BNL-NUREG-32860
CONF-830607--12

BNL-NUREG--32860

DE83 012224

Dynamic Simulation of Z-bend and Comparison with Experimental Data

By

P. Bezler and M. Subudhi
Structural Analysis Division
Department of Nuclear Energy
Brookhaven National Laboratory
Upton, NY 11973, USA

This work was performed under the auspices of the U. S. Nuclear Regulatory Commission, Washington, DC.

Abstract

The ongoing program for benchmark computer methods used to design and qualify nuclear piping has been expanded to the consideration and use of physical test results. In the first evaluation, the capability of the linear elastic piping code, PSAFE2, was undertaken to predict the response of a simple planar piping configuration, tested by others, designated for the 'Z-bend'. The time history solution was developed using the modal superposition method and considering independent support excitations. The results include acceleration and displacement time history responses of all interior points. Both the inertia and pseudo-static responses are included. Comparisons are made between the measured and predicted time history results for selected points in the system. The overall agreement was found to be good and a discussion of discrepancies between the results is presented in the paper.

Introduction

Dynamic structural analysis of piping systems is one of the most extensive engineering efforts required for the safety design of nuclear power plants. Such an analysis is normally performed by using computer programs which can handle complex system geometries and various loading conditions, static or dynamic. Of particular concern is the class or programs which are used by the industry to perform dynamic structural analyses of complex piping systems using the response spectrum method. These are generally large programs, based on the finite element method, which consider the structures to be elastic over the entire deformation history and to experience small displacements and rotations. Some of these programs are commonly available general purpose programs, while others are of a proprietary nature.

Over the past few years, efforts were undertaken to develop analytical benchmark solutions for piping problems suitable for the verification of the piping analysis methods used by industry to qualify nuclear power plant piping. This effort has now been extended to the consideration and use of physical test results. The Z-bend evaluation, described herein, is the first study carried out in this program. It is anticipated that these evaluations will be extended to increasingly more complex systems culminating in the evaluation of actual power plant piping configurations excited by multiple independent seismic excitations.

The accuracy with which these computer methods predict system response may be assessed by a comparison of program generated solutions with corresponding test results. Since many parameters could influence the dynamic characteristics of a system, this first evaluation was conducted with a very simple planar model of a piping system designated to a 'Z-bend'. The configuration is shown in Figure 1. This system was tested under EPRI contract by ANCO engineers and all the test results were made available for this evaluation.

The test configuration consists of three hydraulic actuators mounted on sleds and constrained to move in one direction to which an approximately 6-meter length of pipe with two 90° bends is attached. The actuators are controlled by an electronic system capable of operating all three actuators in phase. The drive signal to the controllers was generated by taping a 20-second burst of white noise which was then selectively filtered and singly integrated to provide a seismic-like input acceleration record. The test was conducted by ANCO engineers and the test results were provided for comparison with the analytical solutions.

This paper described the analytical methods used in predicting the piping response and the comparison of these with the test data. The computer program "PSAFE2" was compiled to analyse the piping system. The independent excitation time history method was used to take into account the individual support motions, i.e., although the inputs were highly correlated, they were not identical. The following sections provide a brief summary of the methodology, the analytical procedure and the results as compared with test data.

Computer Method

The PSAFE2 program is a modified and extended verions of the elastic analysis code EPIPE. It is a full feature, elastic piping analysis code based on the finite element method. In addition to the usual computational options, it has the capacity to perform both response spectrum and time history analyses of systems subjected to independent support excitations and stress evaluations in accordance with ASME Class 2 and 3 design criteria.

