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STANDARD PROBLEMS TO EVALUATE PIPING RESPONSE COMPUTER CODES

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ABSTRACT

A program has been underway to evaluate the analysis methods used by industry to qualify nuclear power plant piping. Two objectives of this program are to develop physical benchmarks for validating the accuracy of computer codes used to simulate piping response and to develop improved procedures for calculating the response of multiple supported piping with independent seismic inputs. The status of the program in these two areas is reviewed.

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 program has been underway 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. Summary reports of the program activities are provided in "Safety Research Programs" sponsored by the Office of Nuclear Regulatory Research Quarterly Progress Reports.

Herein the highlights of the most current work areas will be provided. This includes a description of the physical benchmarking effort and the analytical efforts undertaken to develop an improved procedure for calculating the response of multiply supported piping with independent seismic inputs (ISM).

PHYSICAL BENCHMARKS

As a logical extension of the analytical benchmarking effort, the development of physical benchmarks was undertaken. The physical benchmark evaluations are used to assess the accuracy and adequacy of the analysis methods and assumptions used in typical piping qualification evaluations. In each evaluation linear elastic finite element methods are used to predict the time history response of a system for which physical test results are available. In the analytical simulation the measured excitations of each support point and the measured damping properties are used as input and the acceleration and displacement response of piping interior points are predicted as output. Each evaluation is performed blind in that only the measured inputs are provided at the time of analysis. At completion, the measured response data are made available and by comparison the accuracy of the predicted results are assessed.

To date physical benchmark evaluations have been completed and reported for four piping systems. Table 1 provides a description of each of these with a summary of key results. Figure 1 shows the extended Z bend configuration, the last evaluation completed. Figure 2 shows the results for the acceleration of node 21 for this model. This figure is typical of the displacement and acceleration results developed in each evaluation.

Two more physical benchmark evaluations are scheduled. Both involve laboratory tests of piping performed under joint NRC-EPRI sponsorship and conducted by ANCO Engineers Inc. The piping in each of these tests is 6 in SCH 40 pipe supported from and excited by four hydraulic actuators. The first configuration consists of a multi bend span between two anchors. The second consists of the first configuration expanded with two branch lines. A reporting of the results of these benchmarks should be available in 1984.

MULTIPLY SUPPORTED PIPING WITH INDEPENDENT SEISMIC INPUTS

Nuclear power plant piping must have the capacity to withstand the dynamic loads associated with postulated seismic events. Seismic adequacy is most commonly demonstrated by analysis with time history or uniform support motion (URS) methods being currently acceptable evaluation procedures. If the response spectrum method is used, a separate calculation must be performed to account for the loads induced by relative support point or anchor point motions. In this case the total piping response is the combination of the dynamic component estimated by the spectrum method and the seismic anchor movement (SAM) component. The Standard Review Plan (SRP, reference 1) provides specific guidelines and requirements for the computation of the dynamic, SAM and total components of response.

For piping systems subjected to multiple independent support motions the present SRP requirements provide a great margin of safety and lead to piping designs which are inherently stiff. The high stiffness of these systems compromise there capacity to absorb the thermal expansions associated with normal operating conditions. In this study alternate procedures to compute the dynamic, SAM and total components of response, based on independent support motion (ISM) algorithms, were investigated. The information developed supports and provides some basis for a potential relaxation of the SRP requirements.

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). Table 2 shows a flow chart depicting the study effort.

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 of the computations were performed using the BNL computer code PSAFE2, reference 2. This code is a general purpose, linear elastic, finite element piping analysis code which was independently developed for the benchmarking purpose. Analysis options include the independent support motion time history and response spectrum methods.

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) and ± 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 the degree of exceedance (define the minimum level of conservatism).

All computations in this effort have been completed. The results are under review and appear to provide some basis for a relaxation of current design requirements.

REFERENCES

1. U.S. Nuclear Regulatory Commission, "Dynamic Testing and Analysis of Systems, Components and Equipment", Standard Review Plan, NUREG-0800, Section 3.9.2.

2. Subudhi, M. and Bezler, P., "PSAFE2-Piping Analysis Program-User's Manual Version 1981", Informal Report, July 1981.

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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 fair 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 with under predictions of 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 2. Multiply-Supported Piping System Research Program

