Robert L. Cloud and Associates, Inc.

RLCA

A TOPICAL REPORT ON THE METHODOLOGY, VERIFICATION, AND APPLICATIONS OF COMPUTER PROGRAM, GAPPIPE

RLCA/P94/04-94/009

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ABSTRACT

Limit Stops are a type of pipe support that permit high temperature piping to expand and contract without interference due to temperature change. Under earthquake or other dynamic loading, Limit Stops will not permit the pipe to displace beyond the spatial envelope defined by the range of thermal expansion. This is accomplished by passive gaps in the Limit Stop. Dynamic analysis of Limit Stop supported piping is performed using the GAPPIPE computer program which is especially developed and formulated for efficient analysis of piping with gapped supports.

Limit Stops are fabricated and qualified to the requirements of the ASME Code Section NF. This report mainly covers the overall development of the Limit Stop technology and addresses the following specific subjects.

- A description of the program GAPPIPE including analysis methods and procedures.
- A complete discussion of the experimental and analytical verification of GAPPIPE including the correlation with full scale tests.
- A description of the applications of Limit Stops and GAPPIPE.

The conclusions reached in this report are:

- GAPPIPE analysis of piping systems supported with Limit Stops is at least as accurate and in many cases superior to analysis of snubber supported piping using current linear methods.
- On the basis of the successful verification and successful experience to date, Limit Stop technology is qualified for use in all nuclear power plants.
- In view of the greater accuracy of GAPPIPE and the greater reliability of the simple passive Limit Stops, nuclear power plant piping supported with Limit Stop technology is safer, more reliable, and less costly to maintain than piping supported conventionally.

1. INTRODUCTION

The purpose of this topical report is to describe and document the development of the Limit Stop technology. The technology consists of a piping analysis computer code, GAPPIPE, that facilitates the analysis of piping systems with gapped supports, and the design of the gapped supports, i.e. Limit Stops. The Limit Stops are separately qualified under the procedures for testing and analysis of the ASME Code, Section NF. Therefore, the main subject matter of this topical report is the mathematical basis for the GAPPIPE code and the verifications that have been performed.

The scope of this report covers the

- description of the technology
- verification studies of the technology
- description of applications to date
- conclusions

The report is applicable to the GAPPIPE computer code based on the methods as described herein and the Limit Stops supports as tested in the tests described herein. No limitations of the Limit Stops technology regarding applicability to piping system support design have been identified by the extensive testing or analysis done to date.

Development of the Limit Stop technology was initiated in 1980 based on the concept of upgrading the successful design of frame-type displacement limiting supports used in some fossil fuel plants to nuclear quality systems. The work proceeded sporadically until 1983. At that time, the Electric Power Research Institute (EPRI) initiated partial support and a more focused effort began.

The completion of the first equivalent linearization algorithm for analyses of gapped supports was accomplished in 1985. Shake table testing of the full scale 3" diameter schedule 80 single span and Hovgaard bend experimental specimen was performed in 1985 and 1987. The first prototype of the present Limit Stop design was completed in 1987. Full scale plant testing at the HDR facility in Germany was completed in 1988. The essential elements of the technology were then complete, and subsequent developments were limited to improvements in the analytical approach, the enhancement of GAPPIPE as a commercial computer program, and the refinement of hardware design.

The first application was a research study at Millstone 2 which is described in the report. It was completed in 1987 but never presented to the NRC nor was the plant modified. The next application was at Byron, also described herein. The design work was completed in 1988. The Byron FSAR committed to have any piping analysis code used at Byron approved by the NRC. On this basis, the Limit Stop application was presented to the NRC at a meeting on May 2, 1989.

Recognizing the design approach as an innovation, the NRC requested a complete review before approving the code or permitting installation of Limit Stops at Byron. The NRC was assisted by experts in piping analyses and non-linear analysis from Brookhaven National Laboratory. A comprehensive in-depth review of all analytical work, original derivations, test work, and test analyses correlations were performed by Brookhaven and the NRC. This review culminated in a favorable SER dated May 21, 1990. The SER, however, required an independent confirmatory analysis of the analysis done for Byron. This was done by Brookhaven and once again culminated in a favorable SER, dated February 7, 1992. The Limit Stops were installed at Byron in their September 1993 outage. The installation was straightforward and trouble free.

The next application was at McGuire. Duke Power engineers reasoned that if Limit Stops and snubbers performed comparably as the test data showed, it should be possible to replace snubbers without analysis. Implicit advantage was taken of the ASME Code Case N-411 damping. The concept was tested analytically and found to be true. The results are included herein.

The Duke approach was to make the replacement using the procedure given in 10CFR50.59 for plant modifications since the replacement involves no unresolved safety issues and there is no change to the plant technical specifications. Nevertheless, as a courtesy to the NRC, Duke presented their work to the NRC staff in a meeting on December 15, 1992. Subsequently, the changeout of the snubbers at McGuire was initiated in the April 1993 outage. In this outage, Phase 1 of the changeout was completed uneventfully, and about 50 snubbers were replaced with Limit Stops. It required less than 30 minutes per unit to change out the snubber, install and adjust the Limit Stop.

The Wolf Creek plant subsequently chose to follow the McGuire approach. A four problem sample of Wolf Creek piping was analyzed to determine if the implicit use of ASME Code Case N-411 damping was sufficient to permit use of Limit Stops without analysis. This "Qualification Study" was successful, and again as a courtesy, the results were presented in detail to the NRC staff on December 9, 1993. It is the intention of the Wolf Creek staff to initiate the one-for-one changeout in their 1995 outage.

Based on the works described herein for GAPPIPE and Limit Stops, it is concluded that the technology is qualified for use in all nuclear power plants. Moreover, it is believed that the application of Limit Stops results in a genuine improvement in nuclear plant operability, maintenance cost, reliability, radiation exposure, and in the amount of low level waste generated. All the experience gained to date supports this belief.

2. ANALYSIS METHODS AND PROCEDURES

2.1 PROGRAM OVERVIEW

The GAPPIPE computer program was developed by Robert L. Cloud & Associates, Inc. (RLCA) with partial support by EPRI to provide a comprehensive analysis tool for the evaluation of piping systems in accordance with the requirements of regulatory codes and industry practice. GAPPIPE was developed based on the public domain code SAP-IV [1], however extensive modifications have greatly enhanced the program capabilities.

The GAPPIPE/GAPPOST/GAPPLOT computer program was developed to complement the Limit Stop applications in place of snubbers. The program contains three separate executable modules named: GAPPIPE, GAPPOST, and GAPPLOT. GAPPIPE performs both linear and nonlinear elastic analyses of three-dimensional piping systems subject to thermal expansion, imposed displacements, internal pressure, externally applied loads, seismic and fluid transient loads or motions.

GAPPIPE differs from other piping computer programs in that it has the capability to analyze piping systems containing gaps. GAPPIPE has two analysis methods to compute the dynamic responses of such systems. The first method is nonlinear time history analysis by modal superposition and pseudoforce representation of gap responses. This method is most suitable for the simulation of piping responses induced by fluid transient loads or excitations where the input cannot be easily or adequately characterized by response spectra.

For excitations defined by response spectra, GAPPIPE offers a second analysis method that uses the response spectrum analysis technique and the method of equivalent linearization to account for the nonlinear behavior of gaps. In this method, GAPPIPE can use either uniform enveloped response spectra or different spectra at different supports using the independent support motion technique.

After all the necessary analyses have been run using the GAPPIPE module, the results can be combined and checked against the requirements of the ASME Boiler and Pressure Vessel Code, Section III Subsections NB-3600 and NC-3600 for Classes 1, 2, and 3 piping systems using GAPPOST, the post-processor module.

For each GAPPIPE analysis performed, a data file with a .POS extension is created containing all of the calculated responses for that analysis. GAPPOST reads these post-processing files and combines them as directed by the user. The combined results are then checked for code compliance and saved in the same post-processing file format. Thus, the combined responses can be treated as a new analysis that can be further combined in subsequent GAPPOST runs. The post-processor, GAPPOST, creates a readable output file, as well as additional binary post-processing files for further analysis combinations.

The third module, GAPPLOT, provides plotting capabilities to view and interpret the analysis models and results. GAPPLOT can plot model geometry and deflected shapes of static and dynamic (mode shapes) analyses. One-screen plots can be generated interactively on the PC/DOS and VAX/VMS system platforms, and hard copy plots can be sent to printers which support the Adobe Postscript language.

The capacity of GAPPIPE depends mainly on the total number of nodal points in the piping model and the number of vibration modes needed in the dynamic analysis. There is practically no restriction on the number of load cases or the order and bandwidth of the system stiffness matrix. With nodes arbitrarily labeled, GAPPIPE internally renumbers the nodes to minimize the memory required. The following are some of the upper limits on problem size (the actual limits may vary as they are interdependent).

1. Maximum number of nodes: 2000
2. Maximum number of modes in a dynamic analysis: 200
3. Maximum number of gapped supports in a dynamic analysis: 99
4. Maximum number of support groups in an Independent Support Motion (ISM) analysis: 30

The piping systems to be analyzed may be composed of combinations of the following elements:

1. Pipe elements (straight and curved segments)
2. Boundary elements (used to model pipe supports, including rigid anchors, springs, struts, snubbers, and Limit Stops)
3. Three-dimensional truss elements
4. Three-dimensional beam elements

GAPPIPE performs the following analyses:

Static Analyses

1. Thermal expansion
2. Deadweight
3. Concentrated applied loads (forces/moments)
4. Support movements (displacements/rotations)
5. Internal pressure effects

The effects of gapped supports, including the preloaded condition, can be considered in all static analyses. The program determines which gaps close under the applied loads and determines the correct reaction force to incorporate into the solution.

Dynamic Analyses

1. Eigenvalue solution. Frequencies and mode shapes are determined using either the Determinant Search or the Subspace Iteration method.

2. Response spectrum analysis (RSA). Excitation can be either uniform or independent support motion (ISM). Directional responses may be combined by either absolute summation (ABS) or square root of the sum-of-the-squares (SRSS). The modal combination options are:

   a. SRSS
   b. ABS
   c. NRC 10% Method
   d. NRC Grouping Method

   When ISM is used, either the SRSS or the ABS method may be used to combine the results associated with different support groups.

3. Equivalent linearization analysis. This analysis is identical to RSA, except that gapped supports are allowed.

4. Seismic anchor movement analysis. The SRSS or the ABS method may be used to combine the results associated with different support groups and to combine directional results.

5. Time history analysis. GAPPIPE can analyze piping systems with or without nonlinear gapped supports subjected to time varying ground acceleration or nodal forces. Force/acceleration time-history analyses are performed using the modal superposition approach.

The equivalent linearization analysis allows gapped supports that are preloaded at the onset of the dynamic loading. This situation can arise in the case of a gapped support with one gap smaller than the maximum thermal expansion, so that the gapped support is preloaded in the "hot" condition. It can also arise in the case of rod hangers preloaded by the deadweight of the pipe system or gapped supports purposely installed in preloaded conditions.

This capability is available in a response spectrum analysis (with or without independent support motion) and is also available in the nonlinear time history analysis. A preloaded gapped support is activated in the analysis by the specification of negative gap sizes.

Another option allows the user to specify a pipe position other than the "cold" position as the static equilibrium at the start of a response spectrum analysis. For example, the user could request that the pipe position (and hence the relative left and right gap sizes) be defined by thermal conditions.

2.2 GAPPIPE ORGANIZATION

Analysis of a piping system typically consists of three phases: model generation, analysis execution, and results processing. A flow diagram of these phases is illustrated by Figure 2.1. A typical GAPPIPE input file structure is shown in Figure 2.2.

In the first phase model data is read and system stiffness and mass matrices are formulated. A user generated input data file specifies the geometry of the piping system via the nodal and element data definition. The mathematical calculations performed by GAPPIPE during this phase are described subsequently.

The analysis execution phase depends on the type of analysis, indicated by the value of the NDYN parameter in the Master Control Specification. Static analyses (NDYN = 0) can be executed as a single analysis execution, which generates a single post-processing file, or the multiple analysis feature can be used to solve several static load cases in one execution, generating a separate post-processing file for each load case. Dynamic analyses (NDYN = 1, 2, 3, 5, 6) can be run one at a time or in series with other static analyses using the multiple analysis option. The eigenvalue solution (NDYN = 1) is calculated for any of the dynamic analysis options.

The final phase of a piping analysis is the processing of analysis results. GAPPIPE generates a number of files after each execution: an output file, post-processing files, restart files, and various temporary files.

- The output file is created for each GAPPIPE execution run. It contains the model geometry, material properties, analysis options requested, and tabulated results. The amount of information in it is controlled by print control parameters in the input file.

- The post-processing file contains all analysis results in a format which can be read by the post-processor, GAPPOST, or the plotting program, GAPPLOT.

- The restart files are created for continuing an equivalent linearization analysis (NDYN = 5, 6) when it does not converge in the number of iterations specified by the user. The program saves data from the iterations completed, and the restart option resumes the solution where the previous run left off, thus eliminating the need to repeat iterations already completed.

- GAPPIPE creates and uses a number of temporary files during each execution. Most of these files are used internally by the program and are discarded after the execution; they contain no useful information for the user.

The input data must be in a consistent set of units. Many of the default values are based the English inches-pounds-seconds system of units and may not be appropriate or reasonable for other systems of units. Users should avoid using default values if the piping model is defined by units other than the English inches-pounds-seconds system.

2.3 FORMULATION OF ANALYSIS MODEL

The basic method of analysis used in GAPPIPE is the finite element stiffness method in which the continuous piping system is approximated as an assembly of elements possessing stiffness but no mass connected at discrete nodes possessing mass but no stiffness. The equilibrium equations representing the piping system can be written:

$$[M]\{\ddot{u}\} + [C]\{\dot{u}\} + [K]\{u\} = \{R\} \qquad (2\text{-}1)$$

where [M] is the mass matrix, [C] is the damping matrix, and [K] is the stiffness matrix of the element assemblage; the vectors {u}, $\{\dot{u}\}$, $\{\ddot{u}\}$ and {R} are vectors representing the nodal displacements, velocities, accelerations and generalized loads, respectively. These global matrices are formed by direct addition of the element matrices; for example,

$$[K] = \Sigma\,[K]m \qquad (2\text{-}2)$$

where $[K]_m$ is the stiffness matrix of element m. Although $[K]_m$ is formally of the same order as [K], only those terms in $[K]_m$ which pertain to element m are non-zero. Thus global matrix operations can be performed by using the element matrices in compact form together with identification arrays which relate element to structural degrees of freedom.

GAPPIPE uses a lumped mass analysis in which the structure mass is the sum of the individual element masses plus additional concentrated masses which are specified at selected degrees of freedom.

The calculation of the stiffness matrix and mass matrix is accomplished in three distinct phases:

1) The node data is read and interpreted by the program. In this phase the equation numbers for the active degrees of freedom at each node are established.

2) The element stiffness and mass matrices are calculated together with the connectivity arrays. The arrays are stored in data files.

3) The global pipe stiffness matrix and mass matrix are formed by addition of the element matrices and stored in block form on tape.

The capacity of GAPPIPE is controlled by the number of nodes in the piping system. For each node six boundary condition codes, three coordinates and the node temperature are required. All node data is retained in high speed storage during the formation of the element stiffness and mass matrices. Since the required high speed storage for the element subroutines is relatively small, the minimum required storage for a given problem must be sufficient to store a number of real*8 variables equal to slightly more than ten times the number of nodes in the system.

The user should allow only those degrees of freedom that are compatible with the elements connected to a node. GAPPIPE always deals with six possible degrees of freedom at each node, and all non-active degrees of freedom should be deleted, so as to decrease the order of the structure matrices.

With the coordinates of all nodes known and the equation numbers of the degrees of freedom established, the stiffness, mass and stress-displacement transformation matrices for each structural element in the system are calculated.

The stiffness and mass matrices of the piping system are stored in blocks. The number of equations per block depends on the available high speed storage and is calculated by the program.

2.4 STATIC ANALYSES

Static analyses involve the solution of the equilibrium equations:

$$[K]\{u\} = \{R\} \tag{2-3}$$

where [K] is the global stiffness matrix, {u} is the nodal displacement vector, and {R} is the nodal load vector.

The solution of Eq. (2-1) is treated in many general textbooks on the finite element method as Reference [2]. The load vector {R} is assembled at the same time as the structure stiffness matrix and mass matrix are formed. The solution of the equations is obtained using a large capacity linear equation solver that uses the Gauss elimination method. The algorithm performs a minimum number of operations; i.e., there are no operations with zero elements. In the program, the $[L]^T [D][L]$ decomposition of [K] is used, hence Eq. (2-3) can be written as:

$$[L]^T \{v\} = \{R\} \tag{2-4}$$

where

$$\{v\} = [D][L]\{u\} \tag{2-5}$$

and the solution for {v} in Eq. 2-4 is obtained by a reduction of the load vectors. The displacement vectors {u} are then calculated by a back-substitution.

In the solution, the load vectors are reduced at the same time [K] is decomposed. In all operations it is necessary to have the required matrix elements in high-speed storage. In the reduction, two blocks are in high speed storage (as is also the case in the formation of the stiffness matrix and mass matrix), specifically, the "leading block", which finally stores the elements of [L] and [D], and in the succession those blocks which are affected by the decomposition of the "leading" block.

The solution procedures described above are used to analyze static load case consisting of any combination of the following load types:

- Thermal expansion
- Internal pressure
- Gravity loading (deadweight)
- Support displacement
- Externally applied forces and moments

2.5 DYNAMIC ANALYSES

All of the dynamic analyses start by solving the eigenvalue problem. The resulting mode shapes and natural frequencies can then be used in various response spectrum analyses, or in a time history analysis.

2.5.1 EIGENVALUE SOLUTION

The generalized eigenvalue problem is given by the expression:

$$[K][\phi] = \omega^2[M]\{\phi\} \tag{2-6}$$

where ω and $\{\phi\}$ are free vibration frequency and mode shape, respectively. The mass matrix is diagonal with partly zero diagonal elements. GAPPIPE assumes that only the p lowest eigenvalues and corresponding eigenvectors are needed. The solution of Eq. (2-6) can therefore be written as:

$$[K][\Phi] = [M][\Phi][\omega^2] \qquad (2\text{-}7)$$

where

$$[\Phi] = [\ \{\phi\}_1\ \ \{\phi\}_2\ \ \dots\ \ \{\phi\}_p\ ]\ ,$$

$[\omega^2\ ]$ is a diagonal matrix with the p lowest eigenvalues, and $\{\phi\}_1$, $\{\phi\}_2$, ..., $\{\phi\}_p$ are eigenvectors ortho-normalized with respect to the mass matrix. Two different solution procedures are used in GAPPIPE, a determinant search and a subspace iteration method. For analyses without linearization iterations, the determinant search solution is carried out when the stiffness matrix can be contained in high-speed storage in one block. For systems of large order and bandwidth or systems with gap supports, the subspace iteration method is used. Both solution techniques solve the generalized eigenvalue problem directly without a transformation to the standard form [Ref. 3].

2.5.2 RESPONSE SPECTRUM ANALYSIS

During seismic events, a piping system receives excitation through its supports. Assuming the structure is uniformly subjected to a ground acceleration $\{\ddot{u}\}_g$, the $\{R(t)\}$ term in Eq. (2-7) becomes $\{0\}$ and the equilibrium equations can be rewritten as:

$$[M]\{\ddot{u}\}_r + [C]\{\dot{u}\}_r + [K]\{u\}_r = -[M]\{\ddot{u}\}_g \qquad (2\text{-}8)$$

where

$$\{\ddot{u}\}_r = \{\ddot{u}\} - \{\ddot{u}\}_g$$

The ground acceleration vector can be written as

$$\{\ddot{u}\}_g = \{\ddot{u}\}_{gx} + \{\ddot{u}\}_{gy} + \{\ddot{u}\}_{gz} \qquad (2\text{-}9)$$

where $\{\ddot{u}\}_{gx}$, $\{\ddot{u}\}_{gy}$, and $\{\ddot{u}\}_{gz}$ are the ground accelerations in the x, y, and z directions, respectively. Using the transformation:

$$\{u\} = [\Phi]\{x\}$$

where the columns of [Φ] are the p [M]-orthonormalized eigenvectors and {x} represents the generalized modal displacements, the equation for the response of mode L is therefore:

$$x_L + 2\mu_L \omega_L x_L + \omega_L x_L = r_{Lx} + r_{Ly} + r_{Lz} \tag{2-10}$$

where x_L is the generalized modal displacement of mode L; μ_L is the modal damping ratio; and

$$r_{rx} = -\{\phi\}_L^T [M]\{u(t)\}_{gx} \tag{2-11a}$$

$$r_{ry} = -\{\phi\}_L^T [M]\{u(t)\}_{gy} \tag{2-11b}$$

$$r_{rz} = -\{\phi\}_L^T [M]\{u(t)\}_{gz} \tag{2-11c}$$

Using the definition of the spectral displacement, the maximum absolute modal displacements of the structure subjected to an acceleration in the x direction are:

$$\{u\}_{Lx}^{(max)} = \{\phi\}_L \left(\left|\{\phi\}_L [M]\{r\}_x\right| \right) S_{dx}(\omega_L) \tag{2-12a}$$

where S_{dx} is the spectral displacement in the x direction corresponding to the frequency ω_L and $\{r\}_x$. Referred to as the influence vector, $\{r\}_x$ is a null vector except that those elements are equal to one which correspond to the translational degrees of freedom in the x direction. Similarly, for the responses due to ground accelerations in the y and z-directions:

$$\{u\}_{Ly}^{(max)} = \{\phi\}_L \left(\left|\{\phi\}_L [M]\{r\}_y\right| \right) S_{dy}(\omega_L) \tag{2-12b}$$

$$\{u\}_{Lz}^{(max)} = \{\phi\}_L \left(\left|\{\phi\}_L [M]\{r\}_z\right| \right) S_{dz}(\omega_L) \tag{2-12c}$$

In a similar fashion as used in the calculation of modal displacement, modal accelerations for all degrees of freedom can be calculated. The only difference is that the spectral accelerations are used. The spectral accelerations and displacements for mode L are related by the expression:

$$S_{ai}(\omega_L) = \omega_L^2 \cdot S_{di}(\omega_L) \tag{2-13}$$

where

$i = x, y, z$
$L = 1, 2, ..., n.$

and S_a, S_d, and ω are the spectral acceleration, displacement and modal frequency, respectively.

After the modal displacements have been estimated, the modal forces or moments for each element are then estimated by multiplying the element's stiffness matrix by the modal displacements of the nodes associated with that element.

The total maximum response of mode L is obtained by combining the responses due to the three directional components of excitation. Then the modal responses from all modes are combined to obtain the total response. The modal combination methods used by GAPPIPE comply with Regulatory Guide 1.92 issued by the United States Nuclear Regulatory Commission (USNRC).

In GAPPIPE, the directional (or spatial) combination is performed first by either the absolute sum (ABS) method:

$$R_L = |R_{Lx}| + |R_{Ly}| + |R_{Lz}| \quad (2\text{-}14)$$

or the square root of the sum-of-the-squares (SRSS) method:

$$R_L = \sqrt{R_{Lx}^2 + R_{Ly}^2 + R_{Lz}^2} \quad (2\text{-}15)$$

where R_{Lx}, R_{Ly}, and R_{Lz} are the maximum values of the response of interest due to the three directional excitation components of mode L.

After directional combination, GAPPIPE combines the modal responses by one of four methods outlined in NRC Reg. Guide 1.92 [Ref. 4]:

- ABS method
- SRSS method
- 10% method
- Grouping method

The SRSS method is applicable to systems without closely spaced modes. For systems with closely spaced modes, either the 10% method or the grouping method should be used to combine modal results. This is because the responses of two closely spaced modes tend to be statistically related to each other, i.e., they are likely to occur at the same time or in the same vicinity of time. Therefore, the SRSS method may give non-conservative results. According to the regulatory guide, two modes are closely spaced if their modal frequencies differ from each other by 10% or less of the lower frequency.

2.5.3 EQUIVALENT LINEARIZATION ANALYSIS

A new method implemented in GAPPIPE to analyze piping systems supported by Limit Stops is based on the equivalent linearization technique. The concepts of linearization for non-linear dynamic systems are well documented (Ref. 5,6,7). The basic idea of equivalent linearization is to determine a linearized system which is "equivalent" to the actual non-linear system. Equivalence may be defined in various ways and is usually defined in terms of the minimization of some measure of the difference between the linearized and actual systems for an assumed class (or pattern) of response. For a piping system with non-linear supports (e.g., Limit Stops), the method provides a set of linearized support stiffness which may be used to model the non-linear supports in order to obtain a solution for the system response. These linearized stiffnesses will have properties which depend upon the response itself. Therefore, an iterative procedure is generally required to obtain the response.

Strictly speaking, non-linear systems do not generally possess natural modes of vibration as do linear systems. However, it has been observed that most lightly damped non-linear systems display a similar response character to linear systems in that the frequency spectrum of the response exhibits a series of distinct peaks or "modes." In such cases, the concept of uncoupling the response into different mode-like components is still very useful. This approach has been used successfully for rigid multi-degree-of-freedom (MDOF) systems with gapped supports (Ref. 5) and is applied herein to the case of piping systems.

Based on time history analysis and actual tests of piping systems with gapped supports subjected to earthquake type excitations (Ref. 8, 9, 10), it is observed that the response is strongly narrow-bound in nature. In other words, there are only a few predominant frequencies in the response associated with mode-like components and the motion in each of these modes tends to be nearly harmonic with a randomly modulated amplitude. This observation motivates the special form of linearization which is employed in the computer program GAPPIPE.

Specifically the following assumptions are made:

- The system response may be uncoupled into mode-like components which may be analyzed separately.

- The response in a particular "mode" is quasi-harmonic (sine wave-like) with a slowly varying random amplitude and phase. Hence, the response in a particular mode resembles a pure trigonometric function over any one cycle of oscillation.

2.5.3.1 LINEARIZED STIFFNESS FOR SYMMETRIC GAPPED SUPPORTS

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2.5.3.2 LINEARIZED STIFFNESS FOR ASYMMETRIC GAPPED SUPPORTS

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2.5.3.3 LINEARIZATION SOLUTION PROCEDURE

Because the equivalent linearized stiffness is response dependent, an iterative procedure is required to obtain the solution. The iterative procedure is illustrated by the flow chart in Figure 2.4. In the figure, [K] is the global stiffness matrix of the piping system excluding the gap supports. [K_{LIN}] is the gap support stiffness matrix. "b" is the convergence factor determining the amount of change in [K_{LIN}] between the two iterations.

In general, the procedure begins by assuming that all linearized stiffnesses are zero as if the gap supports are not present. The pipe displacement responses at gap locations are then calculated using the conventional response spectrum method. Based on these responses, a new set of linearized stiffnesses are calculated using the linearized procedure described above. With this new set of linearized stiffnesses added to the piping system, the response spectrum analysis procedure repeats. The iteration continues until the differences between the assumed and calculated linearized stiffness for each gap is within a prescribed tolerance, E.

Other than the iteration flow chart, Figure 2.4 also illustrates that the converged pipe response is that associated with the cross point of two K_{LIN} vs. pipe displacement curves. One of the curves is the predicted K_{LIN}-curve, and the other is the calculated K_{LIN}-curve. Note that the pipe displacement represented by the horizontal axis is evaluated in the gapped support direction. Around the neighborhood of the solution, the response is inversely proportional, as indicated by the predicted K_{LIN}-curve to the value of the predicted linearized stiffness used in the calculation. However, based on the linearization theory, the calculated linearized stiffness, as indicated by the calculated K_{LIN}-curve, increases as the response does. In the process of iternation, the two K_{LIN} values approach the cross point simultaneously along the two curves. When they reach within the small area representing the allowed tolerance, the linearization solution is achieved.

