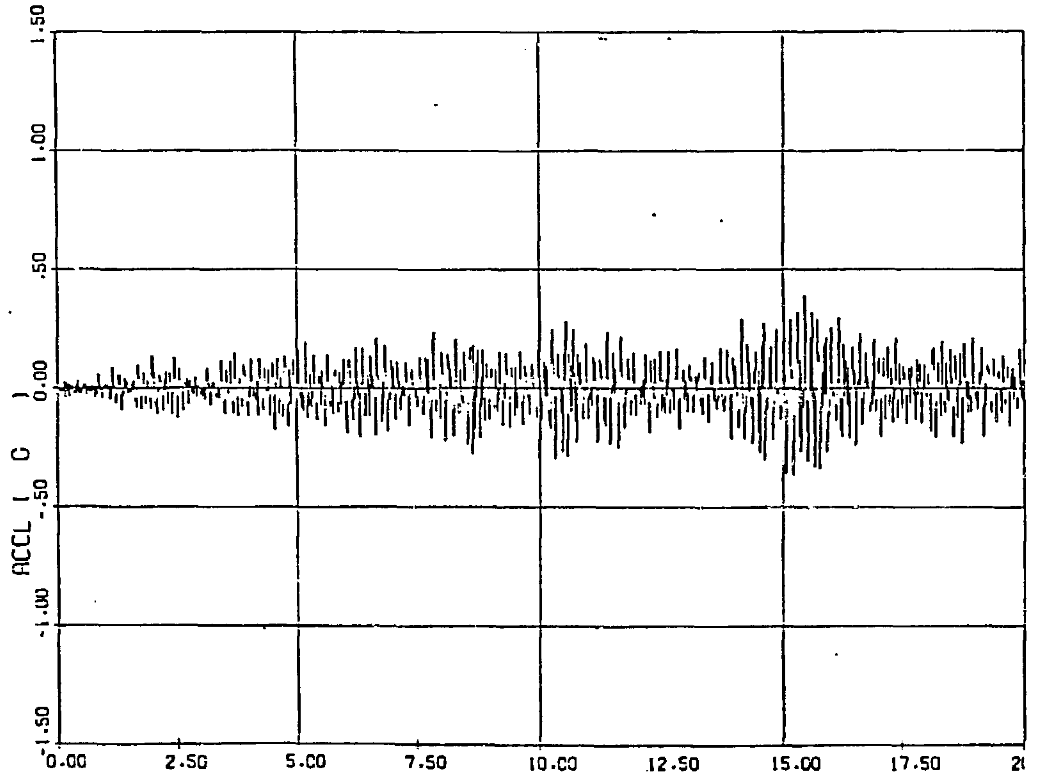


Analytical

Fig. 3 Acceleration Response, Main Pipeline Node No. 59X



Experimental



Analytical

Fig. 4 Acceleration Response, Main Pipeline Node No. 29Z

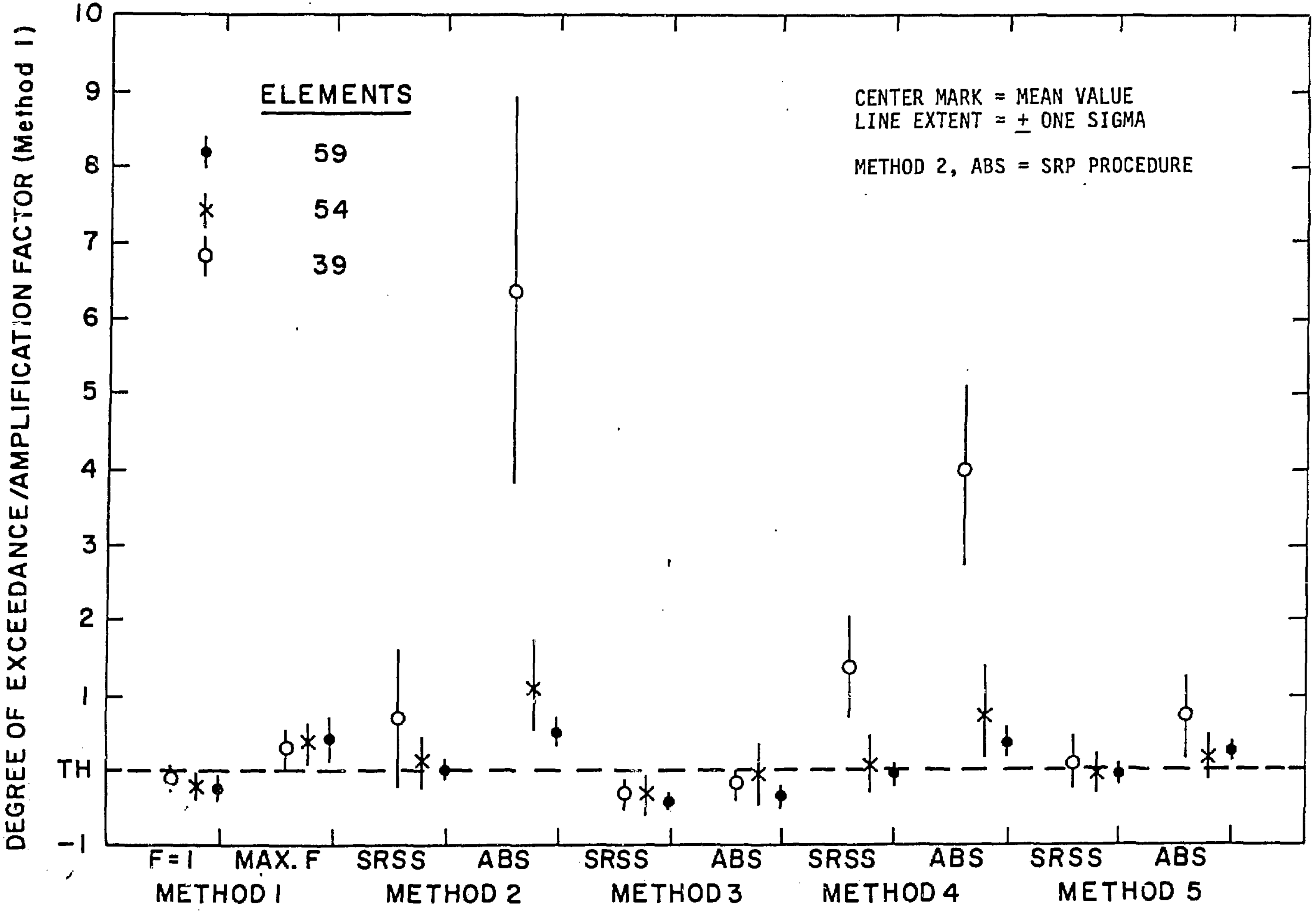