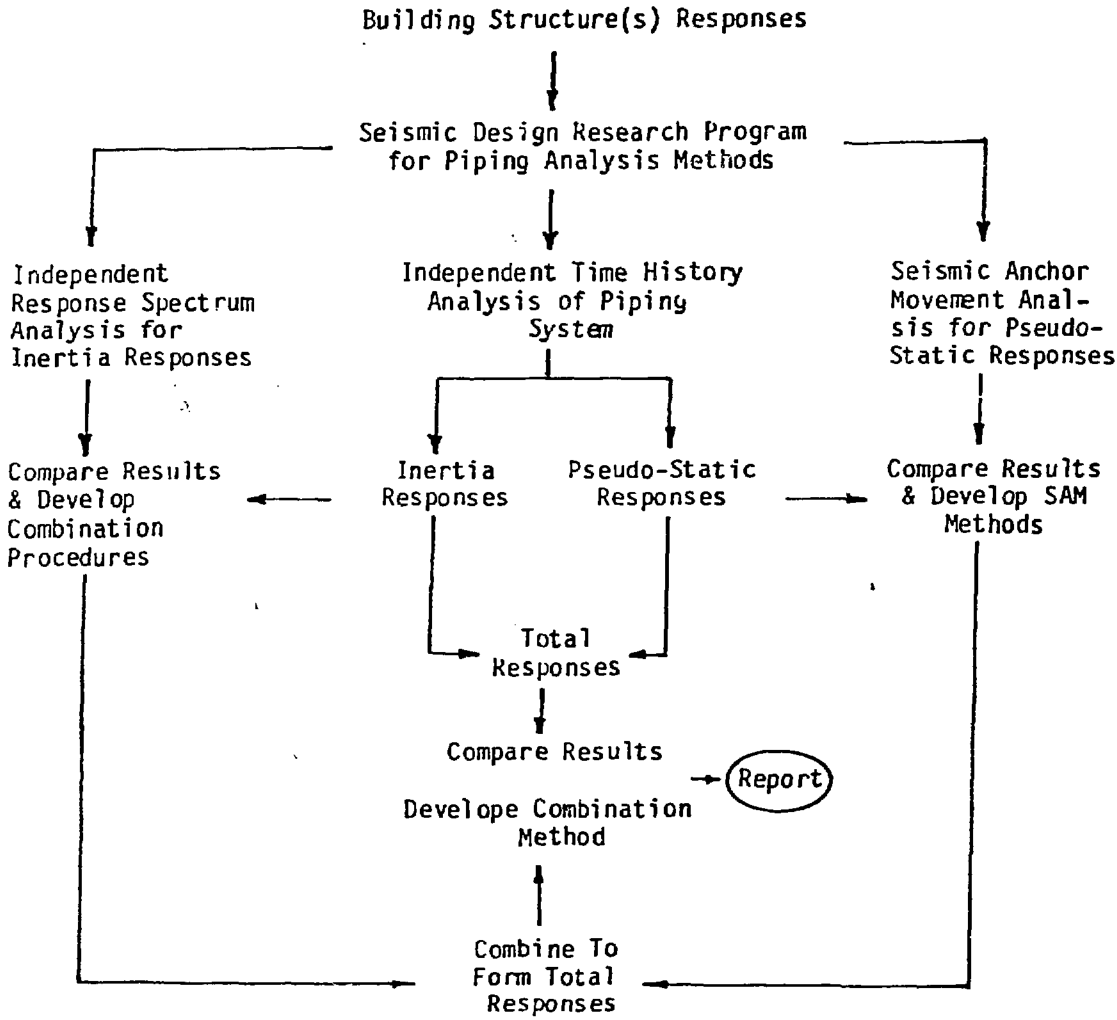


Table 3. Model Parameters

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

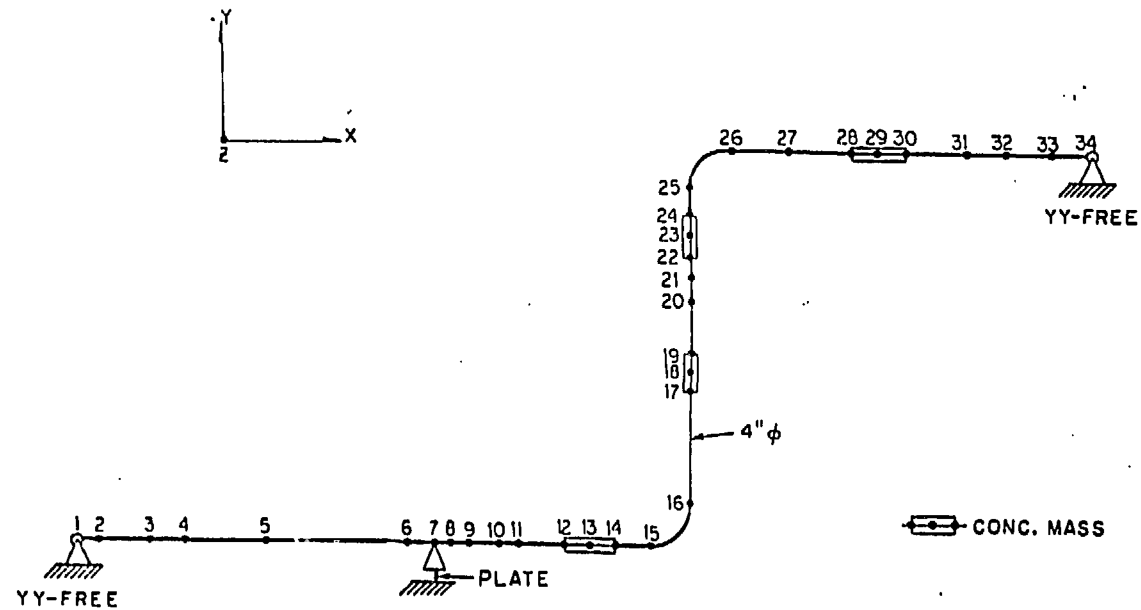