The step-by-step linearization iteration procedure is:

1) Assume a null [K_{LIN}].
2) Add [K_{LIN}] to [K].
3) Perform the response spectrum analysis to determine the maximum displacement amplitudes at gaps.

4) Use the maximum displacement amplitudes to calculate a new $[K_{LIN}]$.
5) Compare the old and new $[K_{LIN}]$'s to see if the difference is within the prescribed tolerance for every gap. If all differences are within the tolerances, the solution is converged.
6) If the tolerance is exceeded by at least one gap, a new updated $[K_{LIN}]$ is calculated for use in the next iteration.
7) Go to Step 2 and repeat.

The whole solution process is a repetition of the response spectrum analysis procedure. The nonlinearity is embedded in the linearization procedure and the interaction between gap supports is inherently accounted for through the iterative solution.

2.5.4 INDEPENDENT SUPPORT MOTION (ISM)

Piping systems of nuclear power plants are attached to buildings and other types of structures (e.g., equipment) by means of supports. The preceding section presented the response spectrum analysis method using uniform spectrum input for cases in which all support points were assumed to be moving in-phase with the same instantaneous acceleration level.

It may be shown that the piping response calculated using uniform support response spectra, which envelopes the response spectra of all supports, is overly conservative in some instances. This is because the building response spectra at various pipe support points can vary considerably depending on the elevation and structure to which the pipe support is attached. Thus using the maximum spectra at all support points exaggerates the input excitation.

Analysis using multiple support excitations allows the smaller excitations at some supports to be accurately modeled, and thus removes some excess conservatism. GAPPIPE allows ISM excitation for systems with linear or gapped supports. The theoretical background of the ISM methodology is presented in this section.

2.5.4.1 DYNAMIC RESPONSE

The degrees of freedom in a piping system can be divided into two groups, constrained and unconstrained, and the equations of motion can be expressed as

$$\begin{bmatrix} M & M_g \\ M_g^T & M_{gg} \end{bmatrix} \begin{bmatrix} V_t'' \\ V_g'' \end{bmatrix} + \begin{bmatrix} C & C_g \\ C_g^T & C_{gg} \end{bmatrix} \begin{bmatrix} V_t' \\ V_g' \end{bmatrix} + \begin{bmatrix} K & K_g \\ K_g^T & K_{gg} \end{bmatrix} \begin{bmatrix} V_t \\ V_g \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix} \qquad (2\text{-}32)$$

where $\{V_t''(t)\}$, $\{V_t'(t)\}$ and $\{V_t(t)\}$ are the total accelerations, velocities and displacements, respectively, of the unconstrained degrees of freedom. The terms $\{V_g''(t)\}$, $\{V_g'(t)\}$ and $\{V_g(t)\}$ are the prescribed input motions at the constrained degrees of freedom; the terms [M], [C], and [K] are the mass, damping and stiffness matrices, respectively, associated with the unconstrained degrees of freedom, while $[M_{gg}]$, $[C_{gg}]$, and $[K_{gg}]$ are the similar matrices associated with the constrained degrees of freedom. $[M_g]$, $[C_g]$, and $[K_g]$ are the mass, damping and stiffness coupling vectors between the unconstrained and constrained degrees of freedom. "T" denotes the matrix transpose operation.

When the upper portion of Eq. (2-32) is rearranged by moving the prescribed forces to the right hand side, the equation of motion, in terms of total displacements, becomes:

$$\begin{aligned} &[M]\{V_t''(t)\} + [C]\{V_t'(t)\} + [K]\{V_t(t)\} = \\ &-[M_g]\{V_g''(t)\} - [C_g]\{V_g'(t)\} - [K_g]\{V_g(t)\} \end{aligned} \qquad (2\text{-}33)$$

The total displacements may be expressed as the sum of the dynamic relative displacements $\{V_d(t)\}$ and the pseudostatic displacements $\{V_s(t)\}$ that would result from static support displacements; i.e.,

$$\{V_t(t)\} = \{V_d(t)\} + \{V_s(t)\} \qquad (2\text{-}34)$$

By omitting the inertia and damping terms in Eq. (2-33), the pseudostatic displacement can be solved from the following pseudostatic equilibrium equation:

$$[K]\{V_s(t)\} = -[K_g]\{V_g(t)\} \qquad (2\text{-}35)$$

It may be solved for the pseudostatic displacements as follows

$$\{V_s(t)\} = [r]\{V_g(t)\} \qquad (2\text{-}36)$$

where the matrix [r] is composed of the pseudostatic influence vectors defined by

$$[r] = -[K]^{-1}[K_g] \tag{2-37}$$

If the number of the constrained degrees of freedom is L, the vector $\{V_g(t)\}$ is a set of L input motions:

$$\{V_g(t)\} = < V_{g,1} \quad V_{g,2} \quad V_{g,3} \quad \cdots \quad V_{g,L} > \tag{2-38}$$

where the symbol < > denotes a row vector. The corresponding influence vectors form the matrix [r] as follows:

$$[r] = [\{r\}_1 \quad \{r\}_2 \quad \{r\}_3 \quad \cdots \quad \{r\}_L] \tag{2-39}$$

Substituting Eqs. (2-34) and (2-36) into Eq. (2-33) leads to the following equation of motion in terms of dynamic relative displacements

$$\begin{aligned} &[M]\{V_d''(t)\} + [C]\{V_d'(t)\} + [K]\{V_d(t)\} = \\ &-([M][r] + [M_g])\{V_g''(t)\} - ([C][r] + [C_g])\{V_g'(t)\} \end{aligned} \tag{2-40}$$

where the $\{V_g(t)\}$ term does not appear because $[K][r] + [K_g] = 0$ from Eq. (2-37). For small damping, the above equation can be further simplified by setting $[C]\{r\} + [C_g] = 0$.

That the lumped mass matrix is used in GAPPIPE implies $[M_g] = 0$. Equation (2-40) then becomes:

$$[M]\{V_d''(t)\} + [C]\{V_d'(t)\} + [K]\{V_d(t)\} = -[M][r]\{V_g''(t)\} \tag{2-41}$$

The dynamic relative displacement can be expressed as the linear combination of the mode shapes $\{\phi\}_n$,

$$\{V_d(t)\} = \sum_{n=1}^{N} \{\phi\}_n Y_n(t) \tag{2-42}$$

where N is the number of unconstrained degrees of freedom.

Equation (2-41) can be uncoupled into N independent equations using the orthogonality properties of $\{\phi\}_n$,

$$Y_n''(t) + 2\mu_n \omega_n Y_n'(t) + \omega_n Y_n(t) = -\langle P \rangle_n \{V_g''(t)\} \qquad (2\text{-}43)$$

$$\text{for } n = 1, 2, \ldots, N$$

where μ_n and ω_n are the damping ratio and modal frequency, respectively, of the n^{th} mode. $\langle P \rangle_n$ is the vector of participation factors for the n^{th} mode defined as

$$\begin{aligned} \langle P \rangle_n &= \langle p_{n1} \;\; p_{n2} \;\; p_{n3} \;\; \cdots \;\; p_{nL} \rangle \\ &= \frac{\{\phi\}_n^T [M][r]}{\{\phi\}_n^T [M]\{\phi\}_n} \end{aligned} \qquad (2\text{-}44)$$

Let $h_{ln}(t)$ be the solution of the following differential equation

$$h''(t) + 2\mu_n \omega_n h'(t) + \omega_n h(t) = -\{V_{g,1}''(t)\} \qquad (2\text{-}45)$$

The solution of Eq. (2-43) becomes

$$Y_n(t) = \sum_{l=1}^{N} p_{nl} h_{ln}(t) \qquad (2\text{-}46)$$

and the dynamic relative displacements are

$$\{V_d\} = \sum_{n=1}^{N} \{\phi\}_n \left(\sum_{l=1}^{L} p_{n1} \, h_{ln} \right) \qquad (2\text{-}47)$$

2.5.4.2 PSEUDOSTATIC INFLUENCE VECTORS

Since the mode shapes $\{\phi\}_n$ are a set of N orthogonal Nx1 vectors, the influence vector $\{r\}_l$ can be expressed as the linear combination of the mode shape vectors as follows:

$$\{r\}_1 = \sum_{n=1}^{N} \{\phi\}_n s_{nl} \tag{2-48}$$

Multiplying both sides of the above equation by $\{\phi\}_m^T[M]$ and applying the orthogonality property,

$$\{\phi\}_m^T[M]\{\phi\}_n = 0 \qquad \text{for} \quad m \neq n \tag{2-49}$$

s_{nl} can be found as

$$s_{nl} = \frac{\{\phi\}_n^T[M]\{r\}_1}{\{\phi\}_n^T[M]\{\phi\}_n} \equiv p_{nl} \tag{2-50}$$

and the influence vectors become

$$\{r\}_1 = \sum_{n=1}^{N} \{\phi\}_n p_{nl} \qquad \text{or} \qquad [r] = \sum_{n=1}^{N} \{\phi\}_n < p >_n \tag{2-51}$$

Substituting Eq. (2-37) into Eq. (2-51) yields

$$[K_g] = -[K]\left(\sum_{n=1}^{N} \{\phi\}_n < P >_n\right) \tag{2-52}$$

Multiplying both sides of Eq. (2-52) by $\{\phi\}_m$ and applying the orthogonality relation of mode shapes with respect to [K] gives the participation factors by the following equation:

$$< P >_n = -\frac{\{\phi\}_n^T[K_g]}{\omega_n^2\{\phi\}_n^T[M]\{\phi\}_n} \tag{2-53}$$

Using Eq. (2-53) to calculate the participation factors requires no influence vectors, [r]. Thus, expensive inversion of the stiffness matrix [K] as indicated in Eq. (2-44) is avoided.

It should be noted that N is the number of unconstrained degrees of freedom and $\{\phi\}_n$ used in Eq. (2-51) is the complete set of modes. In the dynamic analysis by mode superposition, only a limited number of modes, say J modes ($J \le N$), are considered to save computation time.

2.5.4.3 GROUPED SUPPORT INPUT

All constrained degrees of freedom with input motions may be grouped into I groups. Each group has three input components in three orthogonal directions. Thus the excitation to which the piping system is subjected may be defined by vector $\{U_g\ (t)\}$ consisting of 3I acceleration input components as follows:

$$\{U_g''(t)\} = < u_{g,11}'' \quad u_{g,12}'' \quad u_{g,13}'' \quad \cdots \quad u_{g,I1}'' \quad u_{g,I2}'' \quad u_{g,I3}'' >^T \tag{2-54}$$

where $u_{g,ik}''(t)$ represents the i^{th} support group in the k^{th} direction. The input motion of each one of the L constrained degrees of freedom can be proportional to a particular input component in one of the I groups by the following relationship:

$$\{V_g''(t)\} = [B]\{U_g''(t)\} \tag{2-55}$$

where [B] is the L x 3I transformation matrix.

The influence vectors [r] and the participation factors $<\overline{P}>_n$ corresponding to $\{U_g''(t)\}$ are

$$[\overline{r}] = [r][B] = -[K]^{-1}[K_g][B] \tag{2-56}$$

and

$$<\overline{P}>_n = <P>_n[B] \tag{2-57}$$

where $<\overline{P}>_n$ is a 1 x 3I row vector of the participation factors of the n^{th} mode; i. e.,

$$<\overline{P}>_n = <\overline{p}_{n11} \quad \overline{p}_{n12} \quad \overline{p}_{n13} \quad \cdots \quad \overline{p}_{nI1} \quad \overline{p}_{nI2} \quad \overline{p}_{nI3}> \tag{2-58}$$

If q_{nik} (t) is the solution of the following equation,

$$q''(t) + 2\mu_n\omega_n q'(t) + \omega_n q(t) = -u_{g,ik}''(t) \quad , \tag{2-59}$$

the dynamic displacement in Eq. (2-47) becomes

$$\{V_d(t)\} = \sum_{n=1}^{N}\{\phi\}_n \sum_{k=1}^{3}\sum_{i=1}^{I}\overline{p}_{nik}\, q_{nik}(t) \tag{2-60}$$

For an independent support input component $u''_{g,ik}(t)$, its spectral displacement is defined as

$$S_{d,ik}(\omega_n, \mu_n) = \max\left(q_{nik}(t)\right) \tag{2-61}$$

By the response spectrum method, the maximum response of $\{V_d(t)\}$ can be calculated from the following equation

$$\max\{V_d(t)\} = \underset{n=1}{\overset{J}{C_m}}\{\phi\}_n \underset{k=1}{\overset{3}{C_d}}\ \underset{i=1}{\overset{I}{C_g}}\ \overline{p}_{nik}\, S_{d,ik}(\omega_n, \mu_n) \tag{2-62}$$

where C_m, C_d, and C_g denote the modal, directional, and group combinations, respectively. Section 2.3.2 gives methods available in GAPPIPE for the directional and modal combinations. For combination between support groups in the ISM analysis, GAPPIPE supports the Absolute Sum and the SRSS methods.

2.5.5 RESIDUAL MODES (MISSING MASS)

Generally, it is impractical to include all modes in the modal analysis of piping systems. To save computation time, the high modes are excluded from the modal response analysis. This truncation is justified because the higher modes in general have small or negligible contributions to the total response. However, although the omission of higher modes may have negligible effects on the response of unsupported piping spans, the effects on the support loads and loads on the in-line components may be significant.

This is because the pipe mass near a support is not effectively excited in the lower modes due to the constraint by the support, which is typically modeled as a stiff spring in the piping model. This fact is seen as a small mode shape displacement in lower modes for nodes near a support spring. Large mode shape displacements for pipe nodes near supports are seen only in higher modes.

Higher mode contribution thus must be accounted for in the calculation of support loads. The method used by GAPPIPE for the estimation of higher mode contributions to the response is presented in the following paragraphs.

The influence vector {r} may be expressed in terms of mode shapes as:

$$\{r\} = \sum_{L=1}^{N} y_L \{\phi\}_L \tag{2-63}$$

where N is the total number of modes. Each entry of {r} is the displacement in its corresponding degree of freedom due to a unit displacement in the excitation direction. For the case of uniform support excitation, the entry is either 1 or 0 depending on whether or not the direction of the corresponding degree of freedom is the same as that of the excitation. $\{\phi\}_L$ is the mode shape of mode L, normalized with respect to the mass matrix [M], i.e.,:

$$\delta_{ij} = \{\phi\}_i^T [M] \{\phi\}_j \tag{2-64}$$

and

$$\delta_{ij} = \begin{cases} 1 & \text{when } i = j \\ 0 & \text{when } i \neq j \end{cases}$$

In the above equation, the orthogonal property with respect to the stiffness matrix is also implied. The proof of the orthogonality may be found in text books on numerical methods. Defining the expression:

$$p_L = \{\phi\}_L^T [M] \{r\} \tag{2-65}$$

as the participation factor of mode L because it represents the participation of piping mass in that mode's vibration response and then, using the orthonormal property of mode shapes given by Eq. (2-64), it can be determined that

$$Y_L = p_L \tag{2-66}$$

Substituting into Eq. (2-63),

$$\{r\} = \sum_{L=1}^{N} p_L \{\phi\}_L \tag{2-67}$$

Due to truncation of higher modes,

$$\{r\} - \sum_{L=1}^{n} y_L \{\phi\}_L = \{0\} \qquad \text{for} \quad n < N \tag{2-68}$$

where n is the number of modes included in the analysis. The non-zero difference depicted by Eq. (2-68) implies that some of the piping mass is not accounted for in the calculation. Therefore, the missing nodal masses due to the higher mode truncation may be expressed as follows:

$$\{m\}_{missing} = [M](\{r\} - \sum_{L=1}^{n} p_L \{\phi\}_L) \tag{2-69}$$

The higher mode responses have negligible amplification and are usually in-phase. Therefore, the maximum inertia forces, {f}, generated by these missing nodal masses can be estimated by multiplying them by the peak input acceleration, i.e., the zero period acceleration, a_{ZPA}, of the input response spectrum, as follows:

$$\{f\} = \{m\}_{missing} \cdot a_{ZPA} \tag{2-70}$$

It is noted that the missing nodal masses have signs. In fact, some nodes are gaining mass rather than losing due to higher mode truncation. It is also noted that {r} is different for the three excitation directions. In dynamic analysis of seismic responses, the earthquake excitation information is generally supplied in three components. Therefore, there are three sets of nodal loads, one set for each excitation component. A separate static analysis of three load cases, i.e., one for each excitation component, yields the contribution from the truncated higher modes.

To obtain the total loads, the results from the static analysis, which account for the contribution from the truncated higher modes, are combined with those from the response spectrum analysis, which account for the contribution from the lower modes. The absolute sum method is used to combine the results.

The program calculates {f} for every dynamic analysis. The user can include the missing mass effect with a one line command using the multiple analysis option or use the output missing mass loads as the input to a separate static analysis and then combine the results using the post-processor.

The missing mass correction for an ISM analysis is exactly the same as above except that the a_{ZPA} used is the envelope of the ZPA's of all the independent support inputs.

2.5.6. TIME HISTORY ANALYSIS

The constraint of gap supports makes the dynamic response of a piping system nonlinear. However, since these constraints are limited in number and discretely located, the time history analysis of linear piping systems including these nonlinearities can be carried out using a modified linear method, namely, the pseudo-force method. The psuedo-force method treats non-linearities as response-dependent forcing functions acting on the linear piping system.

The equation of motion for the piping system with gap supports can be expressed as:

$$[M]\{\ddot{u}\} + [C]\{\dot{u}\} + [K]\{u\} = \{p\} - \{F\} \tag{2-71}$$

where $\{\ddot{u}\}$, $\{\dot{u}\}$, and $\{u\}$ are the acceleration, velocity and displacement vectors of the piping degrees of freedom. [M], [C] and [K] are the mass, damping and stiffness matrices of the linear piping system. {F} is the force vector generated by the gap supports. {p} is the loading vector. If the system is subjected to ground motion $\{\ddot{u}_g\}$, the loading vector can be expressed as:

$$\{p\} = -[M][r]\{\ddot{u}_g\} \tag{2-72}$$

If the system has n gap supports, let g_j, k_j and c_j be the gap size, stiffness and damping, respectively of gap support j. The force along gap support j, f_j is defined as:

$$f_j = \begin{cases} 0 & \text{for } d_j \le g_j \\ K_j(d_j - g_j) + c_j \dot{d}_j & \text{for } d_j > g_j \end{cases} \tag{2-73}$$

where d_j and $\dot{d}_j$ are the displacement and velocity along gap support j. If q is the force vector along the gap support, which is an n x 1 vector, the force vector along the piping degrees of freedom, {F}, can be found as:

$$\{F\} = [S]\{f\} \tag{2-74}$$

where [S] is a transformation matrix defined by the direction cosines of each gap support. The displacement vectors along the gap supports, {d}, can be calculated from the expression:

$$\{d\} = [S]^T\{u\} \qquad (2\text{-}75)$$

Let ω_i and $\{\phi\}_i$ be the modal frequency and mode shape of mode i of the linear piping system without the constraint of gap supports. By modal superposition, the piping deformation {u} can be expressed as:

$$\{u\} = \sum_{i=1}^{m} \{\phi\}_i \, y_i \qquad (2\text{-}76)$$

if m modes are considered. If the mode shape, $\{\phi\}_i$, has been normalized such that $\{\phi\}_i^T[M]\{\phi\}_i = 1$, Eq. (2-71) may be decoupled into m independent equations as:

$$\ddot{y}_i + 2\mu_i\omega_i\dot{y}_i + \omega_i^2 y_i = \alpha_i - \delta_i \qquad (2\text{-}77)$$

where μ_i is the damping ratio of mode i. α_i and δ_i are defined as:

$$\alpha_i = \{\phi\}_i^T\{p\} \qquad (2\text{-}78)$$

$$\delta_i = \{\phi\}_i^T\{F\} \qquad (2\text{-}79)$$

Since the load vector, {F}, is a function of $\{\dot{u}\}$ and {u}, δ_i will be a function of $\dot{y}_i$ and y_i. Thus, Eq. (2-77) becomes nonlinear and cannot be directly solved. Through the pseudo-force method, Eq. (2-77) is solved by the following procedure:

1) Solve the following equation for each mode:

$$\ddot{y}_i^{(1)} + 2\mu_i\omega_i\dot{y}_i^{(1)} + \omega_i^2 y_i^{(1)} = \alpha_i\,, \qquad i = 1, 2, ..., m \qquad (2\text{-}80)$$

2) Based on $\dot{y}_i^{(1)}$ and $y_i^{(1)}$, calculate the deformation along each gap support and check if the gap is closed.

3) If none of the gaps is closed, then,

$$\ddot{y}_i = \ddot{y}_i^{(1)}$$

$$\dot{y}_i = \dot{y}_i^{(1)}$$

$$y_i = y_i^{(1)}$$

and,

$$\delta_i = 0$$

and Eq. (2-77) becomes a linear equation. Go to step (1) to solve the next time step.

4) If some gaps are closed, calculate δ_i and solve the following equation:

$$\ddot{y}_i^{(2)} + 2\mu_i\omega_i\dot{y}_i^{(2)} + \omega_i^2 y_i^{(2)} = -\delta_i, \quad i = 1, 2, ..., m \qquad (2\text{-}81)$$

5) The final solution is

$$\ddot{y}_i = \ddot{y}_i^{(1)} + \ddot{y}_i^{(2)}$$

$$\dot{y}_i = \dot{y}_i^{(1)} + \dot{y}_i^{(2)}$$

$$y_i = y_i^{(1)} + y_i^{(2)}$$

The procedure is repeated for the next time step.

2.6 ANALYSIS OF SEISMIC ANCHOR MOVEMENTS

There are two approaches in the response spectrum method of analysis. The first approach assumes, for each excitation component, that the anchor nodes of all supports move in-phase as defined by a single spectrum enveloping the input spectra at all anchor nodes. The other approach is a multiple spectra method that uses different enveloped spectra for different groups of anchor nodes.

In both approaches, the calculated results only account for the inertia effect due to the in-phase displacements. The effect due to the out-of-phase, differential seismic anchor movements (SAM) is not included in the analysis. Although SAM happens dynamically, the effect can be approximated using a separate static analysis.

There are three assumptions regarding the calculation of the effect of anchor movements:

1) Anchor nodes are divided into groups depending upon their elevations.

2) Anchor nodes belonging to the same group move in-phase in each of the three global directions.

3) When the anchor nodes in one group move, the anchor nodes in all other groups remain stationary.

GAPPIPE reads the SAM displacements and converts them into equivalent nodal loads. According to the assumptions stated above, the in-phase movements of the anchor nodes of a group in each global direction are analyzed as a separate static load case. Therefore, the number of load cases equals three times the number of groups.

The equivalent nodal load calculation is based on the fact that the effect of an anchor node displacement on the attached pipe is the same as that of applying to the pipe a nodal load equal to the anchor displacement multiplied by the support stiffness.

The results from all load cases are then combined using one of the following possible combination choices:

	Direction	Group
(1)	ABS	ABS
(2)	ABS	SRSS
(3)	SRSS	ABS
(4)	SRSS	SRSS

where ABS and SRSS denote the absolute sum and the square root of the sum-of-the-squares methods, respectively. The directional combination is performed prior to the group combination.

2.7 CALCULATION OF IMPACT FORCES

The reaction force at a gapped support can be determined simply by multiplying the gap stiffness, K_g, to the calculated pipe displacement beyond the gap size.

On the convergence of a GAPPIPE linearization analysis, the global piping responses, such as displacement and bending moments, can be calculated accurately in the context of response spectrum analysis methodology. But it is recognized that, since the stiffness K_g of a gapped support is generally much higher than the pipe global stiffness, K_p, the conservatism inherent in the response spectrum analysis may lead to a large variance in the magnitude of the calculated impact force. To minimize this variance, an improved method has been developed for the calculation of impact forces for the gapped supports.

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3.0 VERIFICATION OF GAPPIPE

The purpose of the effort presented in this section is to verify the adequacy of the computer program GAPPIPE for use in the dynamic analysis and design of nuclear piping systems. The verification effort consists of four independent sources of comparison:

1. Comparison with the NRC benchmark problems described in NUREG/CR-1677, Volumes I and II [Ref. 12,13],

2. Correlation with laboratory shake table test data [Ref. 14] and the ANSYS computer program [Ref. 15],

3. Correlation with the in-situ HDR Experimental Tests [Ref. 16],

4. Comparison with literature analytical results [Ref. 17, 18].

The comparison using the NRC benchmark solutions is a mandatory verification procedure specified in Section 3.9.1 of the NUREG-0800 Standard Review Plan to meet the requirements of 10CFR Part 50, Appendix B and GDC 1. This comparison of the NRC benchmark solutions with GAPPIPE results is intended to validate the linear response spectrum analysis option and the associated programming structure and logic of GAPPIPE. These include the validation of element formulation, solution algorithms, eigensolution techniques, modal combination methods, and element load and stress calculations.

The second source of verification is to use the shake table test data which were obtained by RLCA as part of the GAPPIPE research and development effort. The intent is to validate the equivalent linearization analysis option of GAPPIPE by correlating the GAPPIPE solutions with actual test measurements. An alternate comparison is also made with nonlinear time history solutions calculated using the ANSYS computer program. This comparison shows the accuracy of GAPPIPE solutions, which are based on the response spectrum technique, relative to the ANSYS nonlinear time history results which are generally considered as "exact" analytical solutions.

The third verification source is the in-situ HDR experiment sponsored in part by the U.S. Nuclear Regulatory Commission Office of Research. In-situ piping and equipment dynamic responses due to seismic-like excitations were recorded for both snubber and gapped support piping designs. The verification performed here compares the GAPPIPE results with the recorded test data. The intent is to show that the analytical solutions of gapped support piping system designs obtained by the GAPPIPE equivalent linearization method are valid design solutions and are comparable to the current industry piping analysis of snubber support system designs. This verification source supplements the preceding efforts in that the HDR test data are realistic in-situ responses of actual hardware and physical conditions. Furthermore, identical tests were performed for snubber and gapped support system designs.

The last source of comparison is the use of analytical results published in the literature. Two examples are used. One is reported and documented in the STARDYNE Verification Manual [Ref. 17], and the other is taken from an ASME technical paper by Molnar, et al [Ref. 18]. The intent of the comparison is to verify the time history analysis option of GAPPIPE.

In the following subsections, the description and results of each of these four sources of comparison are discussed and summarized.

3.1 COMPARISON WITH NRC BENCHMARK PROBLEMS

A total of eleven Benchmark Problems are provided in NUREG/CR-1677, Volumes I and II [Ref. 12,13] for the purposes of verifying the adequacy of any computer programs used for dynamic analysis and design of nuclear piping systems. There are seven problems in Volume I for analysis using the Uniform Support Motion Response Spectra method, which will be referred to as the UNI Benchmark problems from here on. In Volume II, there are four problems for analysis using Independent Support Motion Response Spectra Method, which will be referred to as the ISM Benchmark problems from here on.

For the UNI Benchmark problems, the seven problems range from simple to complex configurations which are assumed to experience linear elastic behavior. The solutions provided include: (1) frequencies, (2) modal participation factors, (3) nodal displacements, and (4) element stresses. The solutions were determined by application of Uniform Support Motion Response Spectrum Method of seismic analysis, based on interspatial combination (SRSS) and then intermodal combination (GROUPING) described in Regulatory Guide 1.92, Rev. 1, February 1976. For Problem Nos. 2, 4, 6 and 7, alternate solutions based on performing intermodal first and then followed by interspatial combinations are also provided in NUREG/CR-1677, Volume I. For verification of GAPPIPE, only solutions based on performing the interspatial combination first and then intermodal combinations are used for comparison.