The equations of motion for a three-dimensional piping system with respect to an inertial coordinate system subject to independent support excitation written in matrix form are:

$$\begin{bmatrix} M_p & 0 \\ 0 & 0 \end{bmatrix} \begin{Bmatrix} \ddot{X} \\ \ddot{Z} \end{Bmatrix} + \begin{bmatrix} C_p & C_{pb} \\ C_{bp} & C_b \end{bmatrix} \begin{Bmatrix} \dot{X} \\ \dot{Z} \end{Bmatrix} + \begin{bmatrix} K_p & K_{pb} \\ K_{bp} & K_b \end{bmatrix} \begin{Bmatrix} X \\ Z \end{Bmatrix} = \begin{Bmatrix} 0 \\ F_b \end{Bmatrix} \qquad (1)$$

where a dot over a variable denotes differentation with respect to time, and subscripts 'p' and 'b' represent the quantities for the piping points and boundary points, respectively. The subscripts 'pb' and 'bp' denote the coupling terms between the piping and boundary points transposed to one another. Also:

M = lumped mass matrix of the piping system
C = the damping matrix
K = the stiffness matrix
$\{X\}$ = the displacement response of the piping structure
$\{Z\}$ = the displacement response of the support points
$\{F_b\}$ = the Reaction Forces at the support points

It is assumed that the total response of the piping degrees of freedom consists of two individual components. One component, known as the dynamic or inertial component, is due to the inertial forces generated by the mass points in the piping system and the frequency of excitation of the ground. It is explicitly dynamic in nature. The second component is caused by the differential ground motion between different boundary attachments when the piping system is subject to the independent support excitations. This component does not exist if all the support points are excited simultaneously with identical excitation. Since the ground excitation is a function of time, this component is also a function of time. It is termed the pseudo-static component because it produces deformations of the piping system similar to those produced by static, relative anchor displacements.

The total response may then be expressed as the sum of the dynamic and pseudo-static component

$$\{X\} = \{X_d\} + \{X_s\} \tag{2}$$

where

$\{X\}$ = total response of the piping system
$\{X_d\}$ = dynamic or inertial component of the response
$\{X_s\}$ = pseudo-static component of the response.

The reduced equations are then

$$M_p\ddot{X}_d + C_p\dot{X}_d + K_pX_d = M_pK_p^{-1}K_p\ddot{Z}(t) \tag{3}$$

$$X_s(t) = -K_p^{-1}K_{pb}Z(t) \tag{4}$$

Equation (3) governs the dynamic or inertial response of the system subject to ground excitation while equation (4) is used to calculate the pseudo-static components.

The solution of equation (3) follows the normal practice. The equation set is diagonalized by operating with the modal matrix for undamped free vibrations. The resulting decoupled equations are then solved separately. A more detailed description of this method is given in the references.

Analysis Procedure

Using the BNL model of the Z-bend in conjunction with the corrected digitized data, time history analyses of the Z-bend were completed. In these analyses, the input forcing functions were the corrected, digitized time history records of the accelerations in the three global directions at each actuator head and the corrected digitized displacement record in the Z global direction at each actuator head. For the analyses, a uniform damping value of 2% was employed. Lastly, all analyses were performed with the PSAFE2 computer code using the independent support motion, model superposition and time history algorithms.

An isometric sketch of the system is shown in Figure 1. This figure shows the location of the actuator heads which were designed to excite the pipe in the Z global direction only. Also shown are the approximate location of the finite element nodes and the attached concentrated masses (shown as enlarged node points). For the physical tests, accelerometers were mounted at the three actuator heads, nodes 1, 5 and 20 and at nodes 3, 6 and 16. Displacement measurements were made at locations adjacent to the actuator heads and at nodes 3, 6, 12 and 16. With the exception of the input acceleration at the actuator heads, only the acceleration or displacement in the Z direction was monitored during the test. For the actuator heads, accelerations in all three coordinate directions were monitored.