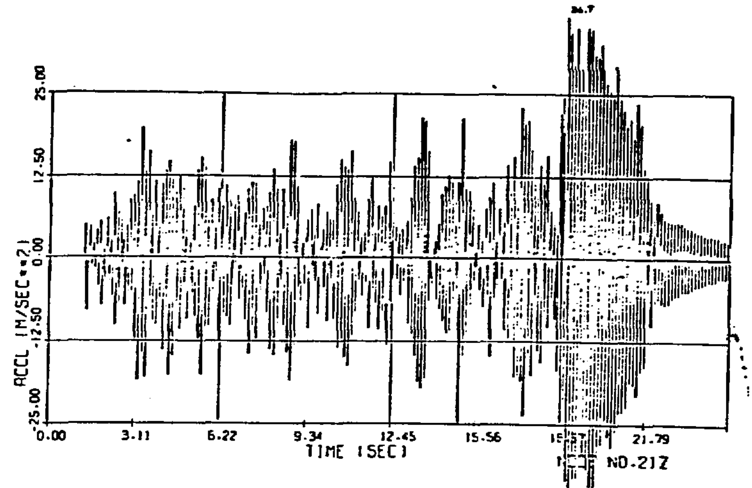
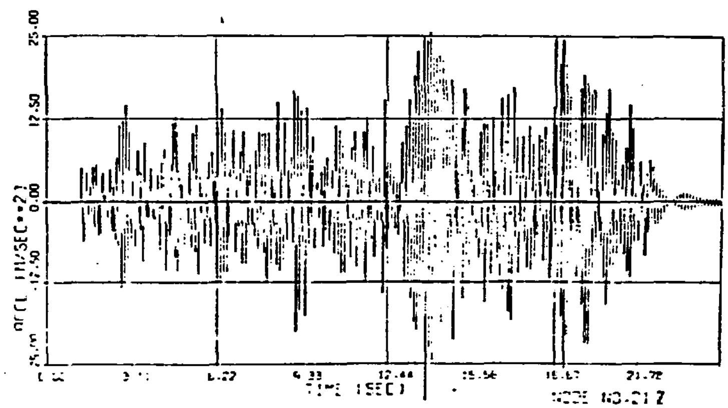


Figure 1 - Z Bend Finite Element Model



EXPERIMENTAL



ANALYTICAL

Fig. 2 - Acceleration Node 21Z.