For the ISM Benchmark problems, the four problems include a simple two anchor problem, a simple three branch problem, and two large problems simulating piping from actual nuclear power plants. The dynamic loadings applied to the four problems are represented by distinct sets of support excitation spectra assumed to be induced by non-uniform excitation in the three spatial directions.

The GAPPIPE solutions that were compared to the NUREG/CR-1677 solutions include: (1) predicted natural frequencies, (2) modal participation factors, (3) nodal displacements, and (4) element stresses. For each problem, three sets of solutions from different combinations are presented; the different combinations are: (1) enveloped spectra excitation, (2) independent support excitation with SRSS combination between support group contributions, and (3) independent support excitation with ABSOLUTE combination between support group contributions.

In all solutions, the combination over group contributions was performed first, followed by SRSS interspatial combination, followed by SRSS intermodal combination without the consideration of closely spaced frequencies (which is consistent with present NRC guidelines). For purposes of GAPPIPE verification, the solutions from independent support excitation with ABSOLUTE combinations are used in the comparison between GAPPIPE and the NRC Benchmark solutions.

3.1.1 PROCEDURE USED FOR VERIFICATION

The procedure used for verification of the linear portion of GAPPIPE program is as follows: (1) model all eleven Benchmark Problems by using GAPPIPE with all parameters identical in NUREG/CR-1677, Vol. I and II, (2) a fictitious gap with a very large gap size is added to each problem, with the intent of verifying the program subroutines involving gapped supports in the GAPPIPE program. Since the large gap does not close upon loading, it will not affect the results of the original problem, (3) run all eleven problems and tabulate the results, (4) compare the results from GAPPIPE to the results in NUREG/CR-1677, Vol. I and II.

3.1.2 UNIFORM SUPPORT MOTION BENCHMARK PROBLEMS

UNI Benchmark Problem No. 1

The model is a simple, three-dimensional piping bend made up of straight and bent pipe elements between two fixed anchors (Figure 3.1).

UNI Benchmark Problem No. 2

The model is a multi-branched configuration resembling a four legged platform consisting of all straight pipe elements (Figure 3.2). The problem has symmetric and antisymmetric modes which allow for quick check on the symmetry of the deformation of the model.

UNI Benchmark Problem No. 3

This problem is primarily an extended version of the first Benchmark Problem No. 1 (Figure 3.3) with several anchors and a branch connection. It also includes intermediate spring supports, used to simulate hangers and snubbers, and a flexible anchor.

For this Benchmark Problem, the results presented in NUREG/CR-1677, Vol. I were determined to be in error from page 84 to page 111 [Ref. 19]. The correct results of natural frequencies and modal participation factors have subsequently been prepared by the authors of NUREG/CR-1677 and presented as Problem No. 2 in NUREG/CR-1677, Vol. II. The corrected results of this problem are used in the comparisons.

UNI Benchmark Problem No. 4

This model simulates the primary system of a hypothetical two loop reactor plant (Figure 3.4). It consists of an elastically supported reactor vessel, two steam generators, and four primary pumps connected by three and four foot diameter piping. The reactor, steam generators, and pumps were modelled with massless pipe elements dimensioned to simulate the stiffness of these components. This model is very significant because it incorporates most of the features found in true piping systems in a realistic configuration.

UNI Benchmark Problem No. 5

This model is an in-line system between two fixed anchors (Figure 3.5). This problem, which was taken from actual nuclear power plant piping systems, has two unique features: one feature is a transition between two materials, and the other feature is the inclusion of valves which were modelled with thick walled, stiffened piping elements by increasing the modulus of elasticity of valve elements by a factor of three. The method of modelling valves is similar to present industry practice.

UNI Benchmark Problem No. 6

The model is primarily one large sweeping bend between two fixed points (Figure 3.6). This problem was also derived from an actual piping system which has a unique and continuous curve geometry.

UNI Benchmark Problem No. 7

The model is a multi-branched structure which contains four anchor points (Figure 3.7). This problem, also derived from an actual piping system, is the largest Benchmark Problem, and thus permits checking of most analysis features including multiple branches, multiple anchors, intermediate supports and hangers, valves and multiple excitation.

3.1.3 INDEPENDENT SUPPORT MOTION BENCHMARK PROBLEMS

ISM Benchmark Problem No. 1

The first ISM Benchmark Problem simulates a 3-1/2 inch diameter water line running between two elevations. It represents a simple configuration joining the anchors and has numerous intermediate supports (Figure 3.8). The excitation consists of two individual single direction spectra corresponding to the two elevations.

ISM Benchmark Problem No. 2

The second ISM Benchmark Problem is a three branch configuration originally used as a Benchmark for the Uniform Support Motion analysis method (UNI Benchmark Problem No. 3). The support elements are divided into excitation spectra sets (Figure 3.9). The four excitation spectra correspond to actual spectra developed for a real reactor structure and show variations with elevation.

ISM Benchmark Problem No. 3

The third ISM Benchmark Problem is a two anchor configuration simulating safety injection piping in a nuclear power plant. It is comprised of 12-inch diameter Schedule 40 stainless steel pipe between two elevations (Figure 3.10). The input excitation consists of four spectra sets; the vertical components of excitation varying from set to set while the horizontal components of excitation are identical for all sets.

ISM Benchmark Problem No. 4

The fourth ISM Benchmark Problem is a three branch, three anchor piping subsystem from an actual nuclear power plant. It contains numerous section changes and complex geometry associated with real systems (Figure 3.11). The input excitation consists of four distinct excitation spectra sets developed for the actual system and show variations for elevations. This problem represents a benchmark having the size and diversity to fully exercise proposed analysis methods.

3.1.4 SUMMARY OF COMPARISON

The comparisons between GAPPIPE and NUREG/CR-1677, Vol. I and II, provide the following conclusions:

(a) Natural Frequencies

The results between GAPPIPE and NUREG/CR-1677 are identical for all eleven problems.

(b) Modal Participation Factors

For all major modes in all eleven problems, the results from GAPPIPE are nearly identical to NUREG/CR-1677; for minor modes, there are some larger differences, but the differences are due to the use of different computer hardware. The original NUREG/CR-1677 problems were run on a CDC-7600 machine which is a 64-bit machine, whereas the GAPPIPE problems were run on a VAX-11/750, which is a 32-bit machine. This produces differences when dealing with small numbers as in the 4 cases of minor modal participation factors. Also, the round-off error has contributed somewhat to the percentage differences. Overall, the differences between GAPPIPE and NUREG/CR-1677 are considered negligible.

(c) Nodal Displacements

For all eleven problems, comparisons between GAPPIPE and NUREG/CR-1677 showed very good agreement.

(d) Element Stresses

Based on the comparisons of element stresses for the eleven Benchmark Problems, the differences between GAPPIPE and NUREG/CR-1677 are negligible.

The numerical results of these comparisons are quite voluminous. As an illustration, the complete comparison for Uniform Spectra Problem No. 7 is presented in Appendix A. Results for the other problems are similar.

It is concluded that the GAPPIPE program can predict and calculate accurate results as compared to NUREG/CR-1677 for linear piping system under both (1) Uniform Support Motion excitation, and (2) Independent Support Motion excitation.

3.2 CORRELATION WITH SHAKE TABLE TEST DATA AND ANSYS

Seismic testing was performed to provide test data in the development of computer program GAPPIPE. The tests were performed using full scale pipe specimens on a shake table located at the University of California Earthquake Engineering Research Center. Two pipe geometry configurations were tested, each involving a variety of support, gap size, and input amplitude parameter combinations. Both configurations used portions of full size 3-inch Schedule 80 pipe with simulated gapped supports. One configuration used a straight pipe span excited only in the transverse direction. The second configuration used a three dimensional Hovgaard Bend which produced multi-axis response with input excitation in only one direction. The two test configurations, as installed on the shake table, are illustrated in Figures 3.12 and 3.13. The geometry of the two test configurations are shown individually in Figures 3.14 and 3.15 respectively.

The test configurations described above were instrumented and monitored so that all the pertinent parameters of the tests were recorded. The instrumentation includes: (1) table motions including displacements, velocities, and accelerations, which were measured by the internal instrumentation of the shake table system, (2) support accelerations and loads for both rigid supports and gapped supports (the accelerations were measured by mounting accelerometers at appropriate locations on supports, and support loads were measured by installing load cells at support connections and by strain gages mounted on supports), (3) piping lateral accelerations at various points, particularly at gapped support connections, were measured by accelerometers mounted on the pipe, (5) displacements of the pipe were measured by potentiometers connected between the pipe and rigid supports, (6) pipe strains at various points along both systems were measured by strain gages mounted on both inside and outside surfaces of the pipe.

3.2.1 CORRELATION PROCEDURE

For each test configuration, numerous seismic tests were performed by varying gap sizes and input excitation amplitudes. The recorded test data were then compared to analytical solutions determined using computer codes GAPPIPE and ANSYS. The GAPPIPE analyses were performed to evaluate the accuracy of the equivalent linearization method for predicting nonlinear responses. ANSYS was used to perform corresponding nonlinear time history analyses as reference basis for accuracy. The method of nonlinear time history analysis, as employed within ANSYS, is an accepted analytical technique for solving nonlinear dynamic problems.

Two simulated building filtered El Centro earthquake motions were used in these tests as input excitations to the shake table. The two earthquake motions correspond to 0.82g and 1.33g ZPA excitation levels. The recorded shake table motions were used as time history inputs for conducting the ANSYS analyses. The same inputs were also used to generate the response spectra employed in the corresponding GAPPIPE analyses. The time history data and response spectra for two earthquake excitation levels are shown in Figures 3.16 and 3.17, respectively.

3.2.2 CORRELATION OF SINGLE SPAN TEST CONFIGURATION

Figures 3.18 and 3.19 show the comparison of the pipe bending stresses for the single span test configuration. The measured and calculated stress values are plotted versus the average gap sizes. The comparison shows that the equivalent linearization method employed by GAPPIPE is as accurate as the ANSYS nonlinear time history analysis in predicting the nonlinear piping response due to gapped pipe supports. This agreement between GAPPIPE and the time history solutions is expected because the single span dynamic responses are first mode dominant. For complex piping systems with multi-mode participation, it is expected that GAPPIPE will calculate more conservative solutions as will all linear response spectrum analysis computer programs in general.

Similar results are also found when comparing the gap impact force results calculated by GAPPIPE and ANSYS. The comparisons are illustrated by Figures 3.20 and 3.21 for the two earthquake excitation levels. It is noted that both analytical solutions are conservative in calculating the gap impact forces as compared to the actual measured responses.

3.2.3 CORRELATION OF THE 3-D HOVGAARD BEND TESTS

The shake table earthquake inputs for the 3-D Hovgaard Bend Test configuration were identical to those used for the single span dynamic tests. The same earthquake input levels of 0.82 g and 1.33g ZPA were used.

The 3-D Hovgaard Bend Test piping system was observed to exhibit significant response coupling as expected. The first mode resonant frequency was found to be approximately 4.9 Hz in the horizontal direction orthogonal to the direction of table motion.

A number of tests were performed with various combinations of gap sizes and earthquake input levels. Analytical results were calculated using ANSYS and GAPPIPE. The ANSYS analysis employed was nonlinear time history analysis and used the recorded acceleration data at the anchor points as input motions. The same acceleration data were used to generate response spectra which were then utilized as input for the corresponding GAPPIPE analysis. Figure 3.22 shows the analysis model of the 3-D Hovgaard Bend Test configuration used in both analysis types.

The maximum pipe bending stresses of the 3-D Hovgaard Bend test configuration are summarized in Table 3.1. The first two columns in the table state the gap conditions used at each of the two gapped supports shown in Figure 3.15. Each gap condition is described by two values that are corresponding the gap sizes on the two sides of the pipe. The value, "open", means a sufficiently large gap was used so that no impact occurred on that side of the gap.

The last three columns in Table 3.1 are the maximum pipe bending stresses corresponding to the recorded test data, the ANSYS and GAPPIPE analysis results respectively. In all tests, the comparison shows that both ANSYS and GAPPIPE results are conservative with respect to the actual responses. The GAPPIPE results are more conservative than the ANSYS results. This is expected since the 3-D Hovgaard Bend test configuration was observed to have multi-mode response. The GAPPIPE analysis results were determined by the equivalent linearization analysis option using the response spectrum method.

3.3 CORRELATION WITH HDR EXPERIMENTAL TESTS

3.3.1 BACKGROUND

A major structural dynamic test program, known as the SHAG experiments, was conducted at the HDR decommissioned experimental reactor facility of Kernforschungszentrum Karlsruhe (KfK), Federal Republic of Germany (FRG) during 1986. These tests were cosponsored by the West German government, the U.S. Nuclear Regulatory Commission Office of Research (NRC/RES) and the Electric Power Research Institute (EPRI). The overall objective of these tests was to generate data on structural response, soil/structure interaction, and piping and equipment response for a full scale reactor under strong excitation conditions. A detailed description of the SHAG test program was presented by Kot, et al., [Ref. 7] at the 15th Water Reactor Safety Research Information Meeting.

The principal objectives of the piping tests in the SHAG program were to provide full scale in-situ test data and to demonstrate the feasibility of alternate piping support designs to be used in place of snubbers. In addition, the test data would serve to qualify the methodologies needed for acceptance of the alternate piping support designs for implementation into power plants. One such alternate pipe support is gapped supports, known as the HDR SHAG Limit Stop design. Figure 3.23 shows the HDR piping system and the support designs. In this section, the HDR SHAG test data are used to correlate with the analysis results obtained by GAPPIPE.

3.3.2 SHAG TEST DESCRIPTION

The SHAG test program was designed such that the building dynamic excitation was provided by a large mechanical coast-down shaker on the operating floor of the HDR reactor containment building. The shaker was configured with two opposing concentrated weights and spun in the balanced condition to the desired circular frequency. Once the desired speed was obtained, one of the rotating arms was released, allowing it to pivot and couple with the other arm. This configuration created an unbalanced force as a function of the magnitude of the concentrated weights and the initial rotational frequency at release. After release from the initial balanced condition, the shaker slowly coasted down with the frequency of rotation and the amplitude of the unbalanced force excitation decaying with time. The shaker transmitted the eccentric loading to the building structure, thus exciting the piping and components in a "building filtered" manner similar to the dynamic loading of a seismic event.

Several types of piping system response data were recorded. These data included accelerations at support bases, pipe, equipment and a motor operated valve. Strains were recorded at selected pipe locations, at the motor operated valve, and at components or discontinuities (reducers, tees, and nozzles) in the system. Strains converted to reaction forces were available for the rigid supports, snubbers, Limit Stop supports, and spring hangers. Support impact forces at the Limit Stop support locations were also recorded. System data such as temperature, pressure, mass flow rate, and the valve position were measured.

3.3.3 CORRELATION ANALYSIS

Post test analysis using GAPPIPE were performed for both the snubber and the Limit Stop supported test configurations. Recorded accelerometer data at the HDR reactor building, the pipe support anchors, the HDU pressurizer, and the DF-16 accumulator were used to generate response spectra as input to the analysis. These spectra were calculated using the Code Case N411 damping values and were enveloped for each of the following three structures groups:

Group 1: Reactor building accelerations at the base of each support.
Group 2: Equipment accelerations at the nozzles of the DF-16 accumulator.
Group 3: Equipment acceleration at the nozzles of the HDU pressurizer.

The GAPPIPE analyses were performed with the Independent Support Motion analysis option using the above three structural groups as three independent groups. In the case of the Limit Stop supported tests, the equivalent linearization method is also used to model the gap responses.

The Regulatory Guide 1.92 grouping modal combination method is used in all analyses. The spatial directions were combined by the SRSS method. The ISM groups were combined by absolute summation.

3.3.4 CORRELATION SUMMARY

Figure 3.24 shows a summary comparison of the maximum pipe accelerations for the snubber and the Limit Stop test configurations. For each configuration, a comparison was made between the test results and the corresponding GAPPIPE analysis results. Five piping locations were compared.

The comparison in Figure 3.24 shows the GAPPIPE analysis results are higher than the actual responses in all cases. This finding is consistent with the analytical assumption that the response spectrum solutions provide conservative designs. As expected, the degree of conservatism, measured by the relative amplitudes of the test and analysis results in Figure 3.24, varies from pipe location to location.

An important characteristics demonstrated by the results in Figure 3.24 is the similarity of responses for the two pipe support configurations. It is noted that the GAPPIPE analysis using the equivalent linearization method for the Limit Stop support configuration retain the same degree of conservatism as the analysis for the snubber configuration. This correlation supports and confirms the use of the equivalent linearization method employed by GAPPIPE.

Similar results were also determined for other piping response parameters. Figure 3.25 shows a summary comparison of the maximum pipe stresses at five pipe locations. Figure 3.26 is a summary comparison of the maximum support loads. In each case, it was found that the GAPPIPE analysis results for Limit Stop provide similar degrees of conservatism as the snubber analysis results.

3.4 COMPARISON WITH LITERATURE ANALYTICAL RESULTS

The purpose of this comparison effort is to validate the time history analysis capability of GAPPIPE. Two sets of literature solutions are chosen to compare to GAPPIPE results. The first case is used to verify the linear time history analysis logic of GAPPIPE. The second set is used to test the nonlinear time history analysis method in GAPPIPE for the analysis of gapped supports.

3.4.1 GAPPIPE LINEAR TIME HISTORY ANALYSIS

This verification case is taken from the STARDYNE Verification Manual Example 30 [Ref. 17]. It is a cantilever beam subjected to a sine pulse forcing function applied at the tip as shown in Figure 3.27. Assume the case where the sine pulse has a period of T = 0.14352 second and the cantilever beam has the following properties:

E	=	1.0×10^6 psi
I	=	1.3333×10^{-4} in^4
A	=	0.04 in^2
p	=	0.1 lb/in^3
l	=	30 inches

The cantilever beam is modeled by six straight pipe elements in GAPPIPE. Using a time step of 0.004784 second, the vertical displacement response at the tip of the cantilever beam is determined. Table 3.2 summarizes the GAPPIPE results at four time intervals as compared with the the theoretical solution. It is determined that the GAPPIPE results differ from the theoretical values by less than 0.5%.

3.4.2 GAPPIPE NONLINEAR TIME HISTORY ANALYSIS

This verification case is taken from the technical paper by Molnar, et al. [Ref. 18]. Molnar presented the methodology and example results for the dynamic analysis of piping systems with gaps. The Molnar method has been used in the design and analysis of Westinghouse PWR piping systems.

Figure 3.28 shows the piping model presented by Molnar. It consists of nine straight pipe elements, two elbows, and three gapped supports. The piping system is fixed at the ends. The gap sizes and stiffnesses at the three gapped supports are:

Gap No.	Gap Size	Gap Stiffness (lb/in)
1	0.250	2.0×10^6
2	0.125	3.0×10^6
3	0.062	1.5×10^6

The forcing functions applied to the piping system are also shown in Figure 3.28. The GAPPIPE analysis is performed using 30 modes and a time step of 0.0000625 seconds. The maximum impact forces at the three gapped supports and the time of occurrence are computed by GAPPIPE and compared with the Molnar results in Table 3.3. The differences in the comparison are found to be less than 4%.

3.5 VERIFICATION CONCLUSION

The analysis solutions of computer program GAPPIPE have been compared with the NRC Benchmark Piping Problems, Shake Table test data, ANSYS analysis results, the HDR Experimental Tests, and analytical results published in the literature. The summary of results presented in the preceeding section shows:

- GAPPIPE linear solutions are nearly identical to the NRC Benchmark Solutions in NUREG/CR-1677.

- GAPPIPE nonlinear solutions are comparable to ANSYS results and in many cases more accurate when compared to test data.

- GAPPIPE nonlinear solutions provide the same degree of conservatism for piping analysis of gapped supports as in current industry practice of piping analysis of snubber supports.

- GAPPIPE time history analysis solutions are nearly identical to literature results.

These comparisons have demonstrated the accuracy, applicability and validity of GAPPIPE in accordance with Section 3.9.1 of NUREG-0800. It is concluded GAPPIPE can be applied for the analysis of nuclear piping systems.

4.0 GAPPIPE AND LIMIT STOP APPLICATIONS

Originally the basic approach to the application of Limit Stops was to redesign and re-analyze the piping system using GAPPIPE with Limit Stops in place of snubbers. This approach is applicable for snubber reduction or elimination programs in which re-analysis is performed with ASME Code Case N-411 damping (Ref. 20) and the number of snubbers required is reduced. By using Limit Stops, snubbers can be eliminated instead of just reduced. This optimization approach is the first strategy discussed below.

However, the cost of re-analysis itself is a significant burden. For this reason Duke Power Company proposed the idea of replacing the existing snubbers with Limit Stops on a one-for-one basis without reanalysis. Since Code Case N-411 damping was not used in the original design, the additional margin theoretically available from this higher damping would presumably cover any changes in pipe stresses, support loads, valve accelerations, etc. This is the second strategy covered herein. The most cost-effective strategy is to analyze systems with large numbers of snubbers, thereby optimizing hardware costs; then to use the one-for-one replacement on the most numerous lines with few snubbers, thereby minimizing engineering costs.

4.1 OPTIMIZATION WITH ANALYSIS

The optimization approach is straightforward in that a complete analysis is done of the piping system, and stresses, support loads, etc. are determined explicitly. These results are then compared to allowable values from the ASME Code or other prescribed plant specific design limits (SAR). In the analysis, the analyst replaces (mathematically) the rigid snubbers with Limit Stops and computes the response of the system with the GAPPIPE computer program. After verifying that the response is within acceptable limits, the engineering work is finished.

Alternatively, however, the analyst may continue with the computer analysis and optimize the design. This is done by taking successive dynamic supports out of the system until the minimum number of Limit Stops are left that will permit stress and load limits to be satisfied. This process is similar to conventional snubber reduction methods in which old piping designs are re-analyzed, usually with new damping ratios, and snubbers are taken out until the least number are left that will permit stress and load limits to be met. The difference with the Limit Stop approach is that by substituting Limit Stops for snubbers, the snubbers can usually be eliminated altogether. Examples of the optimization approach are discussed in detail in References 21 and 22.

4.1.1 MILLSTONE 2 - ANALYSIS WITHOUT USING N-411 DAMPING

Reference 21 presents a study done on the Safety Injection System piping shown in Figure 4.1 for the Millstone 2 nuclear plant. In this study, the new N-411 damping was not used. The system consisted of 6 and 12 inch stainless piping supported by fifteen rigid hangers, one spring hanger, and eight snubbers. This study was a research effort. No licensing was done, nor were the results previously presented to the NRC.

Of the eight original snubbers, the optimized support configuration retains one, replaces five with Limit Stops, replaces one with a rigid support, and deletes one.

Although a support configuration with no retained snubbers met code compliance requirements, the nozzle loads increased in some cases. As some of the increases were large enough to cause concern, one snubber in the horizontal X-direction was retained in the optimized configuration to limit these loads. With that snubber retained, the seismic displacement in the X-direction was reduced to less than the thermal envelope at the node, thus making a seismic support at that location unnecessary.

One snubber was replaced by a rigid strut based on the small thermal movement at that node. All other snubbers were replaced with Limit Stops. Table 4.1 summarizes the support modifications at the eight original snubber locations.

The gap sizes were determined from the enveloped thermal deflections at each Limit Stop location in the direction of the support. Gap sizes were rounded up to the nearest 1/16", corresponding to installation tolerances.

Pipe Stresses - Millstone 2

As shown in Table 4.2, the maximum pipe stresses are well within the ASME Code allowables. The Code Equation 8, 10, and 11 stresses are essentially the same as in the original (eight snubber) support configuration, because neither the snubber nor the Limit Stop offers any resistance to thermal or deadweight loads. A decrease in Code Equation 10 and 11 stresses would be expected because seismic anchor motion (SAM) loads should decrease due to the removal of the one X-direction snubber. On the other hand, replacing one snubber with a rigid support increases thermal stresses.

Support Loads - Millstone 2

The "new" support loads for the optimized support configuration are given in Tables 4.3 and 4.4 in comparison to the "original" values calculated for each support. Most support loads are reduced in the new support design. Those that have increased are judged to be within the support structural capacities.

Of primary concern are the loads at the equipment nozzles, which show some increases and some decreases. The maximum moment increase is 21% for the vertical Y-component at node 190. For a further indication of the acceptability of these equipment nozzle loads, the stresses at the nozzles are compared to the allowable stresses in Table 4.5. As shown, all stresses are under 50% of allowable except for the Code Equation 10 and 11 stresses at node 190. However, the Code Equation 10 and 11 stresses should not change due to replacing snubbers with Limit Stops, because neither support resists thermal expansion. Therefore, if these stresses are acceptable in the original design, they should be also acceptable for the optimized support configuration.

Conclusion - Millstone 2

The snubber elimination study at the Millstone 2 Nuclear Power Plant demonstrates that existing snubbers can be eliminated without using the ASME Code Case N-411 damping values. This elimination is accomplished by replacing the existing snubbers with Limit Stop pipe supports, which offer maintenance-free performance.

4.1.2 BYRON 2 - ANALYSIS WITH N-411 DAMPING

Reference 22 presents a study done on the main hot to cold leg bypass line in the Commonwealth Edison Byron 2 plant. The objective of this study was to eliminate all snubbers and optimize the support design taking full advantage of the improved N-411 damping ratios.

Optimized Support Configuration - Byron 2

The existing pipe support configuration consisted of a total of eighteen supports: thirteen mechanical-type snubbers and five rigid-acting frame supports. The first GAPPIPE analysis, using a one-for-one replacement of Limit Stops in place of the existing snubbers, satisfied ASME Code and design specification acceptance criteria. By engineering judgement, however, it was determined that some of the Limit Stops could be eliminated, further improving upon the overall support configuration. The final configuration, as shown in Figure 4.2, is one in which eight of the thirteen existing snubbers were replaced with Limit Stops, five snubbers were eliminated with no support replacement, and the five existing rigid-acting supports remained unchanged.

Analytical Results - Byron 2

The piping system consisted of 8", 1 1/2" and 3/4" stainless steel piping. Although the reactor coolant system bypass line was designated as ASME Class 1 piping, the 3/4 inch piping was evaluated using ASME Section III-NC (Class 2) rules, as permitted by paragraph NB-3630 of the Code. The 8 inch and 1-1/2 inch diameter piping was evaluated with ASME Class 1 rules. The results of the analysis reported in this paper are limited to maximum pipe stresses and a support load summary, comparing new support loads versus the existing support loads. Numerous other items, such as valve accelerations, valve end loads, nozzle loads, decoupled branch lines, and flange loads required evaluation to acceptance criteria, but are excluded here for brevity.

Pipe Stresses - Byron 2

The maximum Class 1 and Class 2 stresses are shown in Tables 4.6(a) and 4.6(b), respectively. For both Class 1 and Class 2 piping, the maximum stresses generally occur near one of the branch connections with the RCL. The other maximum stress points are located near two vertical rigid-acting supports.

The location of the maximum stresses did not change substantively from the existing design stress calculation. This is because the locations of the maximum stresses are near points which were analytically modeled as rigid anchors. Even though existing snubbers were eliminated or changed to Limit Stops in these regions, the rigidly supported points control the local frequency characteristics at these locations. Furthermore, the N-411 acceleration spectra have the same basic profile as the original uniform damping spectra, with the major differences being in the acceleration magnitudes. The Class 1 fatigue evaluation is characterized by thermal gradients through the pipe wall and at gross structural or material discontinuities in the pipe. These are local effects which are not influenced by the modifications to the support configuration. The results of the fatigue evaluation were effectively unchanged from the original analysis of record.

Pipe Support Loads - Byron

Table 4.7 shows a comparison of the support design loads between the original snubber configuration and the modified configuration using Limit Stops. Although there are some significant support load increases, there were substantial margins between the original design loads and the maximum loads which would still satisfy acceptance criteria. Despite the increases in loads, no support modifications were required, except for the hardware changes from snubbers to Limit Stops.