For the analysis, the input consisted of the three measured acceleration components and one measured displacement component at each of the three actuator heads. Figure 2 shows the time history traces of the input "measured" accelerations at node 1. As can be seen, the acceleration in the Z direction is dominant with peak values in excess of 1 g. The accelerations in the X and Y direction exhibit peak values of approximately 0.2 g's which are large for the unexcited directions. The input displacement at node 1, not shown, exhibited peak magnitudes of .635 cms at 10 sec. The inputs at the other two actuators were comparable in magnitude and character but were independent (i.e., the inputs although similar differed from each). Unfortunately, the displacements in the X and Y directions at the supports were not measured and thus, could not be specified at input. Since their magnitudes could have been 1/5 the Z inputs, this is not insignificant. In any case, the X and Y displacements at the actuators were input as zero for the analysis.

A listing of the first ten natural frequencies predicted with PSAFE2 for the Z-bend are presented in Table 1. In the last column of this table are the corresponding experimental estimates for the two fundamental frequencies. As can be seen, the agreement between measured and predicted values is quite good indicating that the finite element model for the system is good.

Results and Conclusions

Figures 3 through 5 show time history traces of the predicted and measured accelerations in the Z direction at node points 3, 6 and 16. In each of the figures the predicted response is shown on the left side. Figures 6 through 9 show the predicted and measured displacements in the Z direction for nodes 3, 6, 12 and 16. In these figures the predicted response is shown in the lower curve.

Referring to the figures, it can be seen that all the predicted responses show the same characteristics as the measured responses. For all responses, the frequency correspondence between the predicted and measured data is excellent. For most responses, the amplitude correspondence is good with better agreement being shown for points on the upper span (nodes 12 and 16). In general, better agreement was achieved for displacements than for accelerations. In summary, the overall agreement is considered good.

A number of possible sources of error have been identified. Firstly, the lack of measured data for the displacements in the X and Y direction at the actuators required the enforcement of null inputs for these quantities in the analysis. Obviously, this is incorrect and must affect the accuracy of the predicted results. Secondly, in the test arrangement, a .16 cm diametrical clearance gap existed between the central actuator and the pipe. This gap introduces non linearities into the system which could not be modeled with the linear analysis code PSAFE2. It is reasonable to assume that this gap will cause maximum discrepancies in its near vicinity (i.e., lower span, nodes 3 and 6), and indeed the poorest correspondence is achieved in this region. Lastly, the input displacements were not measured at the actuators, but rather inboard on the pipe some 2 cms. Therefore, these quantities exhibit some amplification due to excitation. Consequently, the displacements input for the analysis were larger than actual and the predicted displacement results should err on the high side. Careful examination of the results show this to be true.

References

1. Subudhi, M., Bezler, P., Wang, Y. K. and Hartzman, M., "Seismic Analysis of Piping Systems Subjected to Independent Support Excitations by Using Response Spectrum and Time History Methods", BNL-NUREG-31296, April 1982, Brookhaven National Laboratory, Upton, NY.

2. ANCO Engineers Inc. Report (Preliminary), "Dynamic Testing of a Pressurized Piping System Beyond the Elastic Limit", October 1981.

3. Subudhi, M. and Bezler, P., "Corroboration of Heissdampfreaktor Reactor Recirculation Loop Piping Investigations", BNL-NUREG-31732, August 1982, Brookhaven National Laboratory, Upton, NY.

P. Lec... + M. ...
-6-

Table 1. Z Bend Configuration Natural Frequencies

Mode No.	Analytical Estimate (Hz)	Experimental Estimate (Hz)
1	7.11	7.2
2	13.03	13.0
3	16.42	
4	60.	
5	60.4	
6	71.12	
7	84.93	
8	91.22	
9	124.3	
10	128.2	