Figure 5 - Static Pipe Resultant Moment Responses for RHR Model

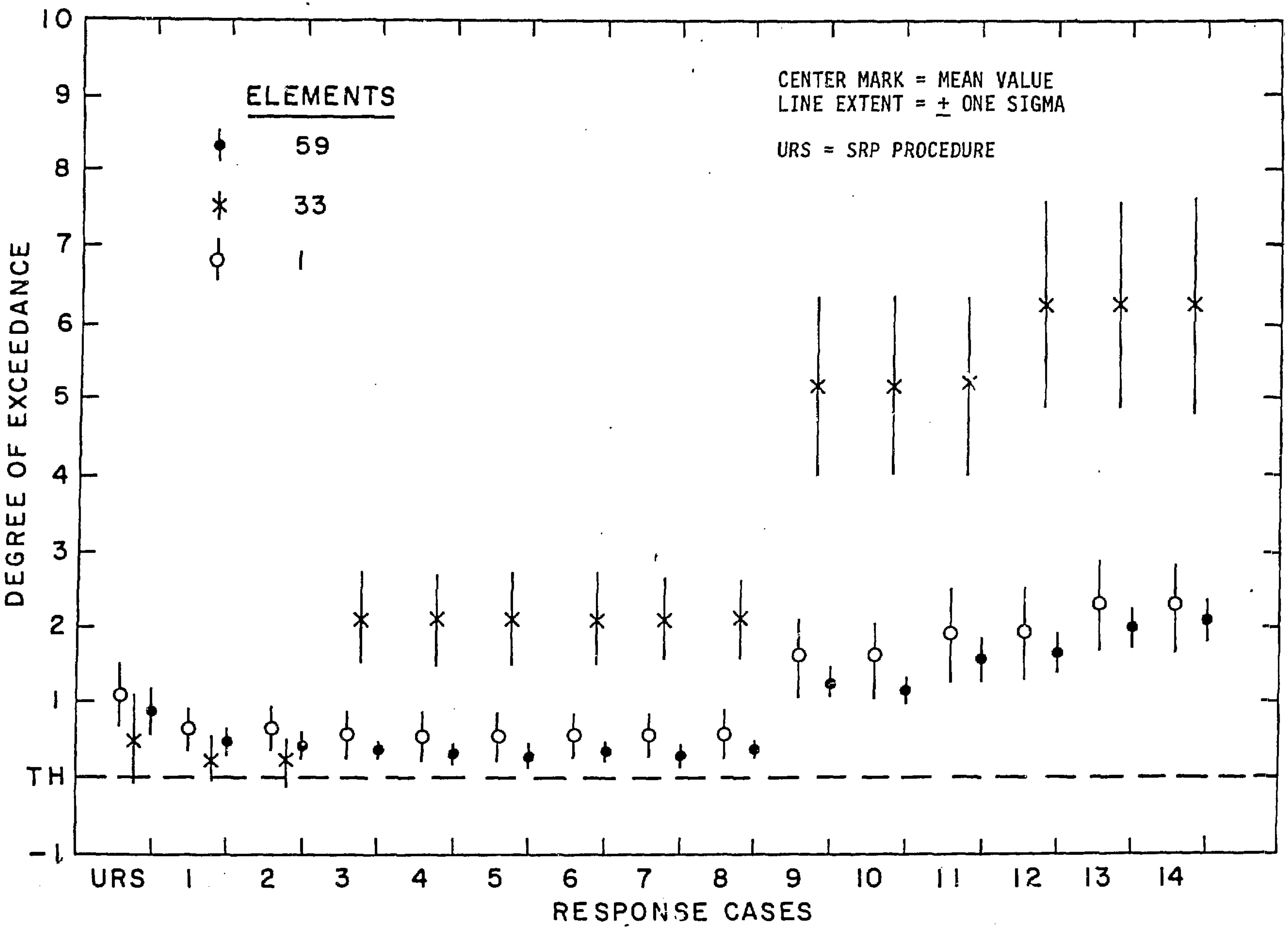


Figure 6 - Dynamic Pipe Resultant Moment Responses for RHR Model

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