4.2 DIRECT REPLACEMENT WITHOUT ANALYSIS

Direct Replacement is the second strategy available for the use of Limit Stops. This approach is being applied to the removal of approximately 3,000 snubbers at the Duke Power Company's McGuire plant. The program is discussed in detail in Reference 23. The direct replacement approach is based upon the concept that the calculated stresses and loads in a conventionally supported piping system will be reduced if the snubbers are replaced by Limit Stops and N-411 damping is used.

Two considerations suggested to Duke that the theory described above would be viable. The first is simply the amount of difference in the input accelerations for Code Case N-411 and Reg. Guide 1.61 damping spectra. Typical OBE floor response spectra at Duke's McGuire plants corresponding to the two damping values are given in Fig. 4.3. It can be seen there is a factor of 2 or more in the frequency region of peak acceleration.

A second reason was that when piping systems tested with snubbers are replaced by Limit Stops in a one-for-one fashion, the responses of the piping systems are remarkably similar. These results have been extensively documented, perhaps most accessibly in the October 1989 issue of "Mechanical Engineering." Figures 3.24, 3.25, 3.26 show this similarity. These graphs contain results from the NRC sponsored HDR research program (Reference 16) where a full size 6" to 10" diameter piping system was tested with snubbers; and then tested with Limit Stops on a one-to-one replacement. Comparisons are presented at five key locations on the system between the snubber-Limit Stop responses, and between the test results and calculated predictions.

The logic is that if the response of the piping is comparable for snubbers and Limit Stops and if the additional Code Case N-411 margin is available for the Limit Stop configuration in a one-for-one replacement, then allowable stresses for the replacement case should continue to be satisfactory. Further, no reanalysis should be required because the margins should be more generous than the existing design of record. A program was designed by Duke Power and RLCA to validate and implement this concept.

4.2.1 DUKE POWER MCGUIRE PROGRAM - NO ANALYSIS, N-411 DAMPING IMPLICIT

The broad objectives of the overall Duke program at McGuire Nuclear Station are:

- Demonstrate that one-to-one replacement can be implemented without reanalysis
- Replace all snubbers at McGuire 1 & 2 with Limit Stop pipe supports on a one-to-one replacement basis
- Establish exclusions, if any, to the one-to-one replacement approach
- Provide hardware performance and reliability data by in-plant installation and inspection
- Define the regulatory procedures for replacing all snubbers with Limit Stop pipe supports

The first objective was accomplished by performing in depth re-analysis of a representative sample of McGuire piping systems. The two key analyses ·

- Analyzing piping supported by snubbers in the original configuration using the original Reg. Guide 1.61 damping.
- Analyzing the same piping in the original configuration with all snubbers replaced by Limit Stops using Code Case N-411 damping.

Comparing the results obtained from these two analyses permits a direct examination of the validity of the basic concept, that the added conservatism implied in Code Case N-411 damping can accommodate changes in piping responses due to the Limit Stop application. The concept is applicable to all plants where the margins afforded by Code Case N-411 damping are available.

Sample Characteristics

The first step was to select a representative sample of the piping systems. The attributes considered in the sample selection and the final sample are shown in Table 4.8. Four systems were chosen ranging in size from 3/4" to 24" in diameter, of both stainless and carbon steel, ranging from 160 to 650°F in design temperature, located in different buildings and at different elevations within the buildings. Sufficient additional attributes such as ASME classes, snubber types and locations, and loading characteristics were also considered. A good representation of the piping systems at McGuire was achieved.

Study Results

Analytical models of the four sample systems were prepared with all snubbers replaced by Limit Stops of comparable load capacity. For the analyses with Limit Stops the range of thermal expansion at each Limit Stop support becomes an item of input, otherwise the input is the same as that of any other piping analysis.

Normally the analysis results are compared to ASME allowable stresses, allowable valve accelerations, etc. However for the present case only the relative results for the two support designs are of interest. Therefore, for simplicity, stress intensification factors from the ASME code were omitted from consideration.

Pipe stress, support loads, and pipe accelerations are shown for the snubber and Limit Stops in Figures 4.4 to 4.6 for the case of the Refueling Water System. The results are remarkably similar for the other cases, as illustrated by Figure 4.7 which shows comparative pipe stresses for the auxiliary feedwater system problem. The pipe stress is a key parameter because excessive pipe stress would lead to a loss of piping integrity. As these results show, when the margin from the Code Case N-411 damping is factored in for the configurations supported by Limit Stops, essentially all computed response values are lower than the "design of record" values with snubbers and Reg. Guide 1.61 damping.

At the outset of this work it was expected that there could be some configurations for which the reasoning presented earlier would require modification. The results confirmed this. It was found that retention of snubbers when they are mounted on heavy valve motor operators in smaller diameter lines and, when mounted in close proximity to equipment nozzles that experience substantial thermal motion will add design margin and simplify equipment qualification. In both these cases the original design was oriented toward the particular features of snubbers. Snubbers will be removed for such configurations only after qualification by analysis. Relatively few snubbers are affected by these considerations.

Licensing Considerations

The one-for-one replacement of snubbers with Limit Stops at McGuire does not give rise to an unreviewed safety question.

- The Limit Stops themselves satisfy ASME NF requirements

- Limit Stops have a 20% greater capacity size-for-size

- McGuire qualifies as a plant for which N-411 damping can be used

- The one-for-one snubber/Limit Stop exchange generally produces lower calculated stresses and loads as shown on representative piping systems

- The snubber/Limit Stop exchange maintains redundancy in the number of pipe supports

- Test programs on full size piping have shown Limit Stops develop stresses and loads comparable to or better than that of snubbers

- Limit Stops being simpler passive devices are intrinsically more reliable

- The Technical Specifications for the plant do not require modification

Since the Technical Specifications do not require changes, and no unreviewed safety questions are introduced, the one-for-one exchange can be done under the rules of 10 CFR 50.59. This is the basic philosophy adopted by Duke Power Company following the completion of the analyses on the representative sample. An ancillary question arises regarding the types of inspection appropriate for the Limit Stops. In answering this question, it can be noted that:

- Limit Stops are passive - there are no mechanisms that are required to be operable

- Limit Stops are constructed of austenitic stainless steel

- Limit Stops are constructed with liberal clearances

- Limit Stops have a generous viewing port that permits easy visual inspection of internal parts analogous to the construction of spring hangers.

For the above reasons, it is recognized that the appropriate means for assurance of functionality of Limit Stops would be the same as presently used for spring hangers, periodic visual inspections as outlined in the industry requirements for In Service Inspection (ISI) programs in Section XI of the ASME Code.

Cost Benefits at McGuire

All decisions of significant financial impact at nuclear power plants require a quantitative cost benefit analysis. McGuire Engineering performed a cost-benefit analysis on the snubber elimination program. The outlines of this analysis are discussed in the following paragraphs.

Cost benefits were determined on the basis of a specific replacement schedule and conservative assumptions regarding the cost and value of other program parameters.

- There are approximately 3000 snubbers in the two McGuire plants. It is planned to replace 90% of these snubbers.

- Benefits are "avoided costs." Benefits represent the opportunity to redirect resources and/or spending.

- The operating and maintenance cost per snubber per year is the critical parameter in the cost benefit study. EPRI did an exhaustive study of these costs country wide and concluded that the industry average was \$1900/snubber/year.[7] This was in 1986 dollars and on average, it may be safely presumed that these costs have since increased. Other utilities have experienced maintenance costs as high as \$6000/snubber/year. Duke Power Company has developed a unique and rigorous program for snubber maintenance and rebuilding. A conservative \$1200/snubber/year was used in the cost benefit analysis by McGuire.

- A second cost parameter used in the analysis is the cost attributed to radiation exposure of plant personnel due to snubbers. A total of 6 REM/year at \$12,500/REM was used in this study. This is conservative because this cost parameter has been increasing steadily in recent years.

- Other assumptions forming the basis for the cost benefit study are:
  - 4.2% inflation rate
  - 9.42% discount rate
  - GAPPIPE license fee
  - Limit Stops hardware costs
  - Installation cost per Limit Stop
  - Radiation waste disposal costs

When the total life cycle cost of Limit Stops is compared to the total life cycle cost of snubbers over the remaining life of the plant using a standard proforma approach, the life cycle cost of Limit Stops is estimated at 3 to 5 times less than the snubber life cycle cost. The result suggests the one-for-one replacement of snubbers with Limit Stops is an attractive program. In present worth dollars (1992 dollars) the Benefit/Cost can be as high as 8.75.

Summary - McGuire

In summary, the results of this technical study show:

- Sufficient margin exists due to ASME Code Case N-411 damping to permit one-for-one replacement of existing snubbers with Limit Stops without re-analysis for the McGuire plant.

- The replacement program at the McGuire plant, when completed, will maintain ALARA, improve reliability and reduce plant operating costs.

Operationally, Limit Stops are considered passive. They have no mechanisms to operate. The design incorporates wide inspection slots and in all other respects is comparable to spring hangers. Functionality can be assured by the same ISI requirements that apply to spring hangers. Therefore, in addition to the significant cost savings, the use of Limit Stops at the McGuire plant will also derive these important benefits:

- Plant reliability will be improved
- Personnel radiation exposure will be diminished
- Resources currently allocated to snubber maintenance and testing can be re-assigned.

4.2.2 WOLF CREEK PROGRAM - NO ANALYSIS N-411 DAMPING IMPLICIT

Following the successful McGuire program, a similar program was undertaken for the Wolf Creek Generating Station. The objectives of the study were the same as that done for McGuire and a similar methodology was followed.

A representative sample of four piping systems was selected for study. The sample encompassed a broad span of piping parameters including size, material, ASME class, operating temperatures, etc. The sample is given in Table 4.9.

The results obtained from the analysis of the Wolf Creek sample were comparable to those obtained at McGuire. The original design configuration based on snubbers and R.G. 1.61 damping was analyzed. Next, the improved configuration with the snubbers and R.G. damping replaced by Limit Stops and N-411 damping was analyzed and the results were compared.

Results of the comparison are given in Figures 4.8 and 4.9 for two of the sample problems. The containment cooling system piping, shown in Figure 4.10, is carbon steel and ranges from 6 to 14 inches in diameter. The CVCS system piping, shown in Figure 4.11, is stainless steel and ranges from 3/4 to 12 inches in diameter. Similar results were obtained for the other two systems. The computer piping response for all parameters is lower for the Limit Stop - N411 cases than for the "design of record."

Exceptions

The need to retain snubbers in certain cases when the systems are not analyzed was identified in the McGuire work. The criteria applicable to such cases were quantified further in the Wolf Creek work. When N-411 damping has not been previously used, snubbers may be replaced by Limit Stops on a one-for-one basis except in the following situations:

- Exclude snubbers which are subjected to total thermal movement of more than 0.5" and are attached to valve operators.
- Exclude snubbers which are the immediate dynamic supports from the equipment nozzles in any transverse direction and are subjected to total thermal movements of larger than 0.5".
- Exclude snubbers that are the only dynamic supports acting to restrain the longitudinal direction of a pipe run between anchors and/or branch connections and are subjected to total thermal movement of larger than 0.5".
- Exclude snubbers in piping systems where they constitute more than 50% of the total number of dynamic supports (the percentage should be calculated after applicable snubbers have been replaced by rigid struts) and where the majority of these snubbers are subjected to total thermal movements of larger than 0.5".

For the cases listed above, the snubbers may be replaced by Limit Stops, when the system is analyzed in the Limit Stop configuration.

Licensing, Cost Benefit, Implementation

The considerations discussed for McGuire regarding licensing and cost benefits are the same or comparable at Wolf Creek. An initial changeout of approximately 50 snubbers for Limit Stops was made at McGuire in the spring of 1993. Implementation of the first systems for Wolf Creek is expected to occur in 1995.

Summary - Wolf Creek

It has been shown on a broad representative sample of piping at Wolf Creek that sufficient margin exists due to N-411 damping to permit one-for-one replacement of snubbers with Limit Stops. The new configuration will have lower computed stresses, loads, and acceleration than the design configuration.

With the new configuration, radiation exposure of personnel will be reduced, creation of low level waste will be reduced, reliability will be increased, and maintenance costs will be reduced.

4.3 GENERAL DISCUSSION

Snubbers are complicated, costly, frequently unreliable, and require expensive maintenance programs. They were used in the design of power piping only occasionally prior to the advent of nuclear power.

Snubbers are now widely used in nuclear plants, not so much for safety or to satisfy regulatory requirements as may have been thought. When acting in an ideal manner, snubbers render the complex motion of piping systems into a linear response. They are, therefore, added by the designer to gain analytical tractability. In other words, by using snubbers, the engineer can analyze the dynamic response of piping with linear methods and linear computer programs. Analytical simplicity is gained at the expense of complex hardware.

Limit Stops work the other way around. The hardware is very simple, but the mathematical description of the motion is complex. Focusing the emphasis on simplicity and reliability of the hardware leads to a more reliable, low maintenance plant. A low maintenance plant is a more cost competitive plant, and a more reliable plant is a safer plant.

Three different approaches toward the application of Limit Stops to nuclear plants to lower maintenance costs have been discussed. At this stage in the development, there are no impediments remaining to the use of Limit Stops. The first group were installed in the spring of 1993 at McGuire with no difficulties whatsoever. At the Byron plant, the Limit Stops were installed also without difficulty in the autumn of 1993, and other installations are in planning.

5.0 CONCLUSIONS

A complete description has been presented of the computer program GAPPIPE. A complete mathematical description as well as a flowchart and description of the logic has been given.

The verification of the program has been summarized. A complete description of the comparison to the NRC benchmark problems that verified the linear features of the code was given. The verification of the non-linear analysis was done by comparison of analysis with full size tests, both on the seismic shake table and in the HDR power plant. The linear piping analysis methods gave excellent agreement with the benchmark problems and the non-linear methods correlated very well with the experimental results.

It is concluded that GAPPIPE is at least as accurate as current piping analysis methods and in many cases is superior. It was on this basis that the NRC approval was granted for the use of GAPPIPE and Limit Stops at Byron. Experience acquired since that time has all been positive, and it is concluded that the Limit Stop technology as described in this report is satisfactory for use in nuclear plants generally.

Four applications of the technology to actual power plants are contained in this report. The application to Millstone 2 was a design effort on the safety injection system. The technology is being implemented at Byron and McGuire, and it will be implemented at Wolf Creek. The installation of Limit Stops was straightforward and trouble free. Experience with the installations has been satisfactory to date.

The qualification of Limit Stops for use in nuclear plants is based on the analytical and experimental test programs on full size piping done to date; the in-depth reviews and verification studies performed by the NRC and Brookhaven National Laboratory; and lastly the successful experience gained to date with actual applications. At the present time, Limit Stops are qualified for applications in nuclear power plants to improve the resistance of the piping and equipment to dynamic loads using the design approaches described in this report.

6.0 REFERENCES

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Table 3.1: Comparison of Maximum Pipe Bending Stresses for the 3-D Hovgaard Bend Tests

Gap Size Condition				Maximum Pipe Bending Stress (ksi)		
GAP 1 (in/in)	GAP 2 (in/in)	Input Level (g ZPA)	Bending Direction	Test Data	ANSYS Results	GAPPIPE Results
open/open	open/open	0.82	z	9.0	12.0	12.3
			y	6.1	7.0	8.0
open/open	0.75/open	1.33	z	13.8	17.4	18.7
			y	8.5	11.2	12.8
open/0.62	0.44/open	0.82	z	9.1	9.5	13.9
			y	5.9	6.2	9.4
open/0.62	0.44/open	1.33	z	11.6	12.9	18.9
			y	7.1	7.1	12.1
open/0.87	0.75/open	1.33	z	13.2	15.2	19.4
			y	8.5	9.3	12.9

Table 3.2: Comparison Summary of GAPPIPE
and Theoretical Results

COMPARISON SUMMARY		
Time, t, (SEC)	Y(t), Tip Displacement (in)	
	GAPPIPE	THEORETICAL
0.04784	-0.396	-0.395
0.09568	-1.150	-1.151
0.17701	0.872	0.868
0.24877	-0.867	-0.871

Table 3.3: Comparison Summary of GAPPIPE
and Moinar Results

COMPARISON SUMMARY		
Gap No.	Maximum Gap Forces	
	Time of Maxima	Value of Maxima
GAPPIPE 1	0.2301	636.1
MOLNAR 1	0.2295	612.6
GAPPIPE 2	0.2839	506.1
MOLNAR 2	0.2836	506.1
GAPPIPE 3	0.2773	678.0
MOLNAR 3	0.2770	664.5

Table 4.1: Optimized Support Configuration

Support Node Number	Support Type		Total Gap Size (in)
	Original	New	
185 X	Snubber	Snubber	----
185 Z	Snubber	Limit Stop	0.563
300 H	Snubber	Limit Stop	0.875
351 X	Snubber	Rigid Strut	----
460 Z	Snubber	Limit Stop	1.250
481 X	Snubber	Limit Stop	0.563
535 X	Snubber	None	----
535 Z	Snubber	Limit Stop	0.750

Table 4.2: Maximum Pipe Stress

Equation 8				
Element	48	49	57	58
Node	385	385	450	450
Allowable (psi)	18400	18400	18400	18400
Stress (psi)	8429	8429	8351	8351
% of Allowable	45.8	45.8	45.4	45.4
Equation 9 Level B				
Element	73	38	73	72
Node	540	330	537	537
Allowable (psi)	22080	22080	22080	22080
Stress (psi)	16474	16162	14302	14302
% of Allowable	74.6	73.2	64.8	64.8
Equation 9 Level D				
Element	73	38	73	72
Node	540	330	537	537
Allowable (psi)	44160	44160	44160	44160
Stress (psi)	25505	24002	21204	210204
% of Allowable	57.8	54.4	48.0	48.0
Equation 10				
Element	13	25	27	25
Node	120	200	220	210
Allowable (psi)	27975	27850	27850	27850
Stress (psi)	36318	24430	23440	23369
% of Allowable	129.8	87.7	84.2	83.9
Equation 11				
Element	13	25	27	25
Node	120	200	220	210
Allowable (psi)	45875	45250	45250	45250
Stress (psi)	38740	31984	31019	30931
% of Allowable	84.4	70.7	68.6	68.4

Table 4.3: Support Load Summary

SUPPORT LOADS (kips)					
Node	Support Type *	Original	New	Change	% Change
65 H	RS	9.6	8.8	-0.8	-9
65 Y	RS	7.2	5.6	-1.6	-23
90 X	RS	6.0	8.0	2.0	32
90 Z	RS	4.1	4.1	0.0	1
100 X	RS	20.4	35.9	15.6	76
100 Z	RS	14.8	26.2	11.4	77
145 H	RS	42.2	64.0	21.8	52
145 Y	RS	48.7	51.6	2.9	6
185 X	SN	34.5	33.1	-1.4	-4
185 Z	SS	39.9	20.1	-19.8	-50
280 Y	RS	32.6	24.4	-8.2	-25
300 H	SS	22.9	13.4	-9.5	-42
315 Y	RS	29.6	18.7	-10.9	-37
351 X	RS	6.3	15.0	8.6	136
385 Y	SP	1.4	1.4	-0.0	-0
430 Y	RS	3.3	2.9	-0.4	-13
430 Z	RS	8.3	4.9	-3.3	-40
450 Y	RS	3.2	3.0	-0.3	-8
460 Z	SS	7.8	11.0	3.2	41
481 X	SS	13.9	6.3	-7.6	-55
495 X	RS	12.3	11.4	-1.0	-8
495 Y	RS	4.2	4.3	0.0	1
535 X	SS	13.9	0.0	-13.9	-100
535 Z	SS	12.6	8.7	-3.9	-31

* Support Type: RS = Rigid Strut
SN = Snubber
SP = Spring
SS = Seismic Stop

Table 4.4: Equipment Nozzle/Anchor Loads

NODE	LOAD TYPE*	ORIGINAL	NEW	CHANGE	% CHANGE
EQUIPMENT NOZZLES					
10 X	F	4.1	3.9	-0.3	-7
10 X	M	371.9	365.8	-6.0	-2
10 Y	F	4.1	4.4	0.3	7
10 Y	M	103.9	89.9	-14.0	-13
10 Z	F	4.5	4.6	0.0	1
10 Z	M	319.2	274.5	-44.7	-14
190 X	F	22.9	27.5	4.6	20
190 X	M	1336.9	1477.9	140.9	11
190 Y	F	28.0	27.8	-0.2	-1
190 Y	M	1794.8	2180.4	385.6	21
190 Z	F	35.3	39.8	4.6	13
190 Z	M	1726.1	1889.9	163.9	9
CONTAINMENT PENETRATION					
330 X	F	8.2	9.1	0.9	11
330 X	M	418.0	294.9	-123.1	-29
330 Y	F	11.2	5.7	-5.5	-49
330 Y	M	308.0	313.7	5.7	2
330 Z	F	3.0	3.0	-0.0	-1
330 Z	M	279.1	261.5	-17.6	-6

* Load Type: F - Force (lbs)
M = Moments (in-lbs)

Table 4.5: Pipe Stresses at Equipment Nozzles

	CODE EQUATION NUMBER				
	8	9B	9D	10	11
NODE 10					
Allowable (psi)	17900	21480	42960	27975	45825
Stress (psi)	3251	5850	8449	7961	11212
% of Allowable	18.2	27.2	19.7	28.5	24.5
NODE 190					
Allowable (psi)	17400	20880	41760	27850	45250
Stress (psi)	7555	10064	12573	19319	26874
% of Allowable	43.4	48.2	30.1	69.4	59.4

Table 4.6: Maximum ASME Class 1 Pipe Stresses

ASME Class 1 Code Equation	9 Design	9 Level B	9 Level D	10	12	13	Cumulative Usage Factor
Node	77	77	77	181	207	77	116
Max. Computed Stress (psi)	11085.	15660.	42316.	44358.	18819.	39446	0.101
Allowable Stress (psi)	24300.	26850.	48600.	48600.	48600.	48600	1.0
% of Allowable	0.46	0.58	0.87	0.91	0.39	0.81	

Table 4.7: Maximum ASME Class 2 Pipe Stresses

ASME Class 2 Code Equation	8	9/Level B	9/Level D	10	11
Node	2	2	68	2	2
Max. Computed Stress (psi)	12936.	17049.	34485.	22941.	35877.
Allowable Stress (psi)	15900	19080.	38160.	27475.	43375.
% of Allowable	0.81	0.89	0.90	0.83	0.83

Table 4.8: Pipe Support Design Loads

NODE	SUPPORT TYPE		EXISTING DESIGN LOADS (lbs)			REVISED DESIGN LOADS (lbs)			RATIO (REV/EXIST)		
	EXIST	REV	N	U	F	N	U	F	N	U	F
189	SN	NONE	0	98	592						
171	RS	RS	80	128	292	48	96	343	0.6	0.8	1.2
170	SN	LS	0	81	246	0	306	465	NA	3.8	1.9
165	SN	NONE	0	240	699						
162	RS	RS	73	91	200	58	81	300	0.8	0.9	1.5
157	SN	LS	0	32	141	0	94	272	NA	2.9	1.9
151	SN	LS	0	30	120	0	49	136	NA	1.6	1.1
147	SN	LS	0	70	270	0	98	253	NA	1.4	0.9
117	RS	RS	311	448	1283	252	392	1414	0.8	0.9	1.1
102	RS	RS	144	197	880	147	239	1657	1.0	1.2	1.9
103	SN	NONE	0	69	747						
98	SN	LS	0	137	561	0	443	653	NA	3.2	1.2
89	SN	NONE	0	259	1146						
57	SN	NONE	0	93	299						
55	SN	LS	0	27	121	0	191	458	NA	7.1	3.8
49	RS	RS	61	96	265	61	107	721	1.0	1.1	2.7
44	SN	LS	0	70	194	0	201	441	NA	2.9	2.3
39	SN	LS	0	82	265	0	243	573	NA	3.0	2.2

SN = Snubber RS = Rigid-acting Support LS = Limit Stop

N = Normal Condition U = Upset Condition F = Faulted Condition

Table 4.9: Characteristics of Sample Piping Systems

Sample Piping	Pipe Class	Pipe Size	Pipe Matl.	Bldg.	Problem Size No. of Snubbers	No. of Nodes	1st Mode Freq. (cps)	Temp. Ranges °F
P027BY	2	2	CS	AUX	5 (X 4)	50 (X 4)	13.3	544, 576
P029B3	2	.75, 1, 2, 3	SS	AUX	14	196	7.7	380
P093A	2	6, 8, 10, 14	CS	R.B.*	8	101	8.1	32, 265
P148	2	.75, 1, 2, 3, 4, 10, 12	SS	R.B.*	23	305	4.8	70-350, 70-560

* Reactor Building

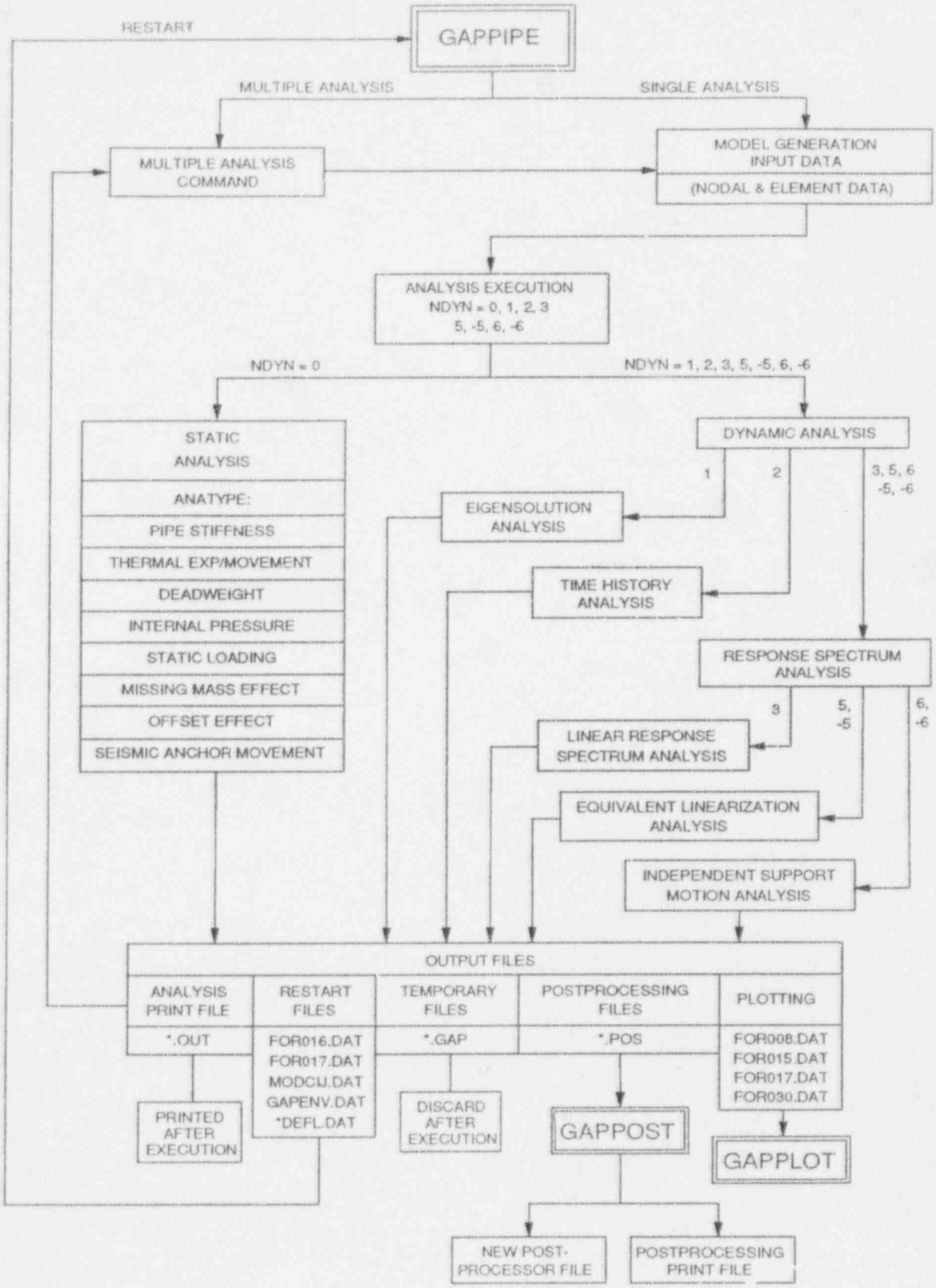

Figure 2.1: Flow Chart of GAPPIPE Program

```
ANALYSIS CONTROL CARD                   |
    TEMPERATURE CARDS                   |repeat as necessary
    ANCHOR MOVEMENT CARDS               |
ENDX
HEADING CARDS
MASTER CONTROL CARD
NODE POINT DATA CARDS
ENDNC
GRAVITY CONSTANT CARD
(TRUSS ELEMENT CARDS if needed)
(BEAM ELEMENT CARDS if needed)
BOUNDARY CONTROL CARD
    BOUNDARY LOAD FACTOR CARD
    BOUNDARY ELEMENT DEFINITION CARDS
PIPE CONTROL CARD
    PIPE MATERIAL PROPERTY ID CARD              |repeat as
        PIPE MATERIAL PROPERTY CARDS            |necessary
    PIPE SECTION PROPERTY CARDS
    (PIPE BRANCH POINT CARDS if needed)
    PIPE LOAD FACTOR CARDS
    PIPE ELEMENT DEFINITION CARDS
        (& PIPE ELBOW DATA CARDS)
CONCENTRATED LOAD/MASS CARDS
ENDCL
SEISMIC ANCHOR MOVEMENT CARDS      |if
ENDSA                              |needed
SYSTEM LOAD CASE CARDS (for static analyses only)
ENDSL
EIGENSOLUTION CONTROL CARD
(TIME HISTORY ANALYSIS CARDS if needed)
RESPONSE SPECTRUM CONTROL CARD
ISM GROUP ASSIGNMENT CARDS
SPECTRUM ASSIGNMENT CARDS
SPECTRUM HEADING CARD                           |repeat
SPECTRUM CONTROL CARD                           |as
    SPECTRUM DATA CARDS                         |necessary
LINEARIZATION ITERATION CONTROL CARD
PRIMARY GAPPED SUPPORT DATA CARD                |repeat as
SECONDARY GAPPED SUPPORT DATA CARD              |necessary
ENDGS
0
```