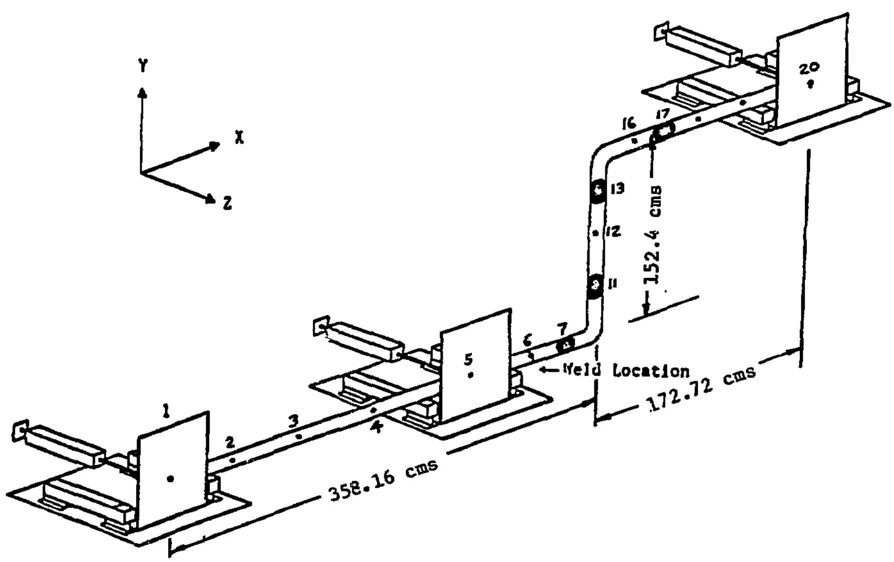

Fig. 1. Z Bend Configuration

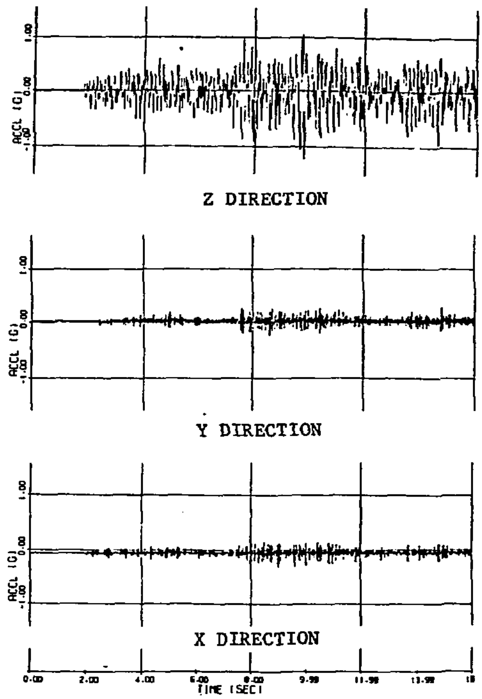

Fig. 2. Z Bend Input Accelerations Node 1

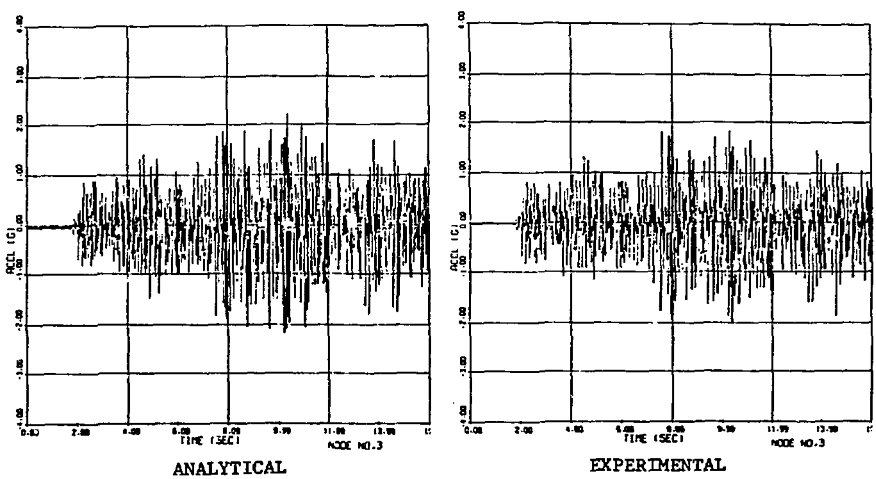

Fig. 3. Z Bend Accelerations Node 3