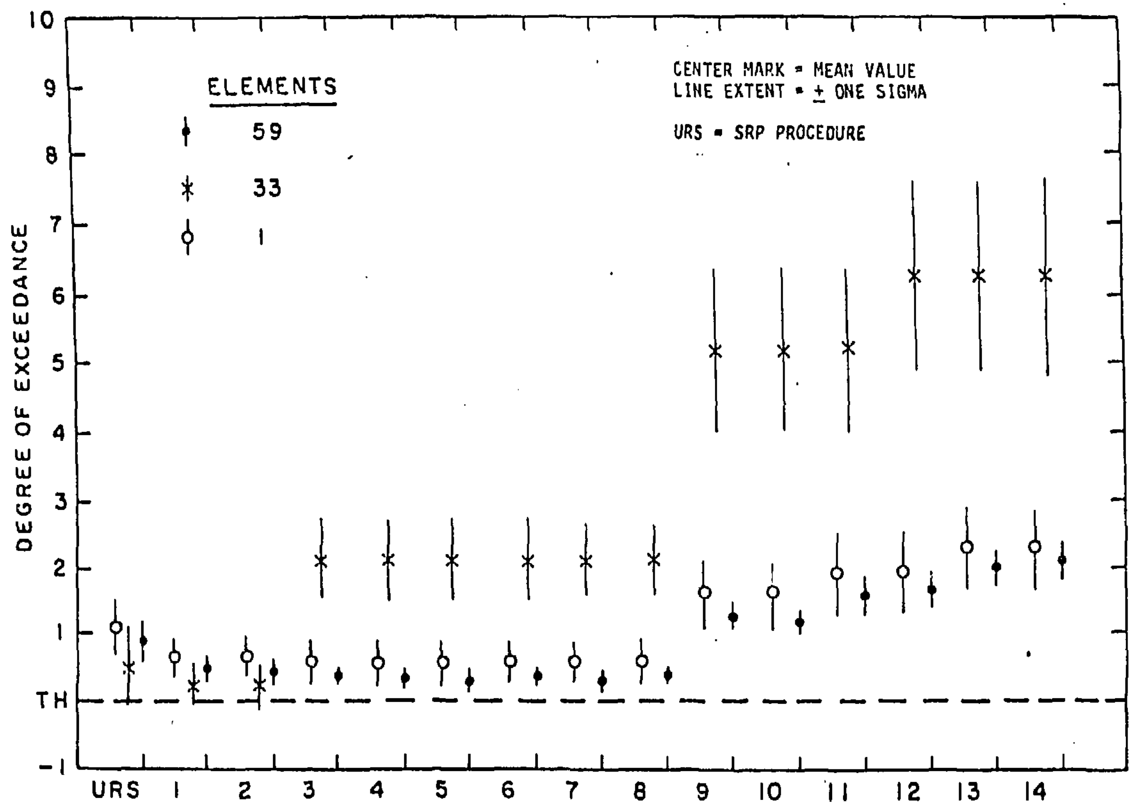


Figure 3 - Dynamic Pipe Resultant Moment Responses for RHR Model

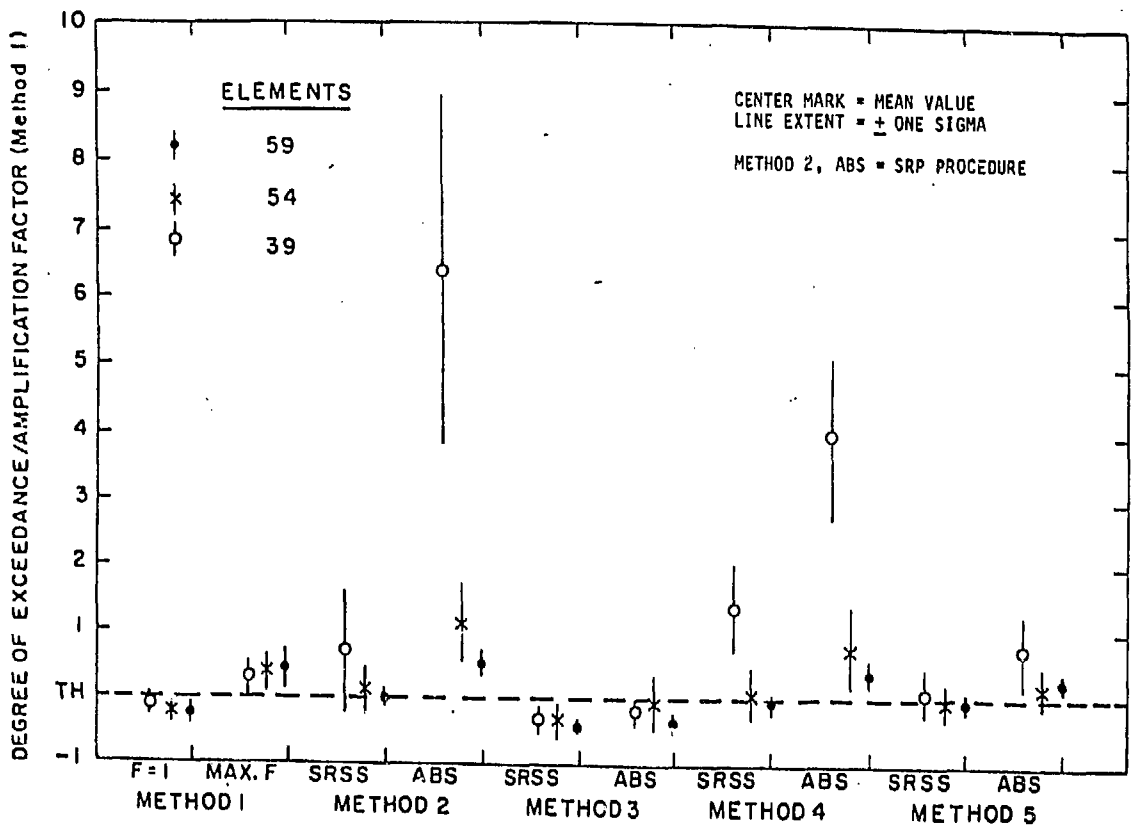


Figure 4. - Static Pipe Resultant Moment Responses for RHR Model