Figure 2.2: GAPPIPE Input File Structure

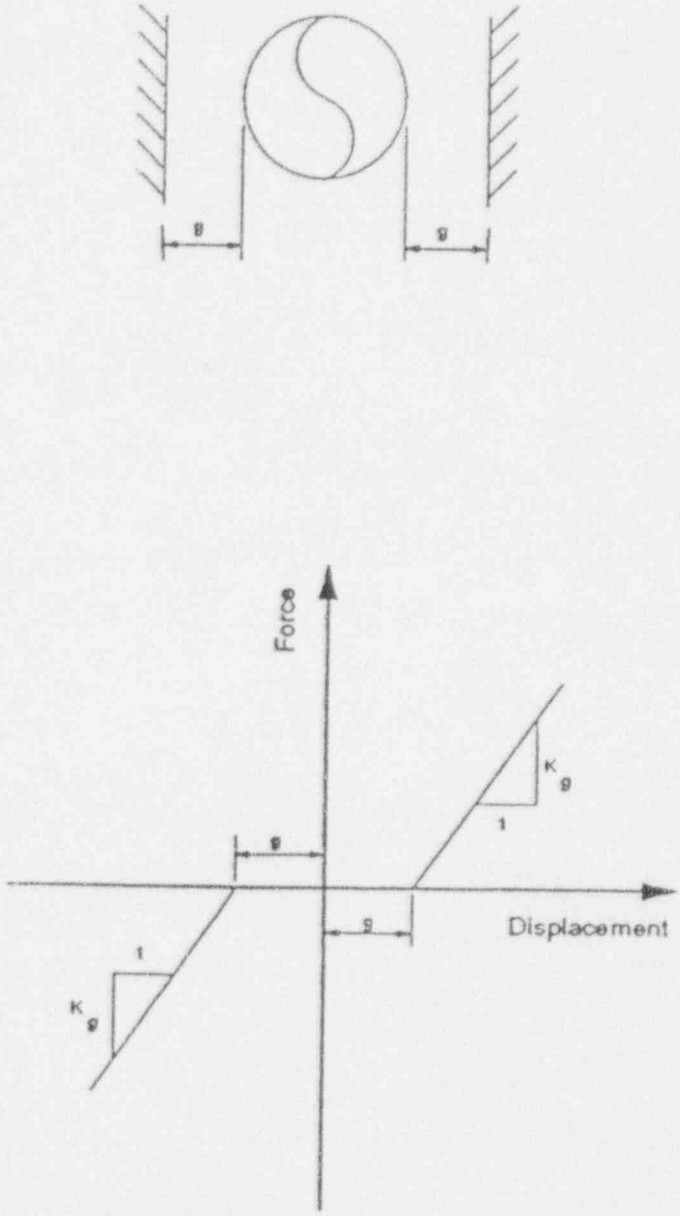

Figure 2.3: Force-Displacement Relationship of a Symmetric Gap Support

NOTICE:

INFORMATION IN THIS SECTION
IS PROPRIETARY TO RLCA AND
HAS BEEN DELETED FROM THIS COPY
OF THE DOCUMENT

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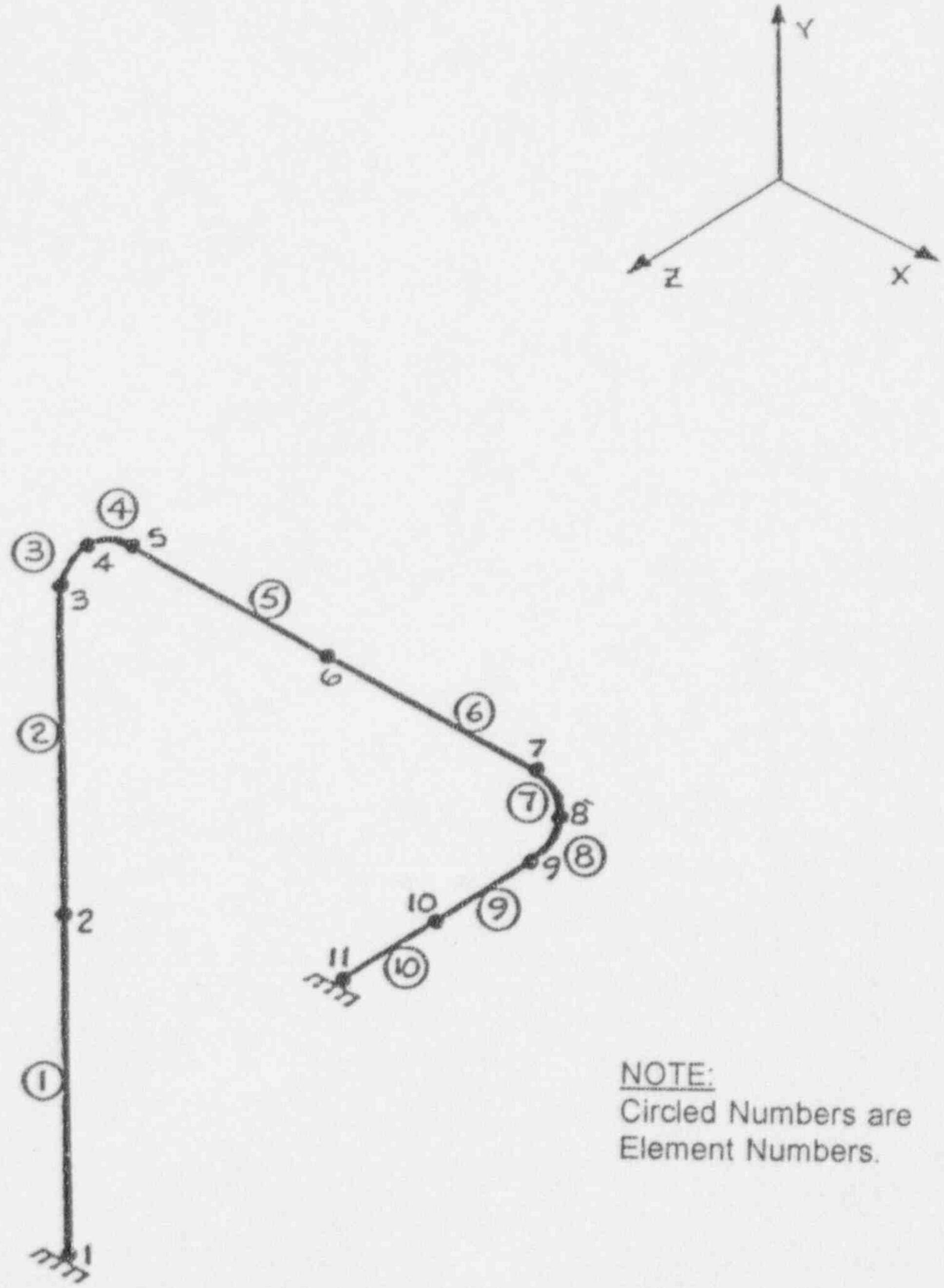
OF THE DOCUMENT



NOTE:
Circled Numbers are
Element Numbers.