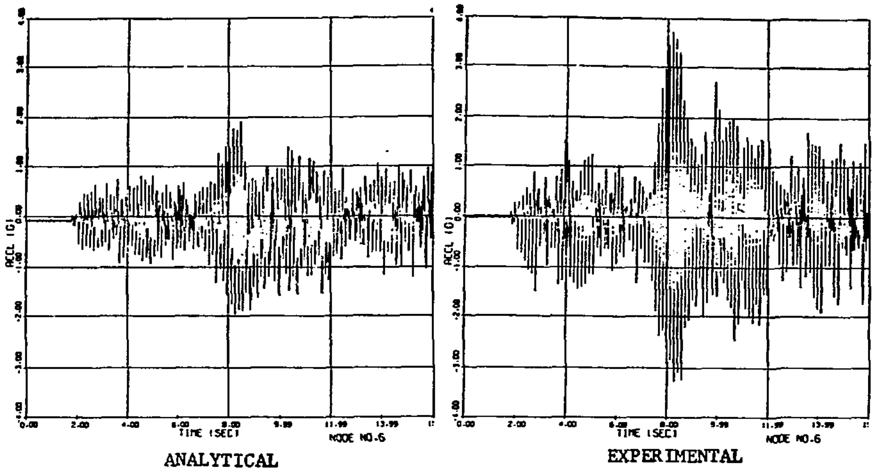

Fig. 4. Z Bend Accelerations Node 6

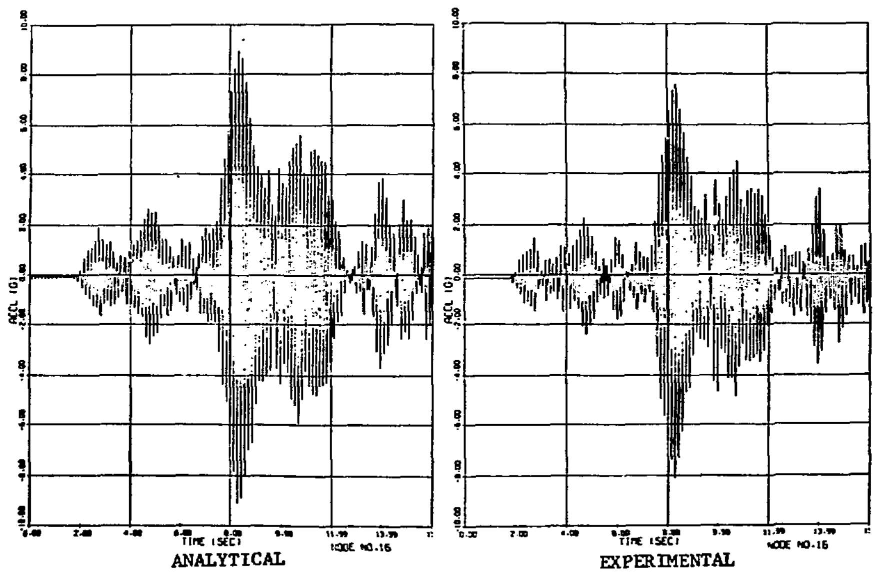

Fig. 5. Z Bend Accelerations Node 16

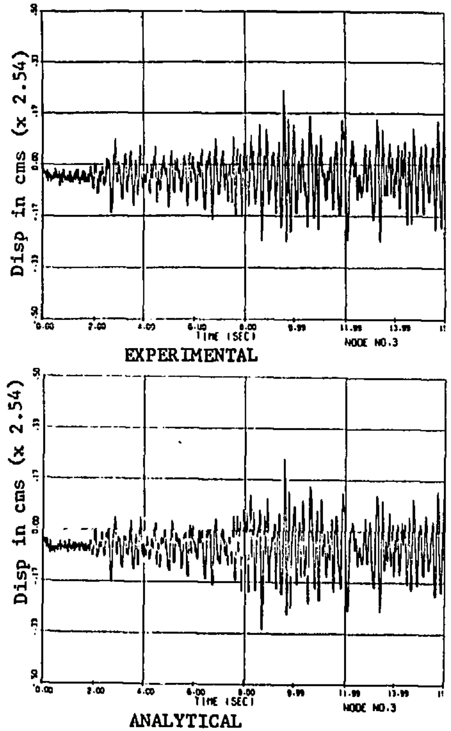

Fig. 6. Z Bend Displacements Node 3