Figure 3.1: UNI-Benchmark Problem No. 1

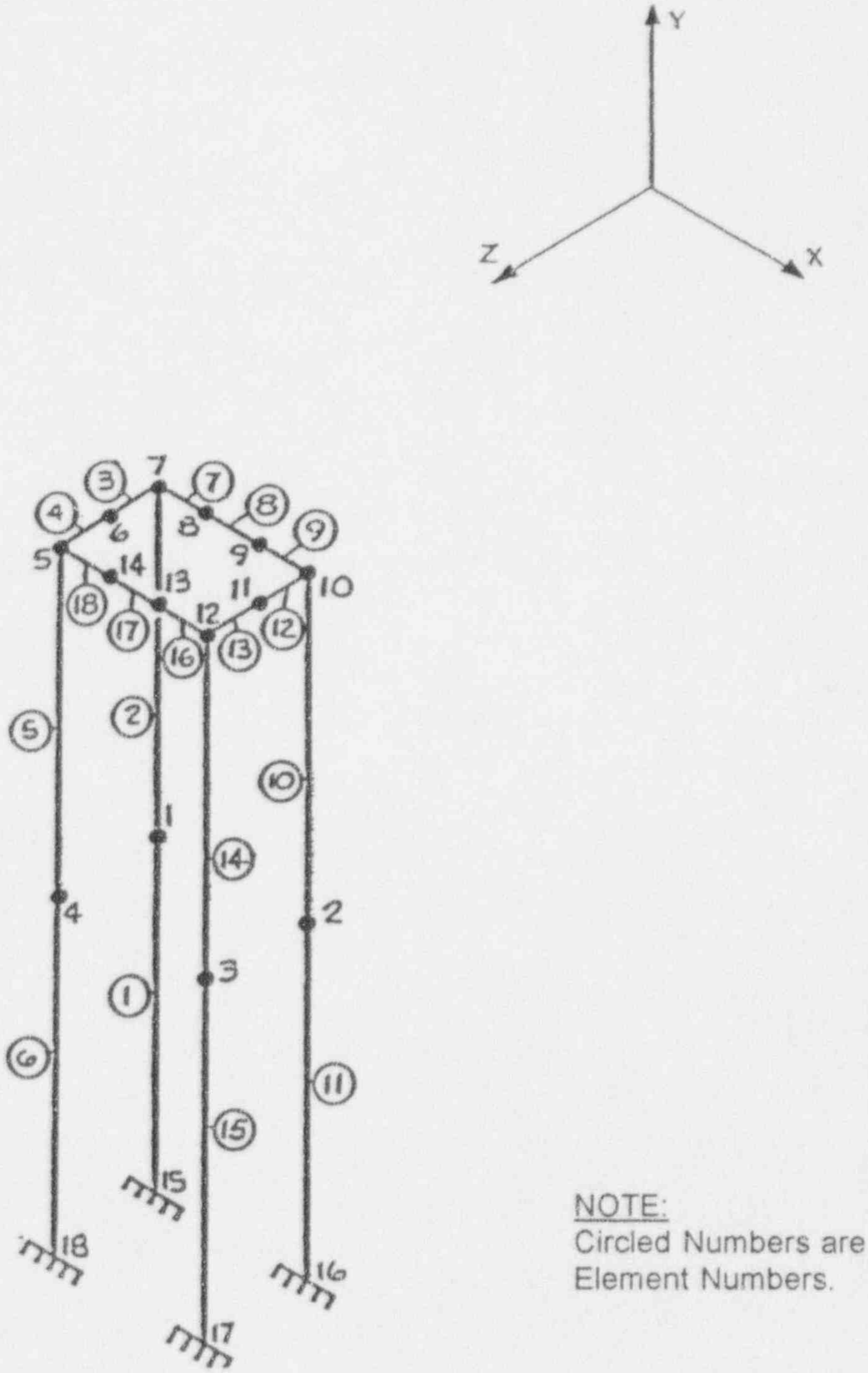


Figure 3.2: UNI-Benchmark Problem No. 2

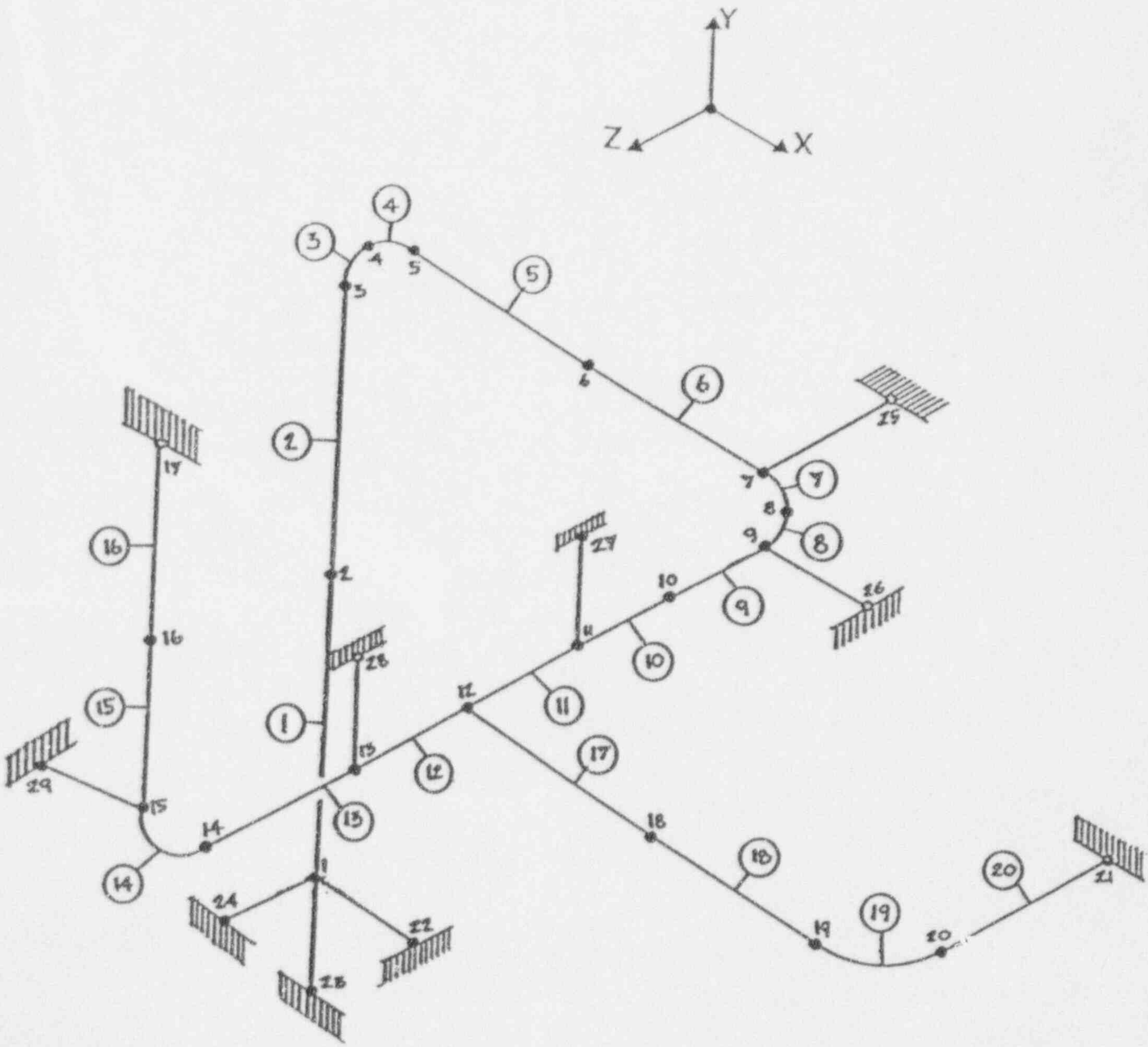


Figure 3.3: UNI-Benchmark Problem No. 3

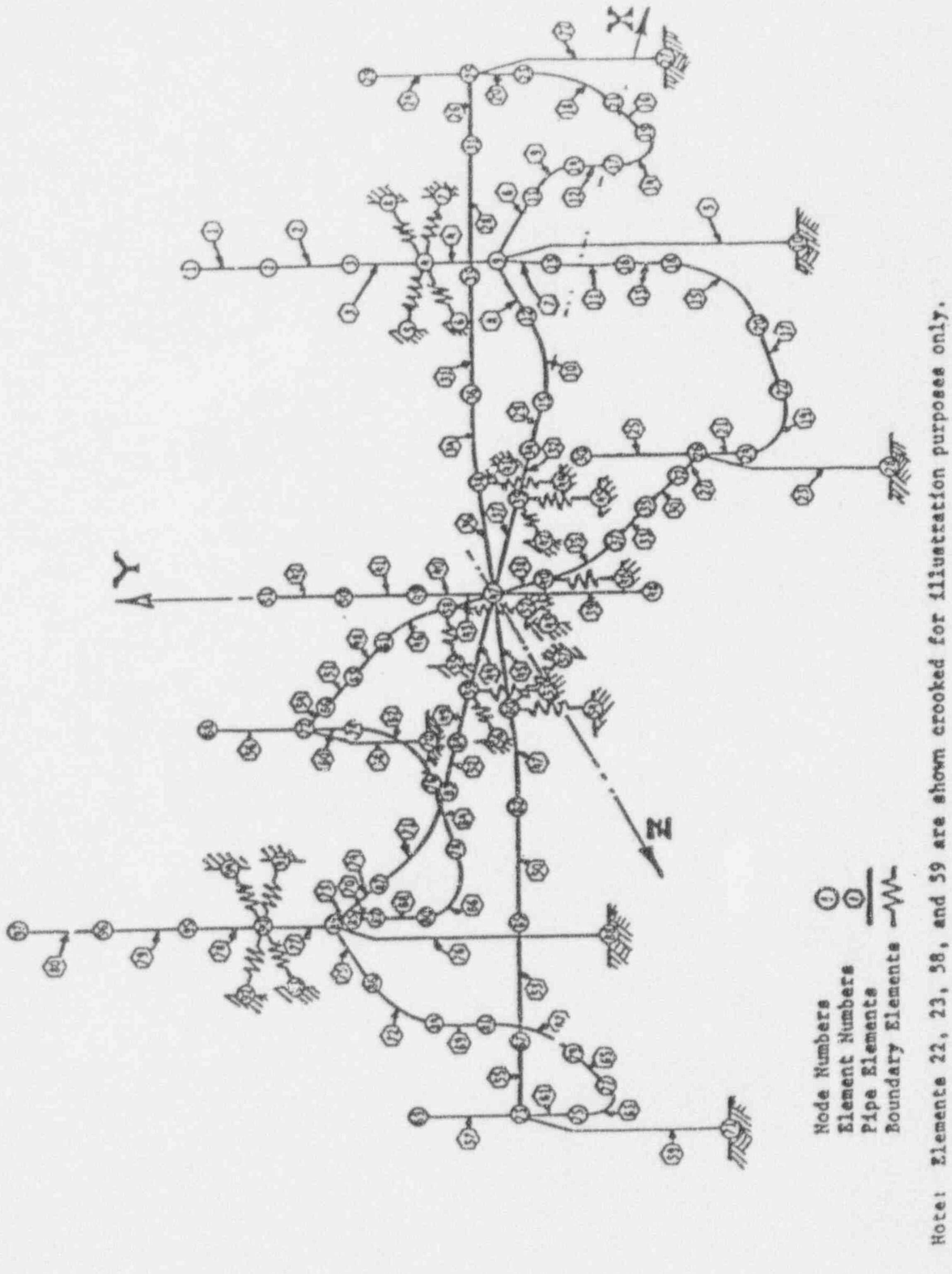


Figure 3.4: UNI-Benchmark Problem No. 4

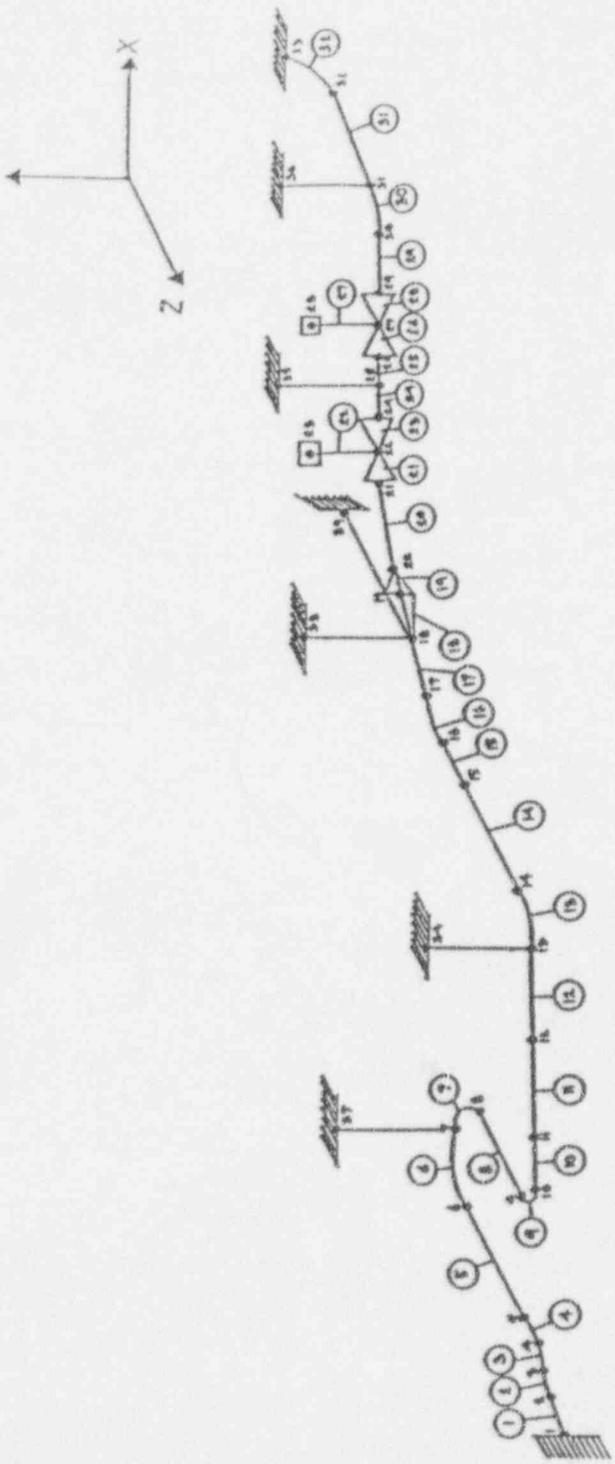


Figure 3.5: UNI-Benchmark Problem No. 5

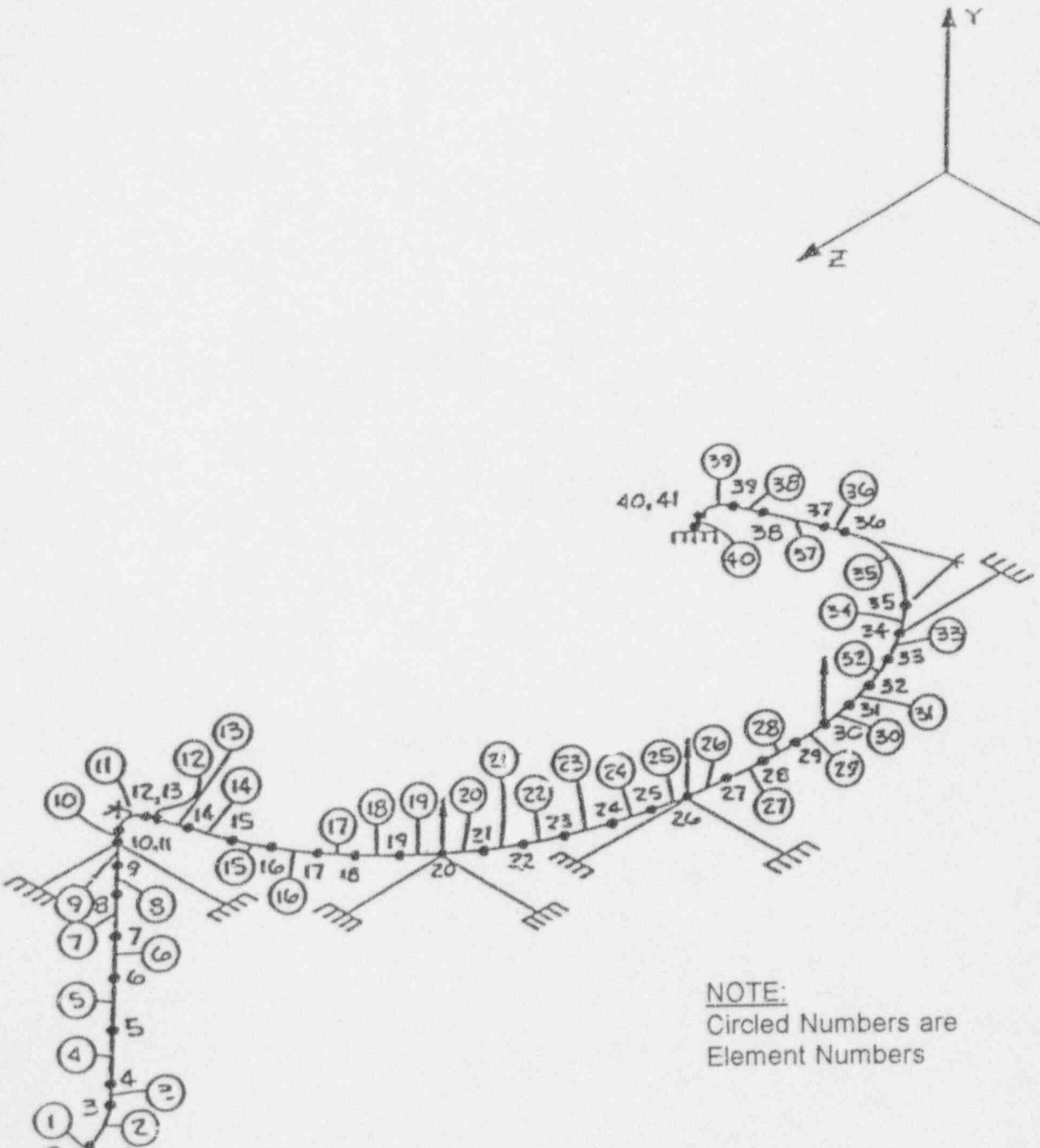


Figure 3.6: UNI-Benchmark Problem No. 6

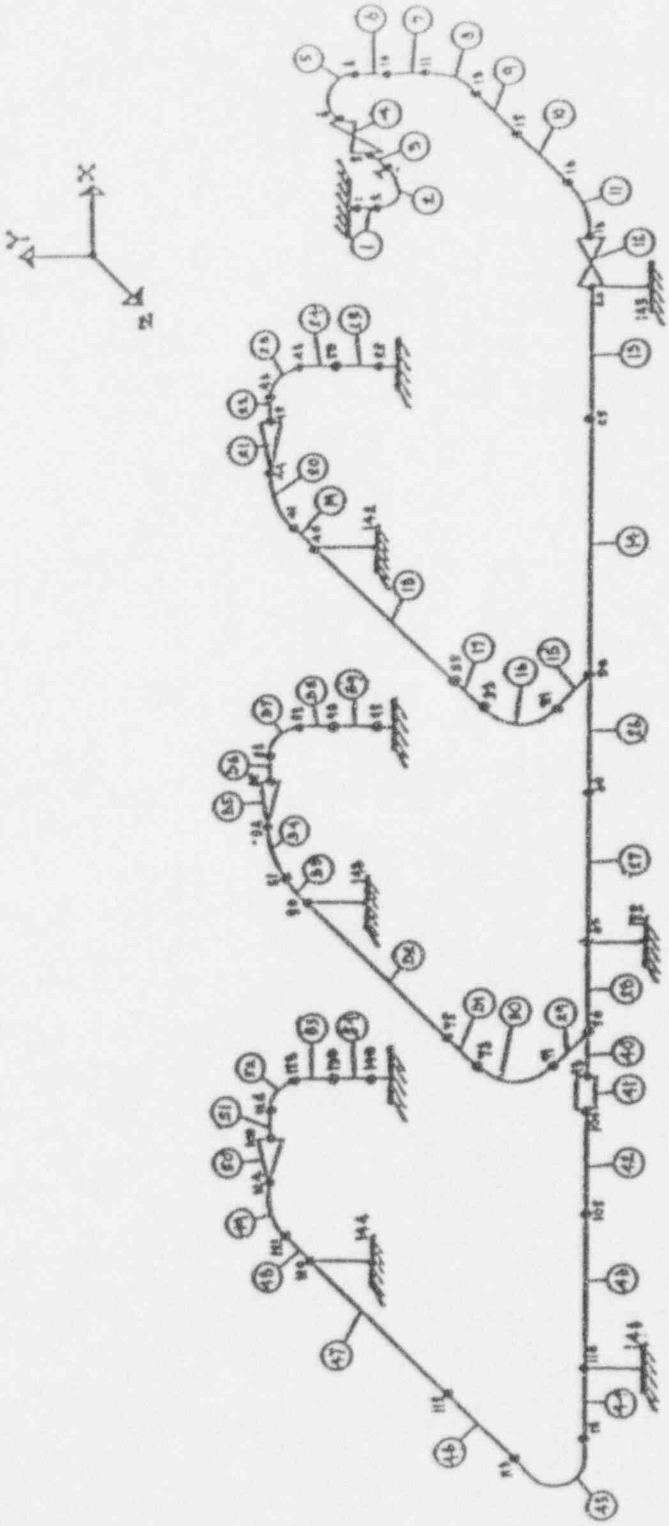


Figure 3.7: UNI-Benchmark Problem No. 7

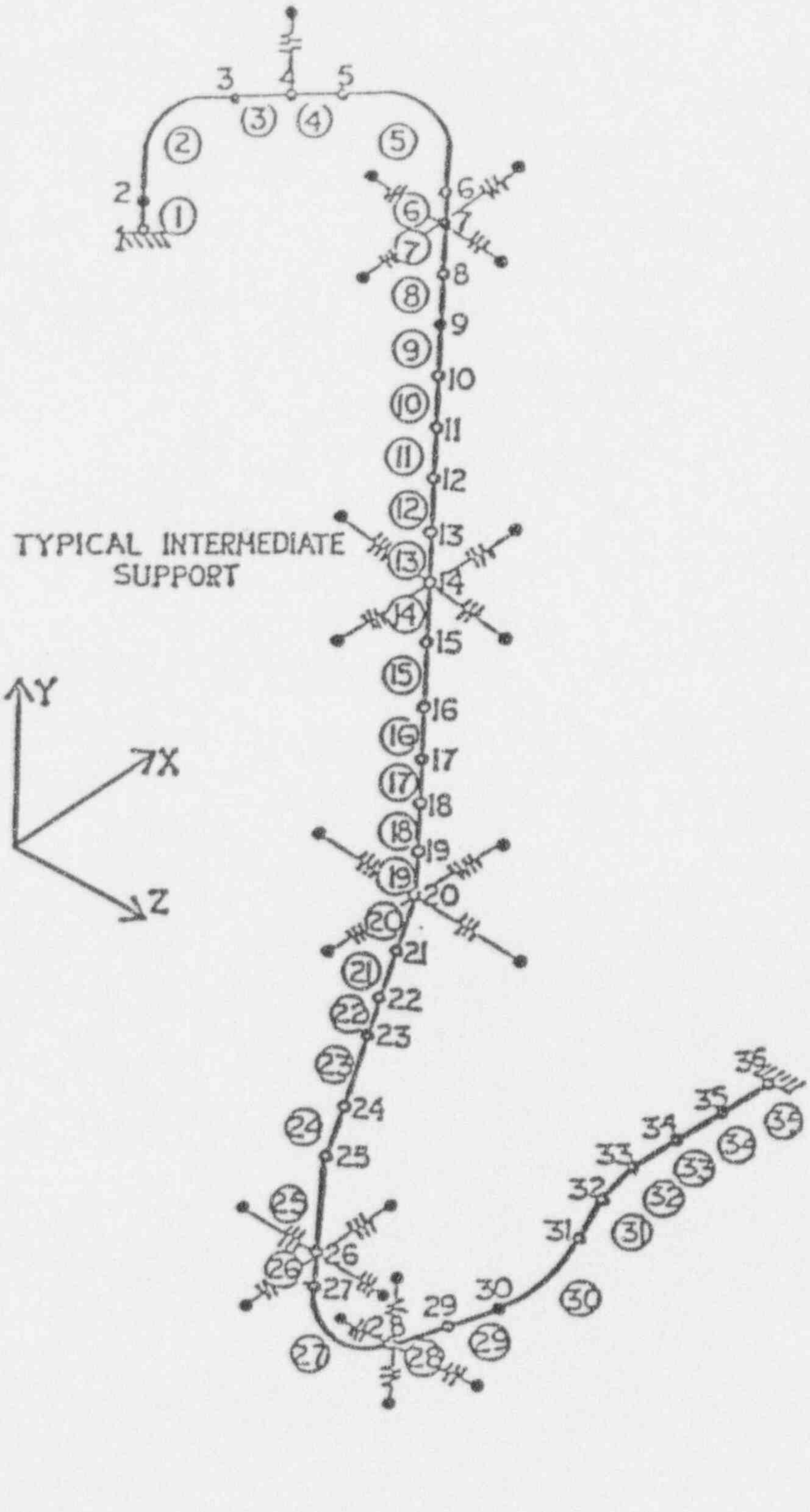


Figure 3.8: ISM-Benchmark Problem No. 1

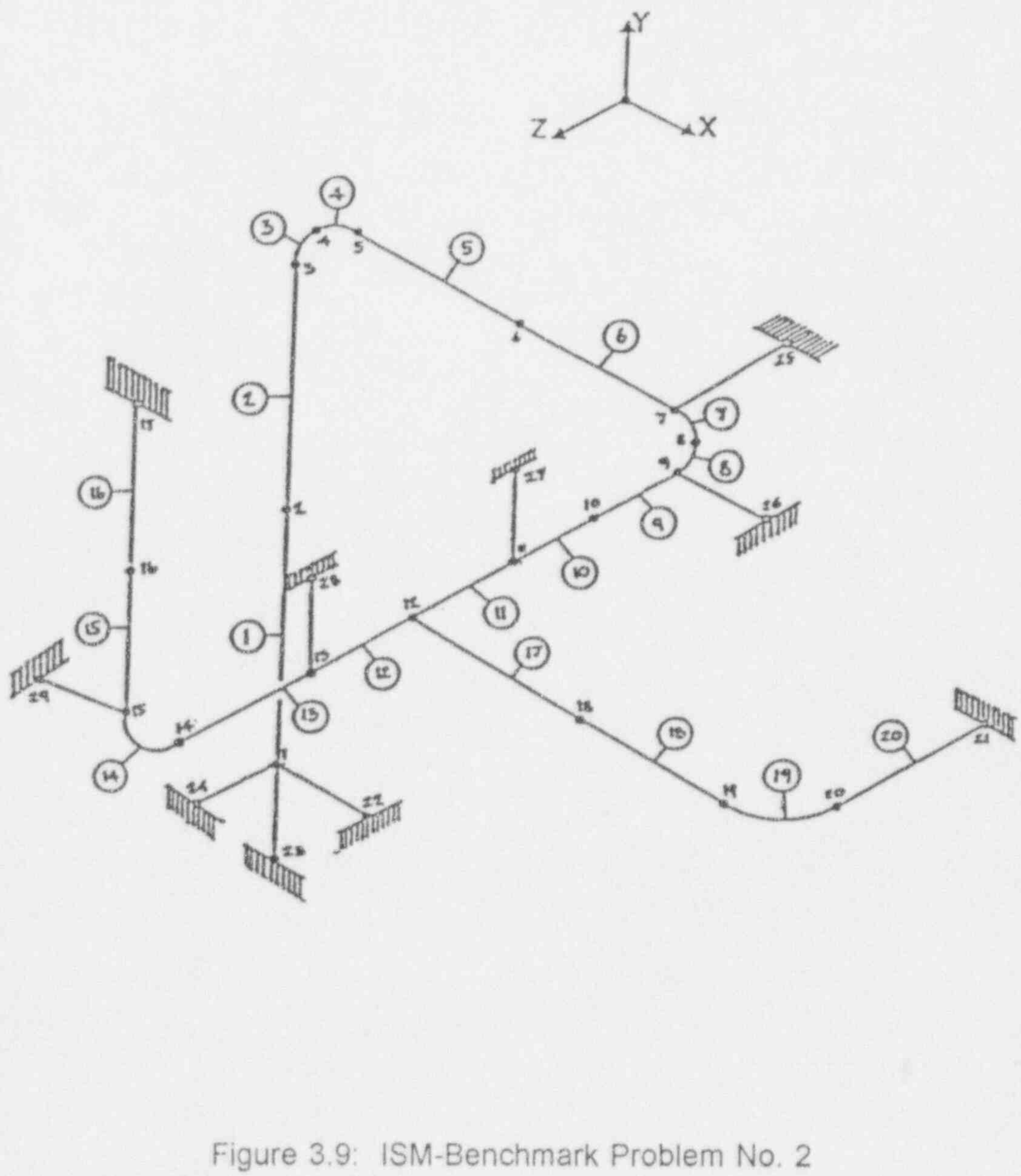


Figure 3.9: ISM-Benchmark Problem No. 2

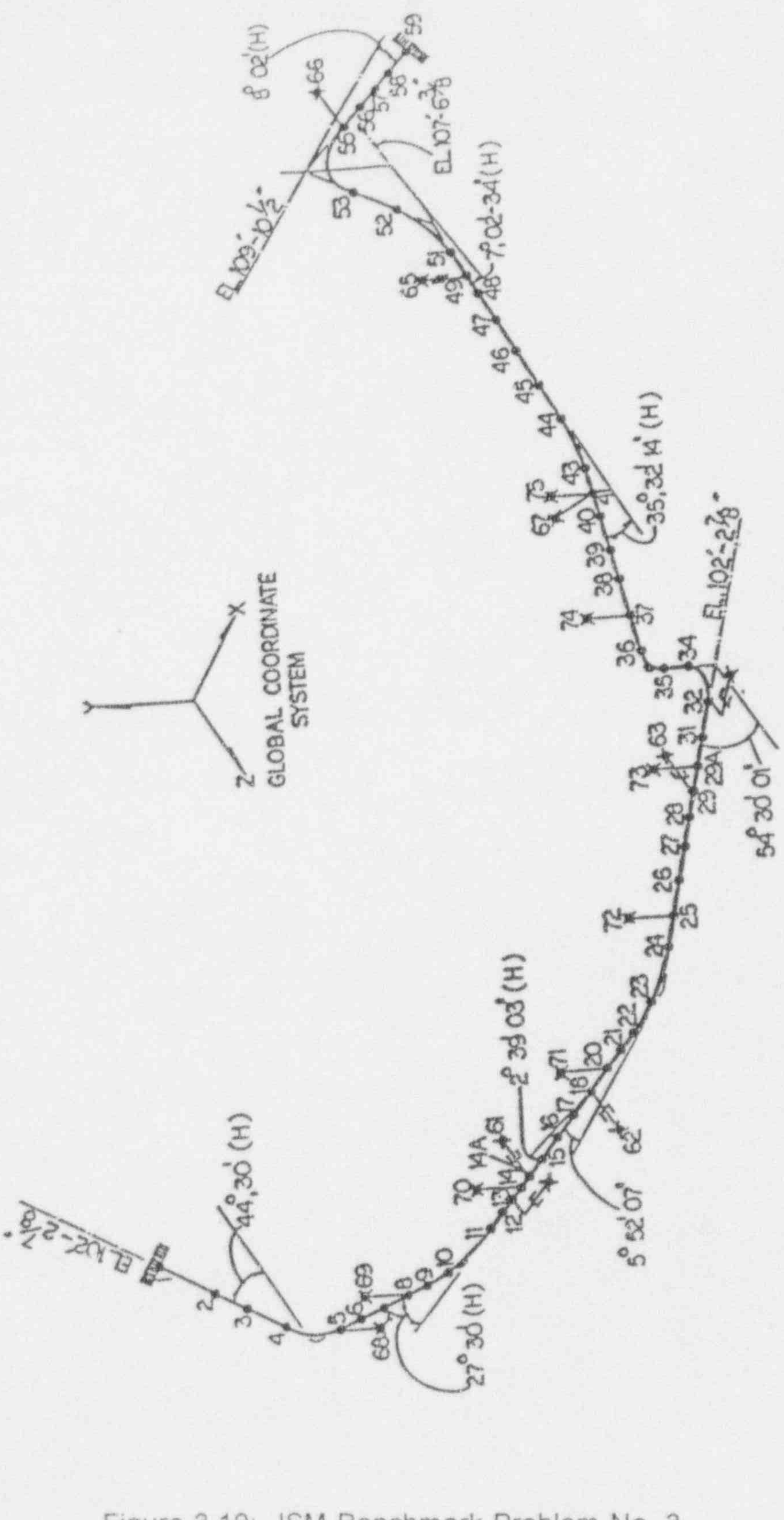


Figure 3.10: ISM-Benchmark Problem No. 3

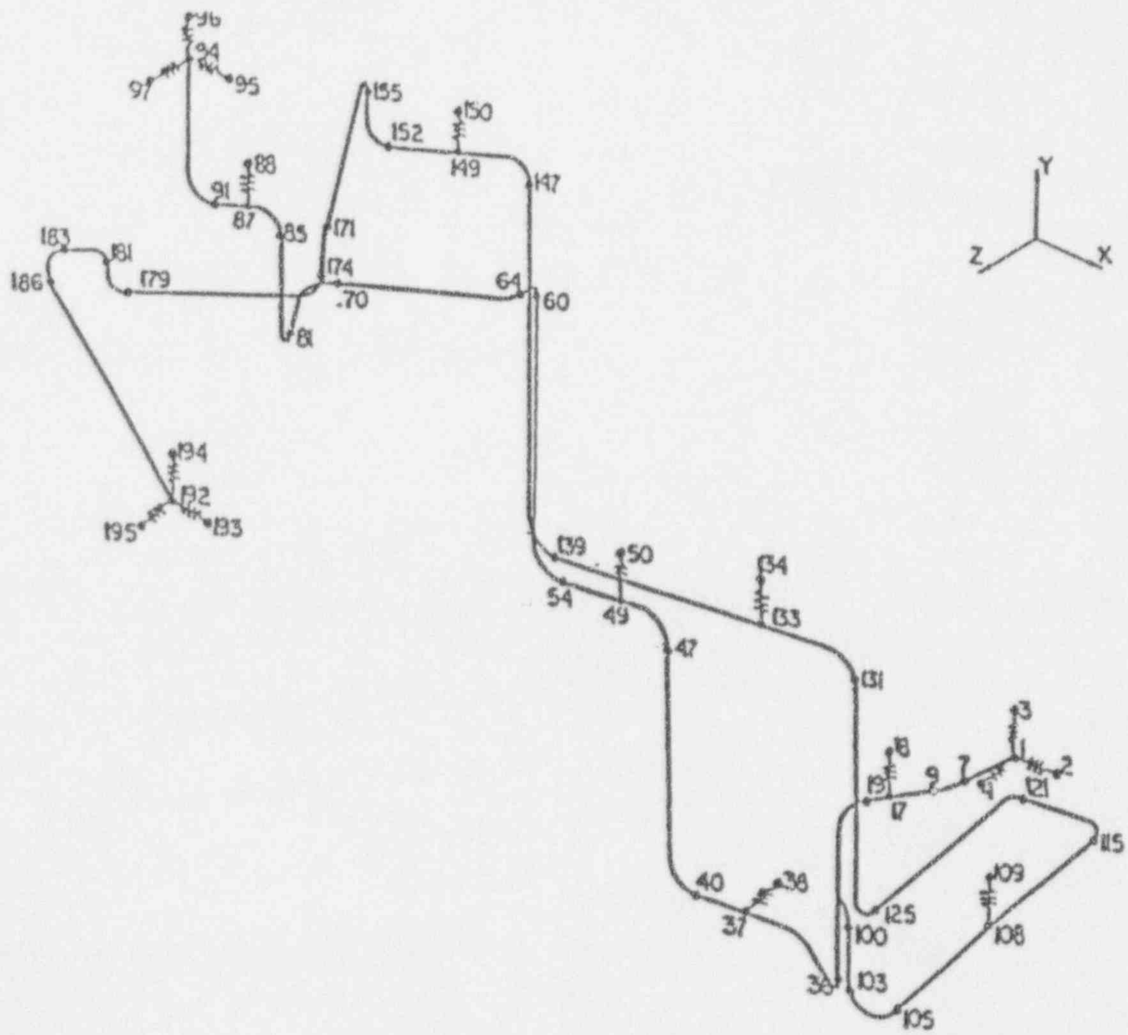


Figure 3.11: ISM-Benchmark Problem No. 4

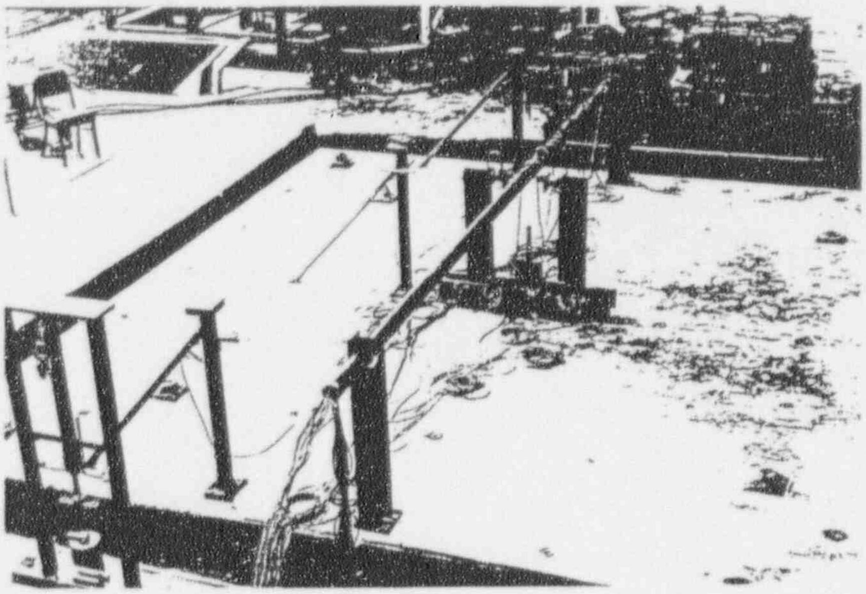


Figure 3.12: Photograph of Single Span Test

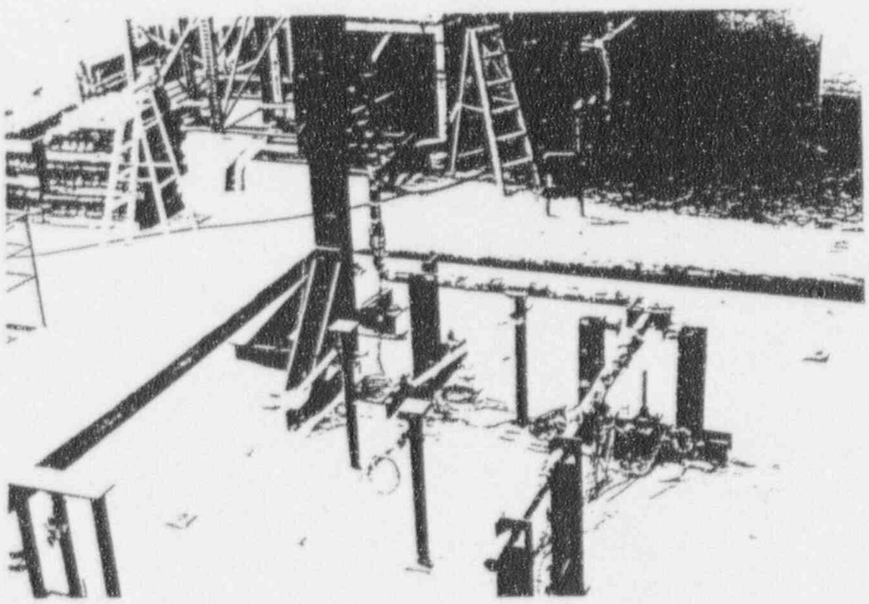
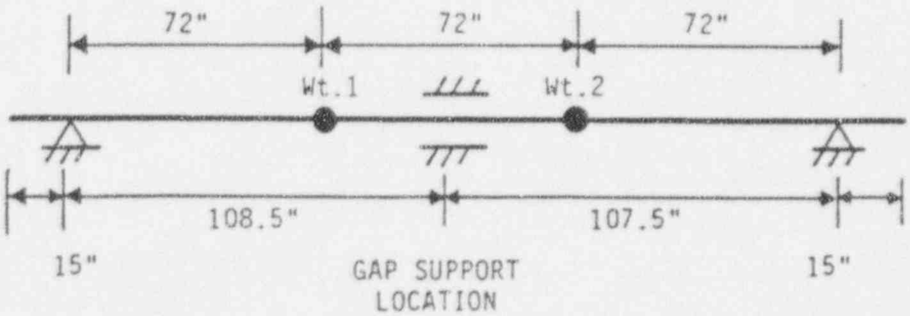


Figure 3.13: Photograph of 3-D Hovgaard Bend Test



SINGLE SPAN DYNAMIC TESTS

TEST SPECIMEN	PIPE DIAMETER	PIPE SCHEDULE
1	3"	80

NOTE:
Supplemental 30 lb. lead weights designated at Wt. 1 and Wt. 2 were included in test specimen 1 (3" SCH 80) only.