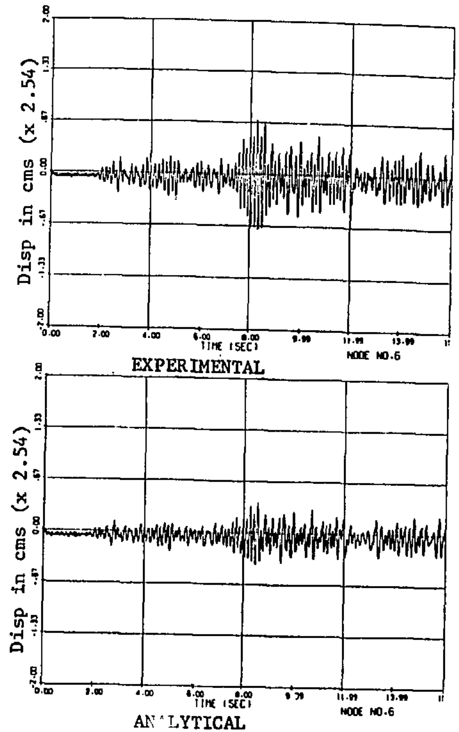

Fig. 7. Z Bend Displacements Node 6

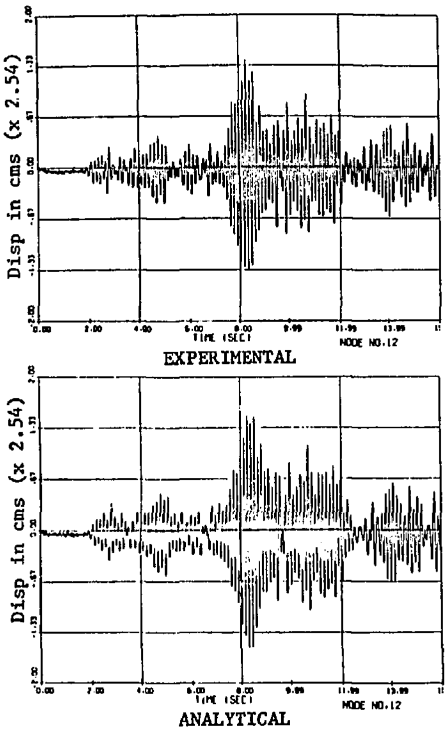

Fig. 8. Z Bend Displacements Node 12

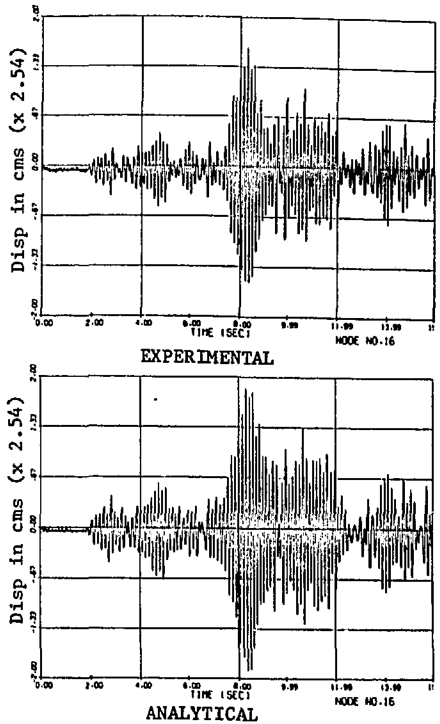

Fig. 9. Z Bend Displacements Node 16