Figure 3.14: Single Span Dynamic Test Configuration

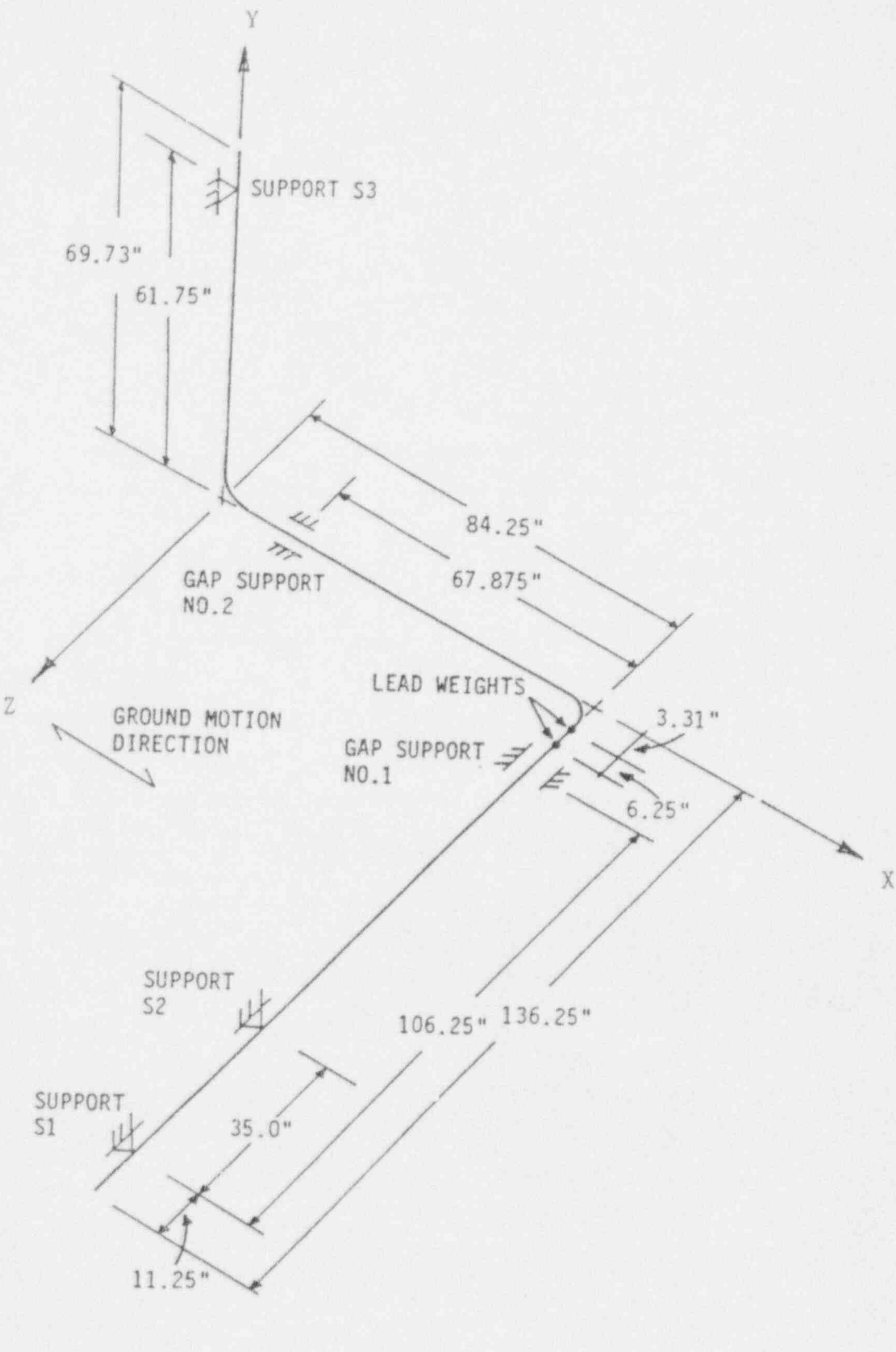


Figure 3.15: 3-D Hovgaard Bend Test Configuration

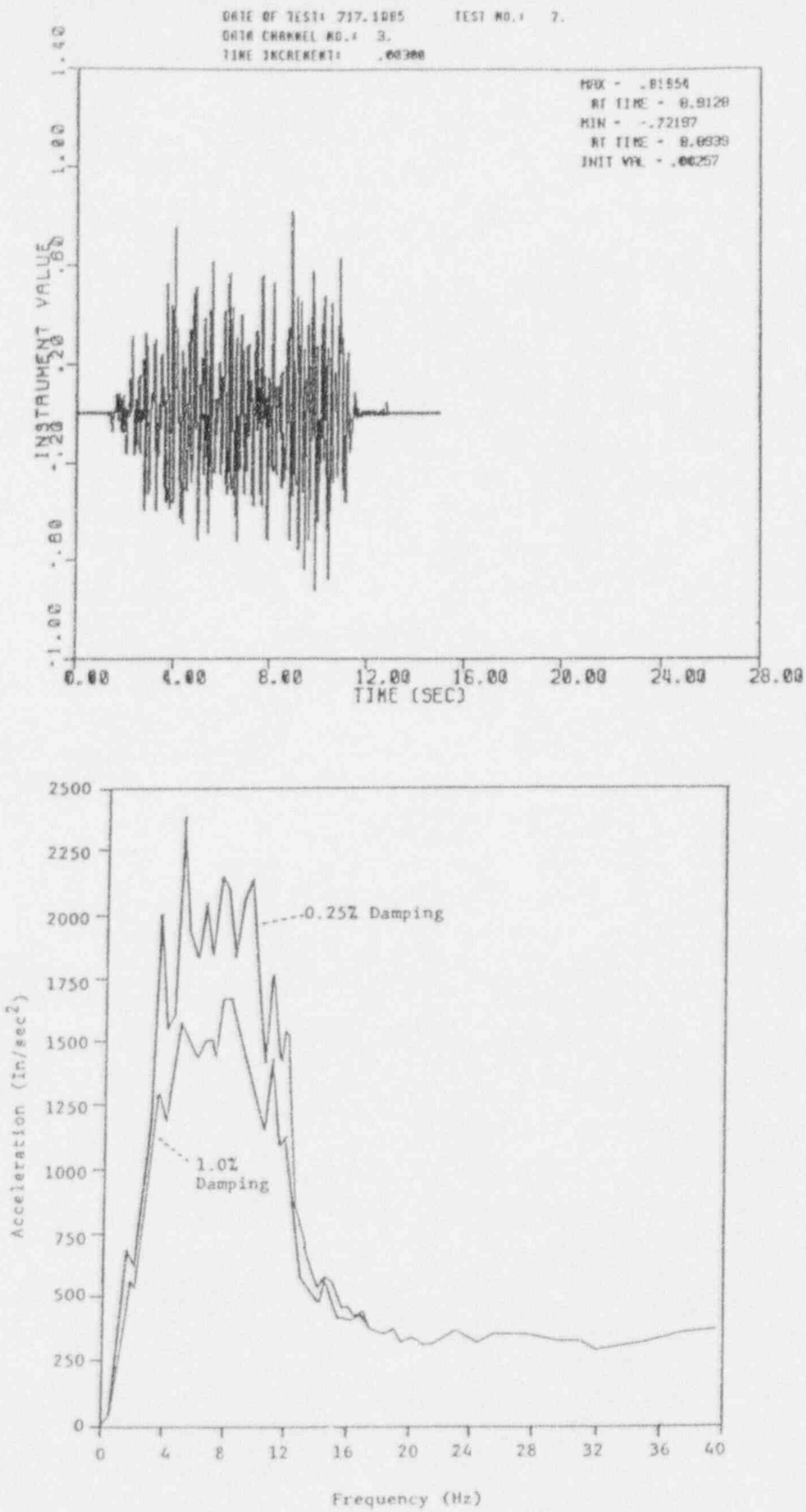


Figure 3.16: Time History and Response Spectra Plots of 0.82 G ZPA Input

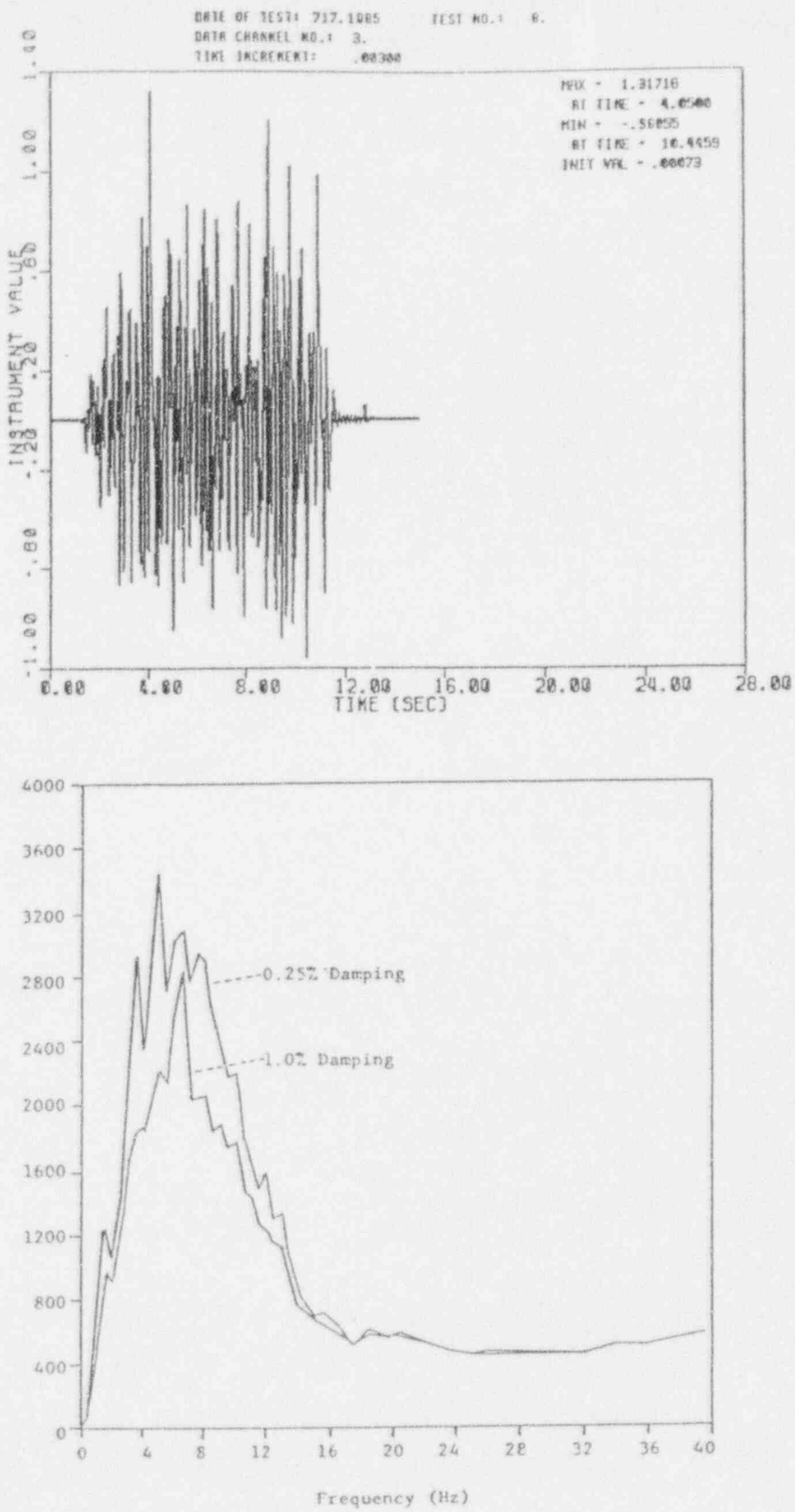


Figure 3.17: Time History and Response Spectra Plots of 1.33 G ZPA Input

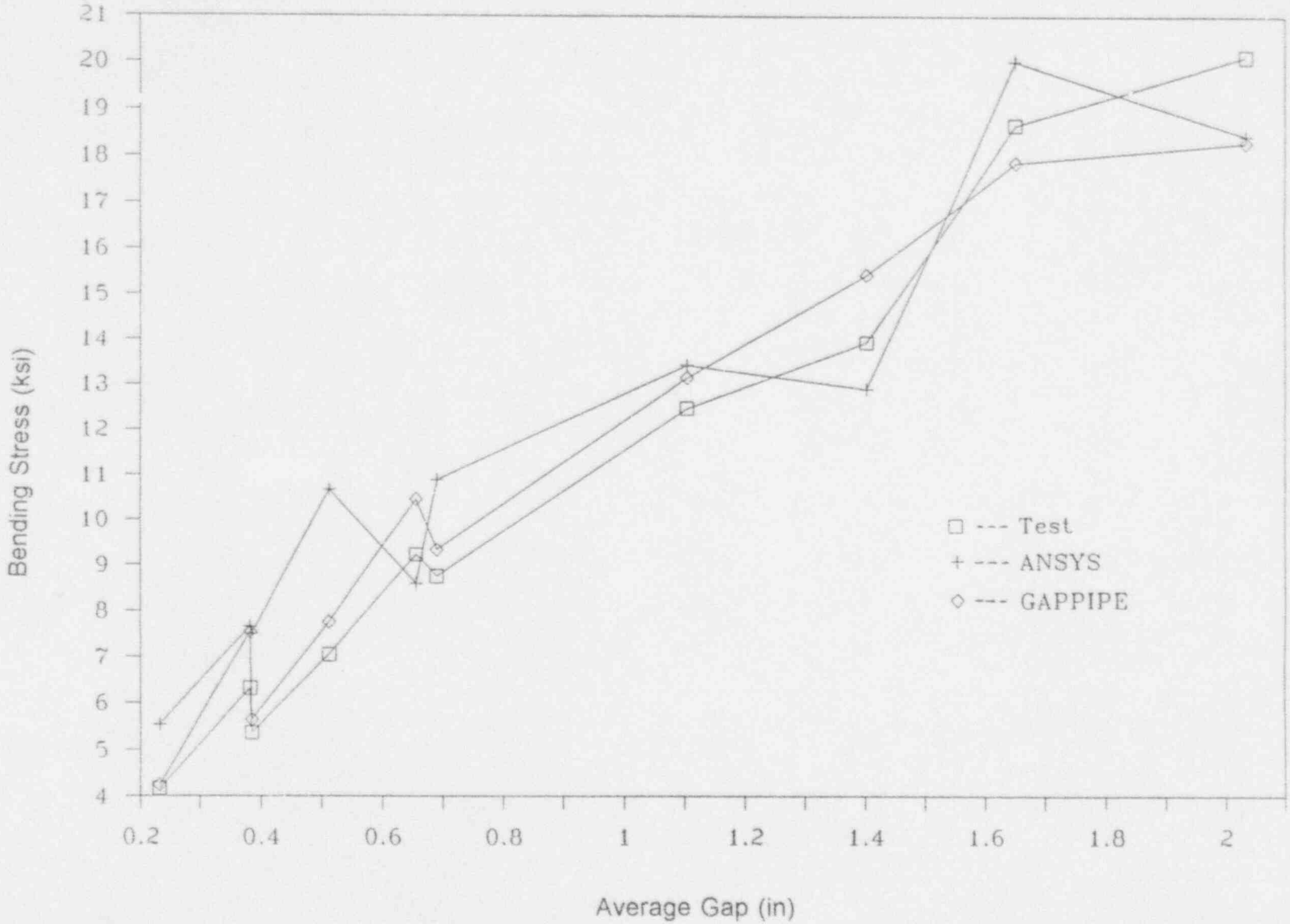


Figure 3.18: Comparison of Pipe Bending Stress @ 1/3 Location Input Level = 0.82 G ZPA

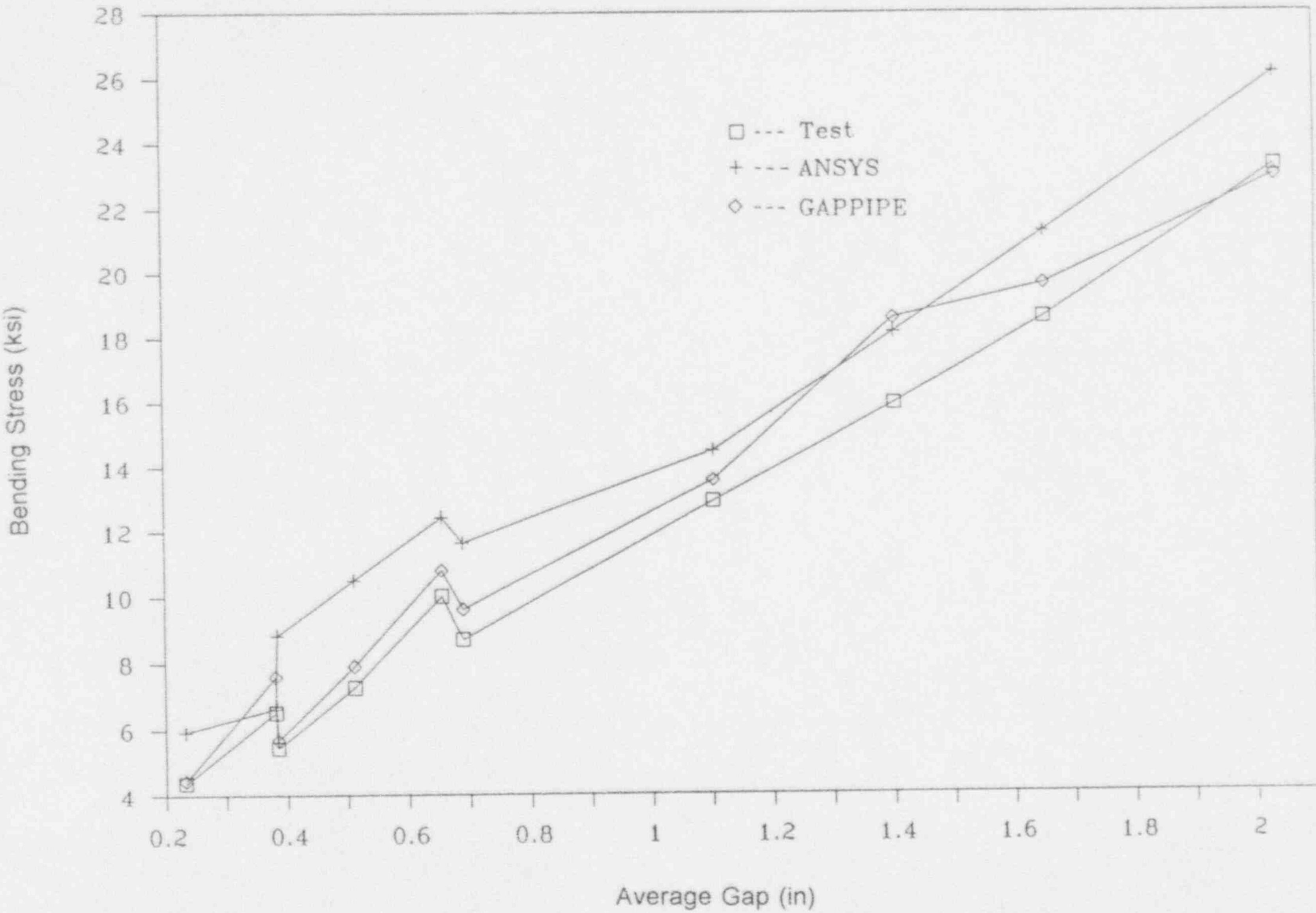


Figure 3.19: Comparison of Pipe Bending Stress @ 1/3 Location Input Level = 1.33 G ZPA

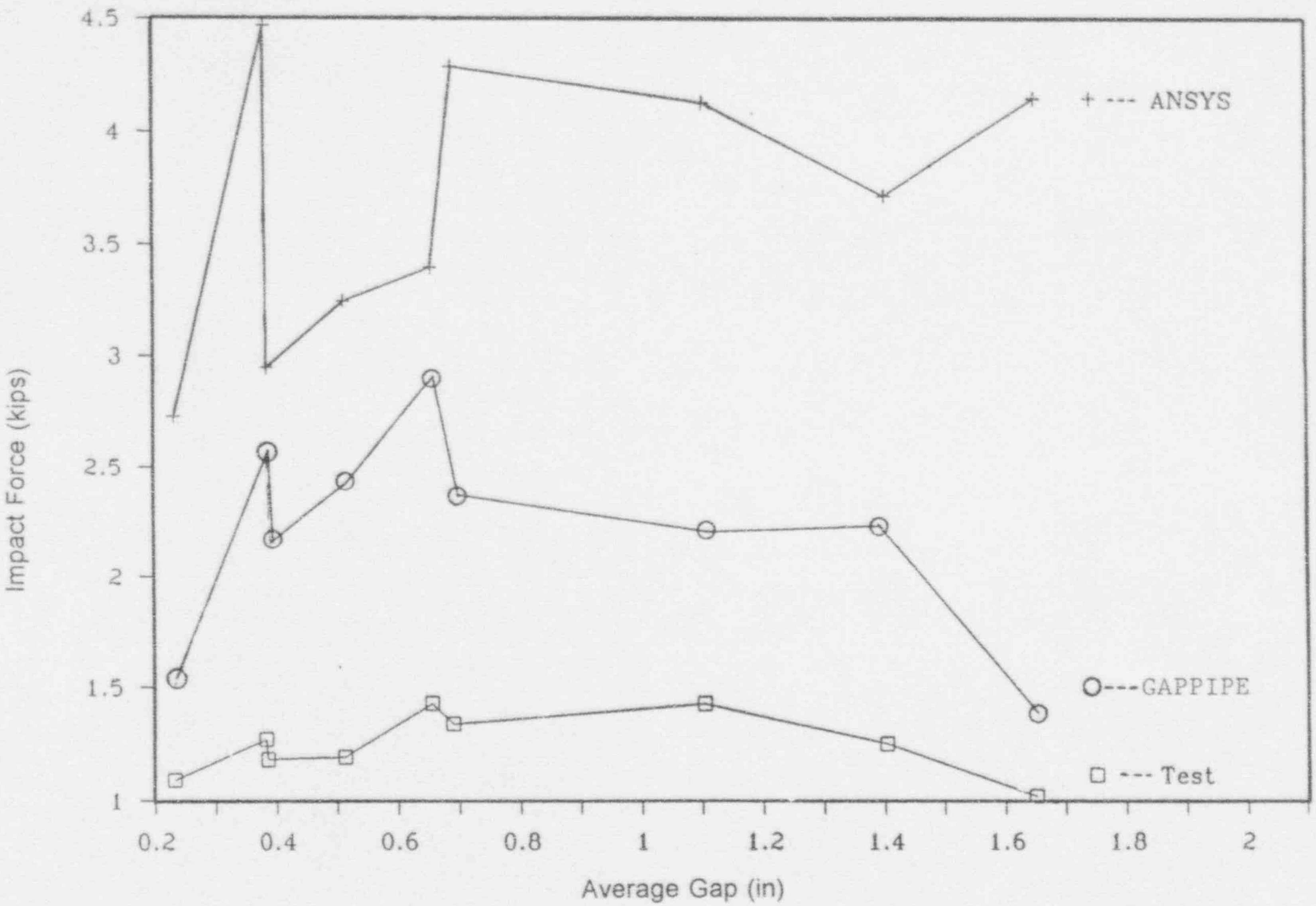


Figure 3.20: Comparison Impact Forces Input Level = 0.82 G ZPA

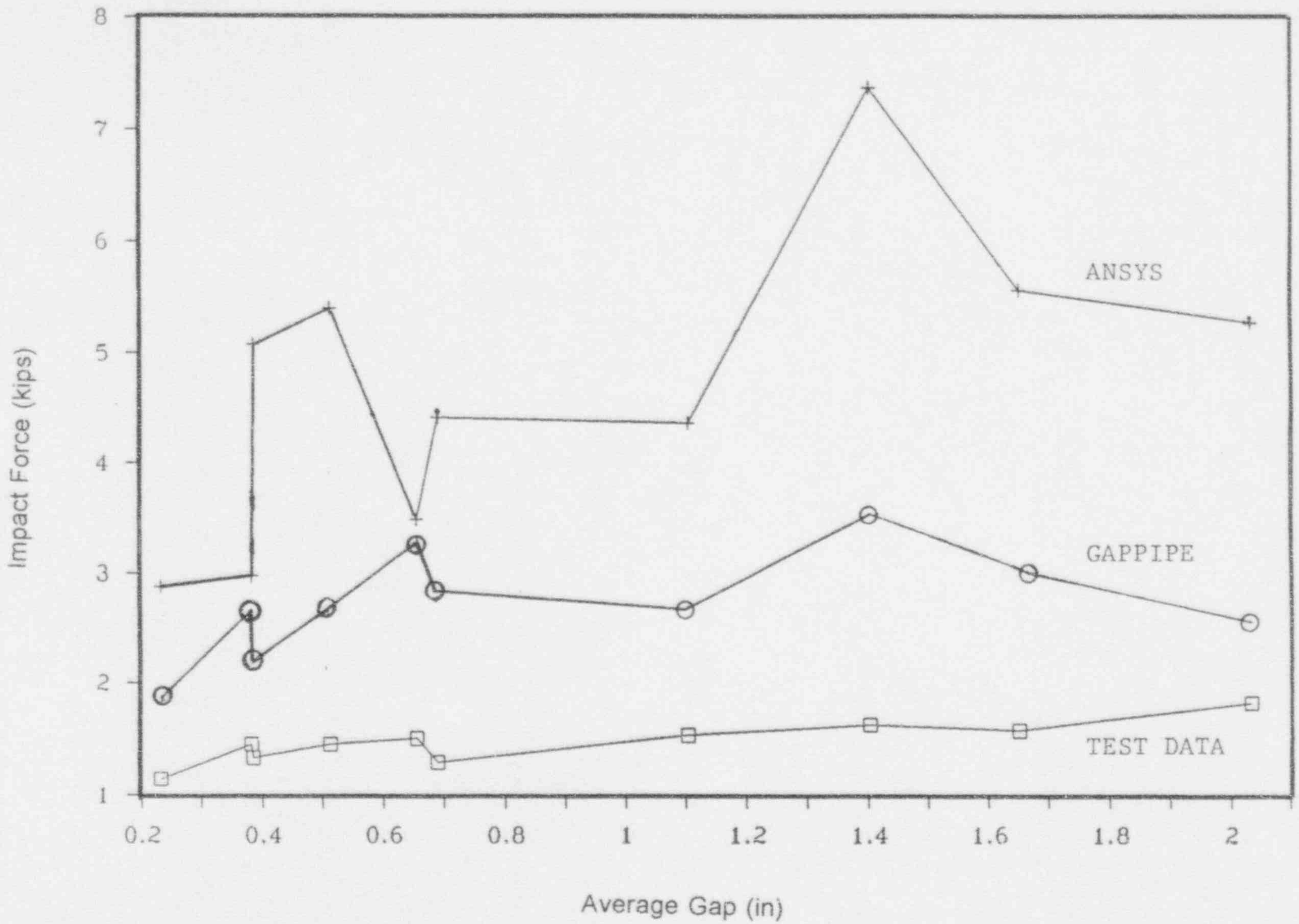


Figure 3.21: Comparison Impact Forces Input Level = 1.33 G ZPA

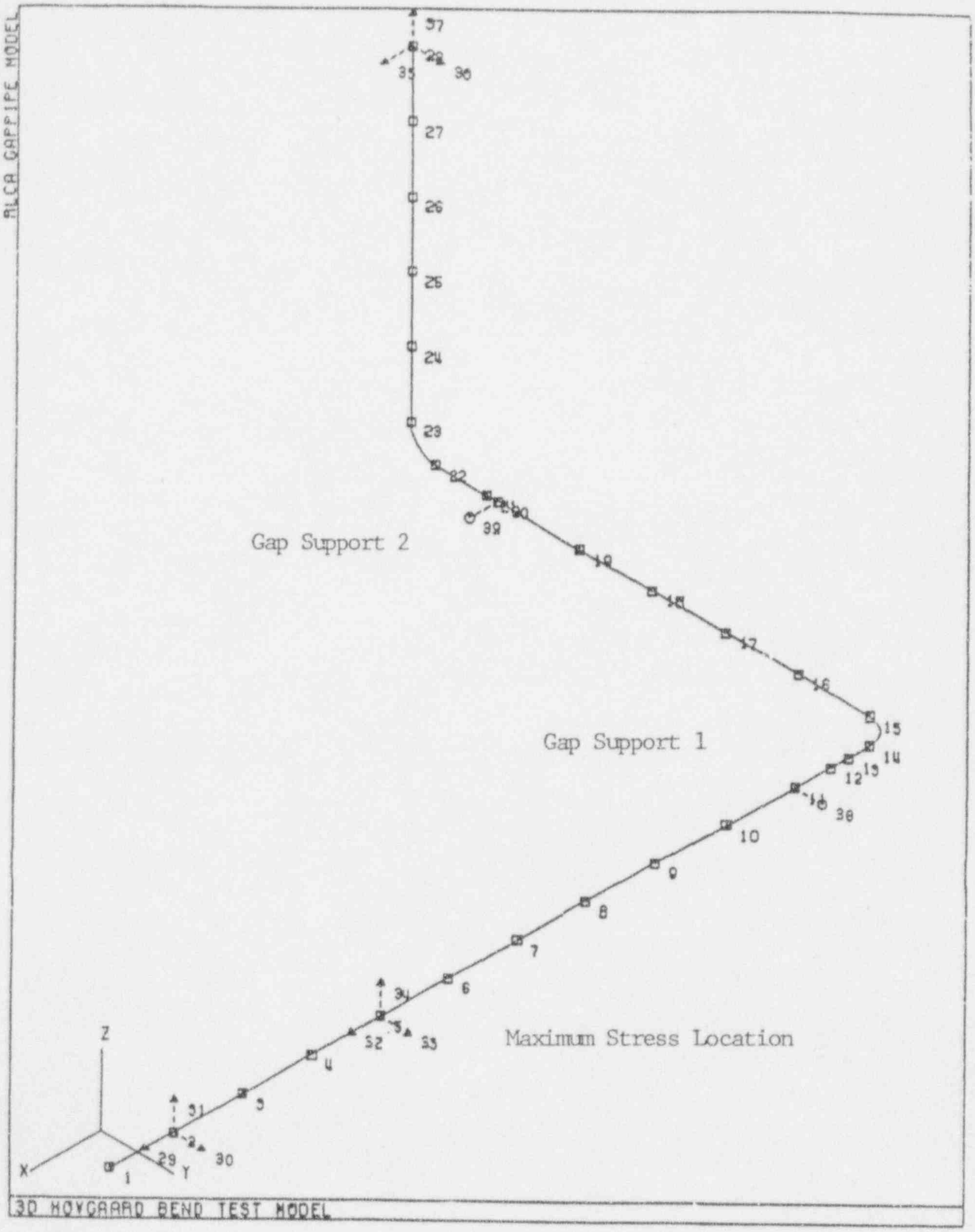
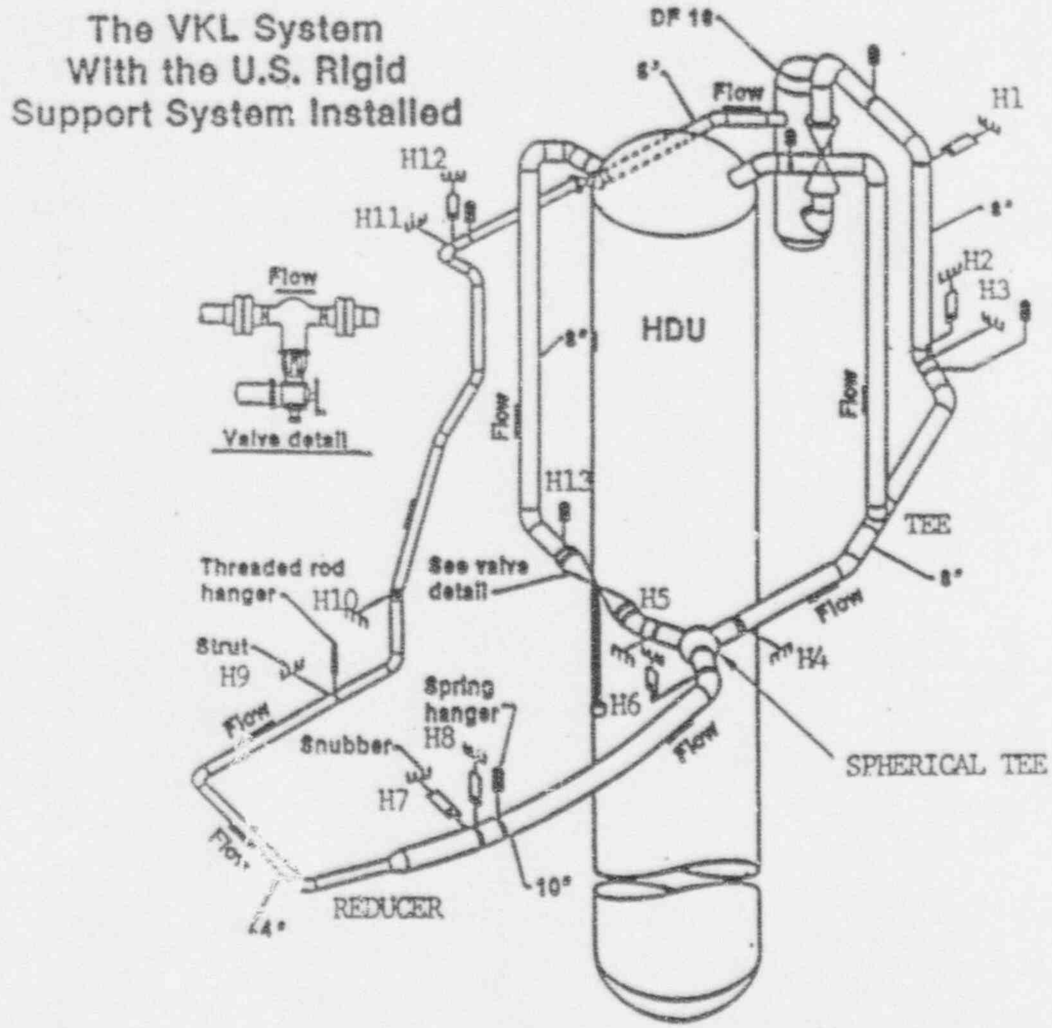


Figure 3.22: Analysis Model of the 3-D Hovgaard Bend Test Configuration



SEISMIC STOP SUPPORT DESIGN

- SIX SNUBBERS (ALL REPLACED BY GAPPED SUPPORTS)
- ALL OTHERS UNCHANGED
- SYSTEM PRESSURIZED; TESTED AT COLD AND HOT CONDITIONS

Figure 3.23: HDR SHAG Experiment Test Configuration

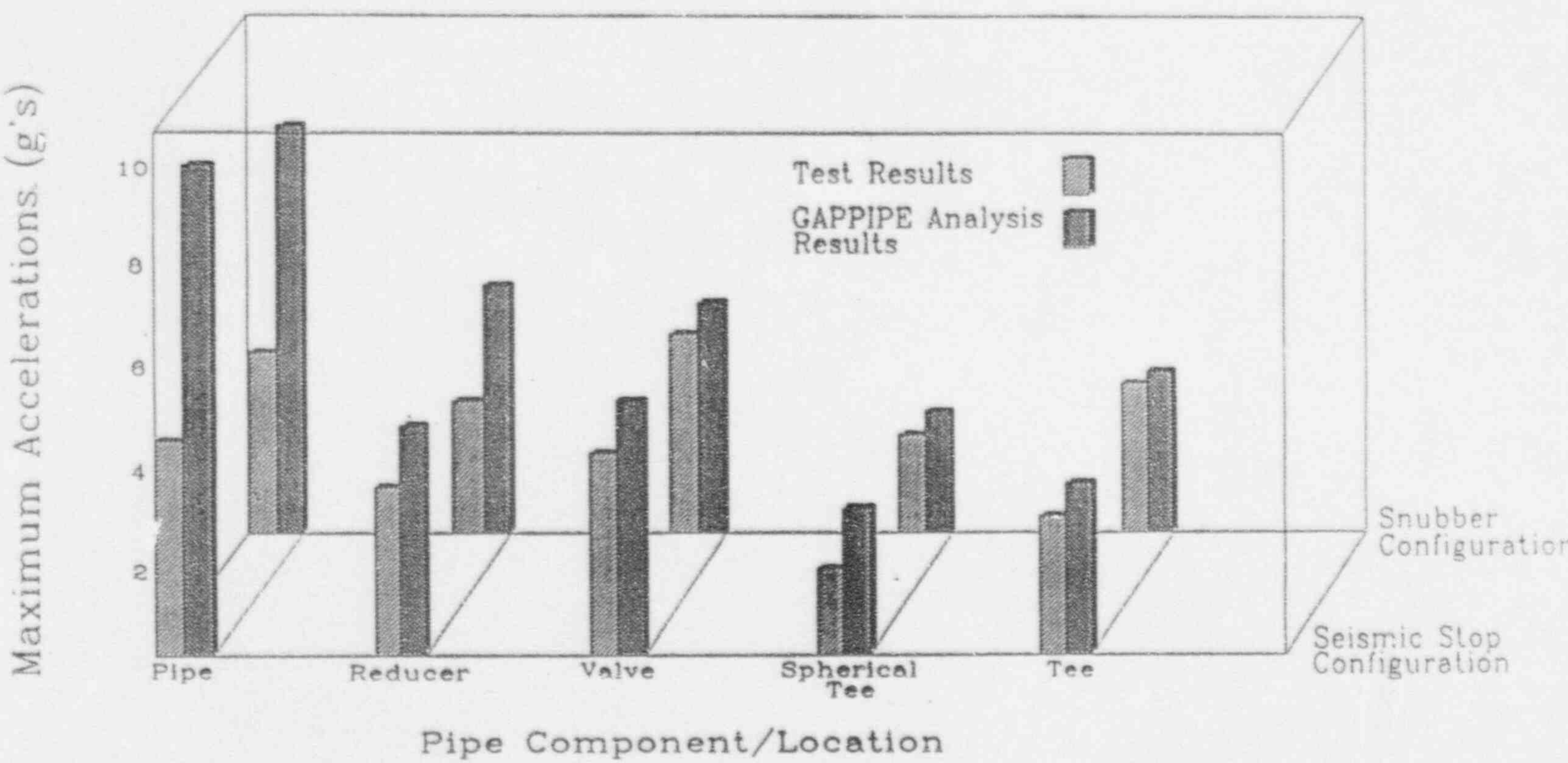


Figure 3.24: HDR SHAG Experiment - Comparison of Maximum Pipe Accelerations

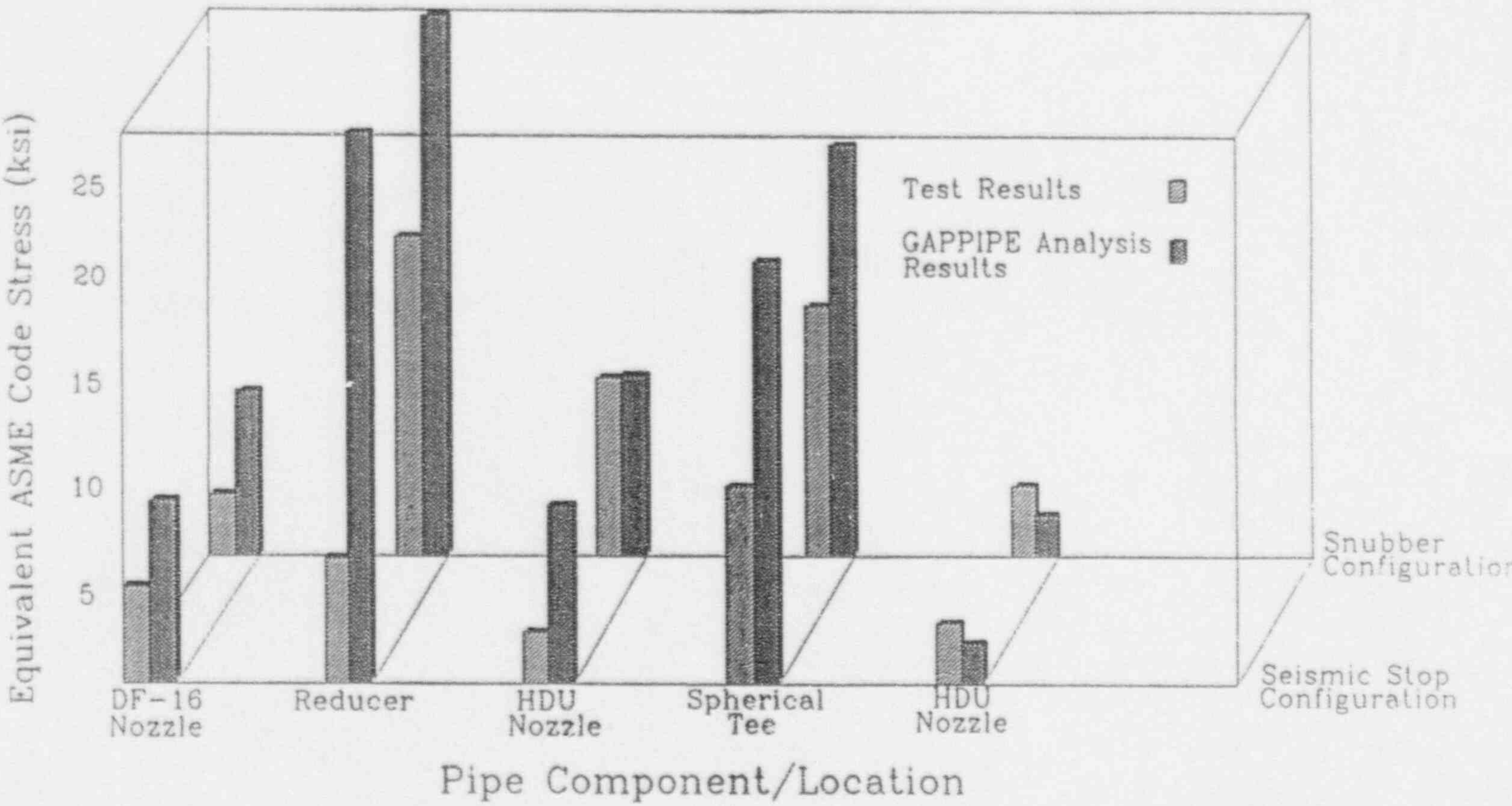


Figure 3.25: HDR SHAG Experiment - Comparison of Maximum Pipe Stresses

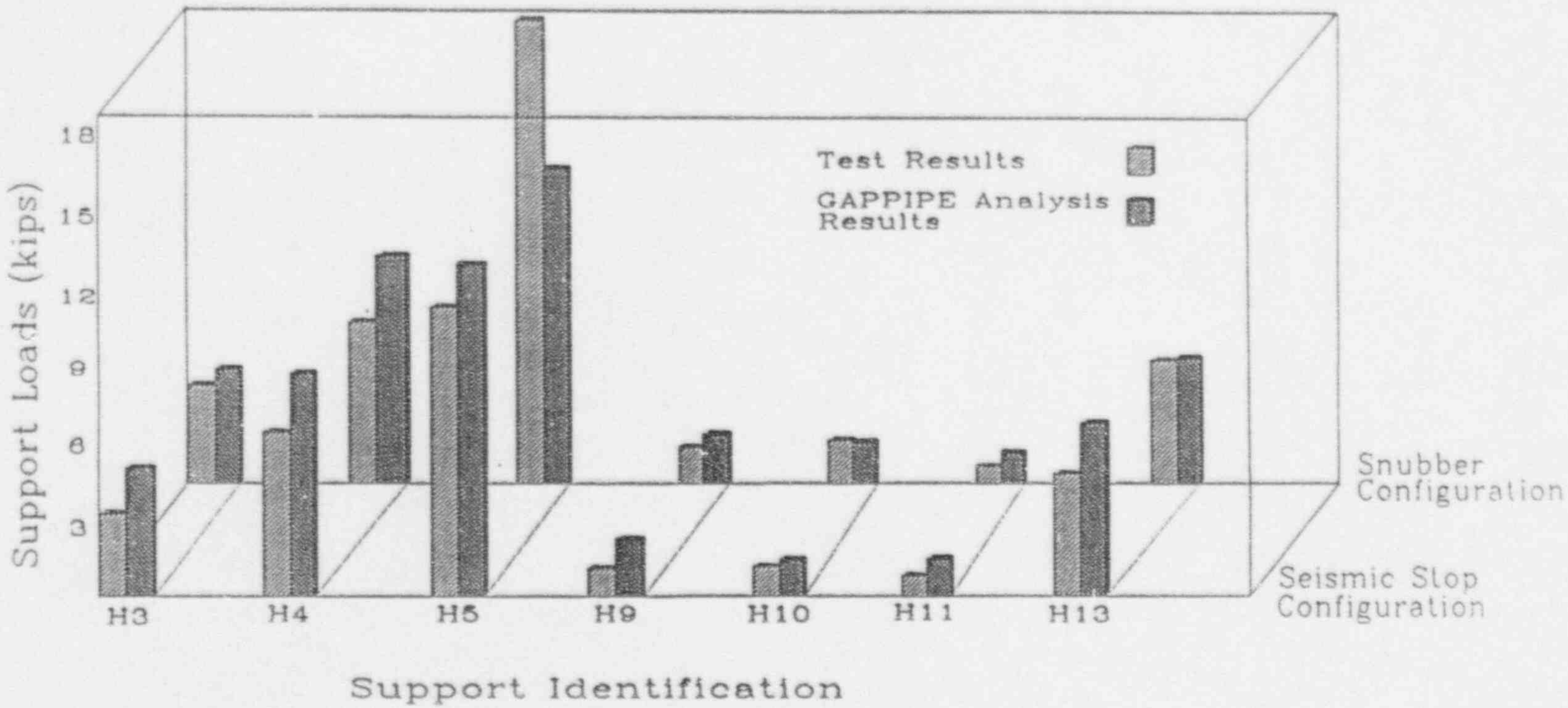


Figure 3.26: HDR SHAG Experiment - Comparison of Maximum Support Loads

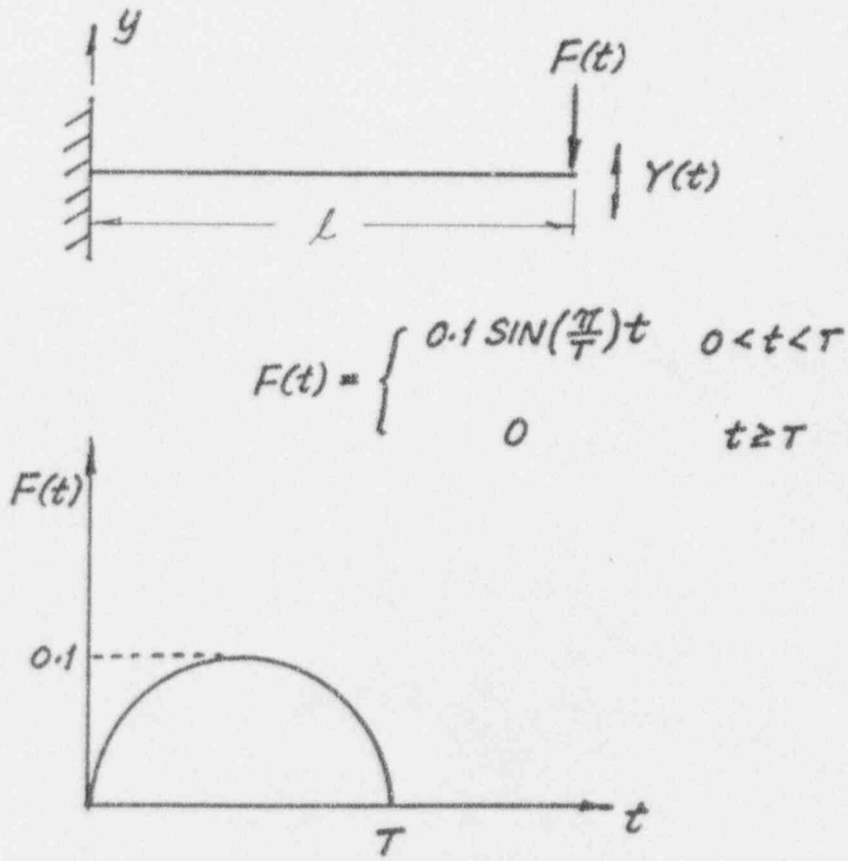
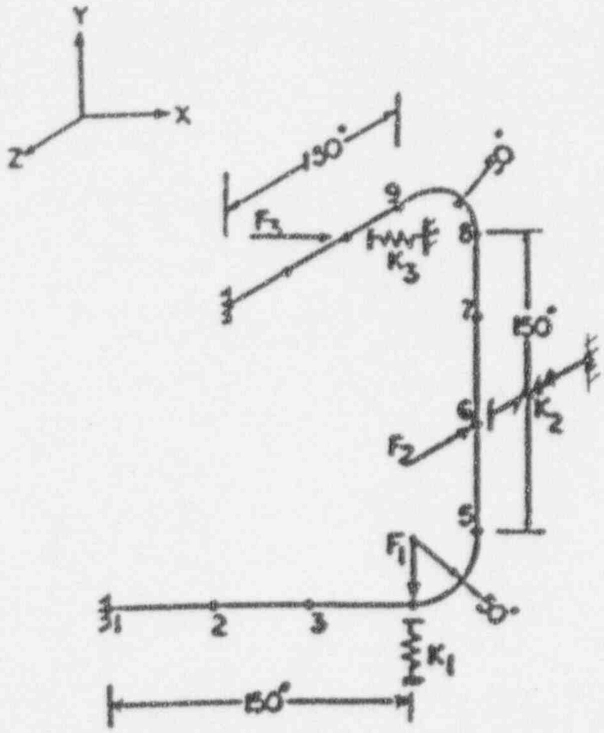
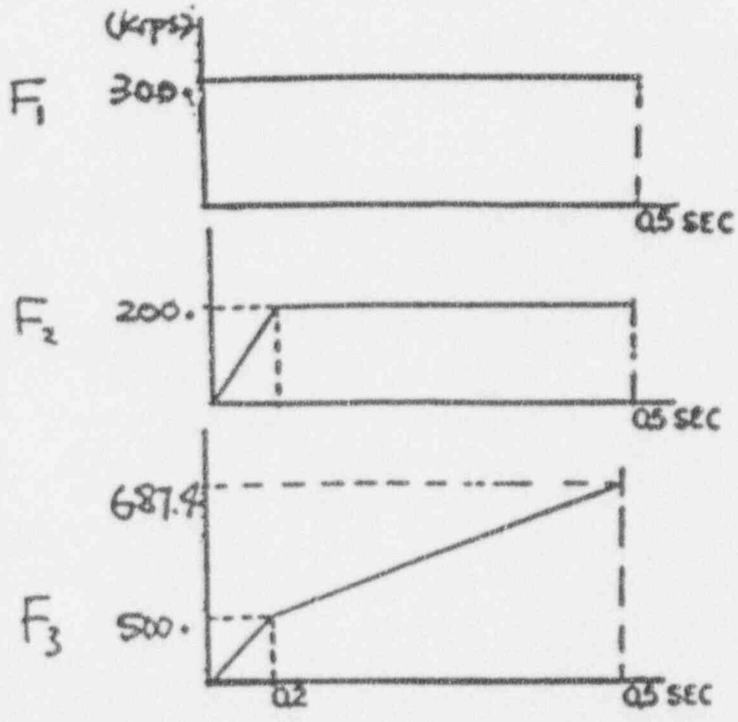


Figure 3.27: Description of STARDYNE Verification Problem 30



3-D Piping System



Applied Forcing Functions

Figure 3.28: Geometry and Forcing Functions of the Molnar Verification Case

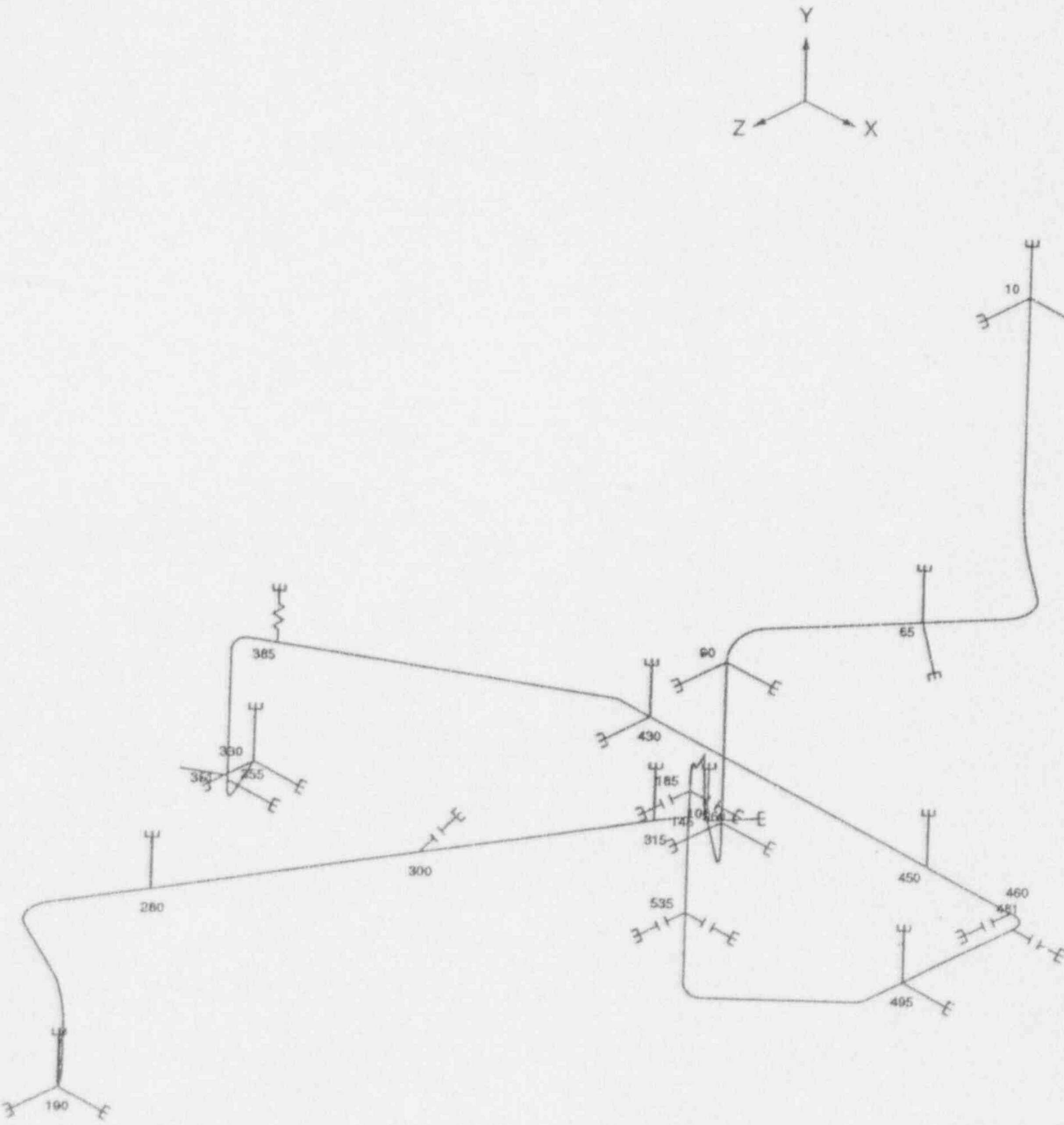


Figure 4.1: Safety Injection System at Millstone 2 Nuclear Plant

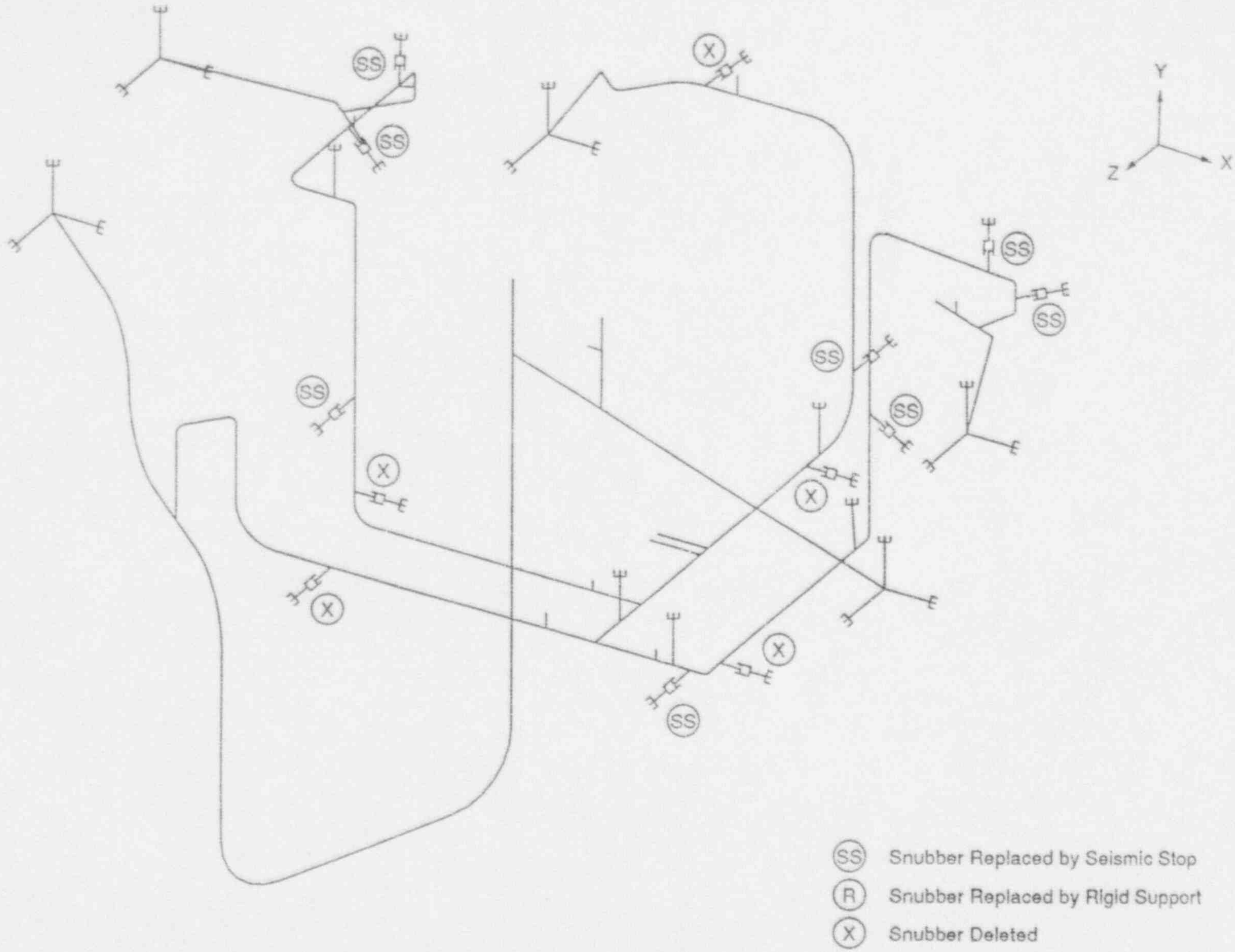


Figure 4.2: Byron 2 - Reactor Coolant Bypass Line 2RC19/04

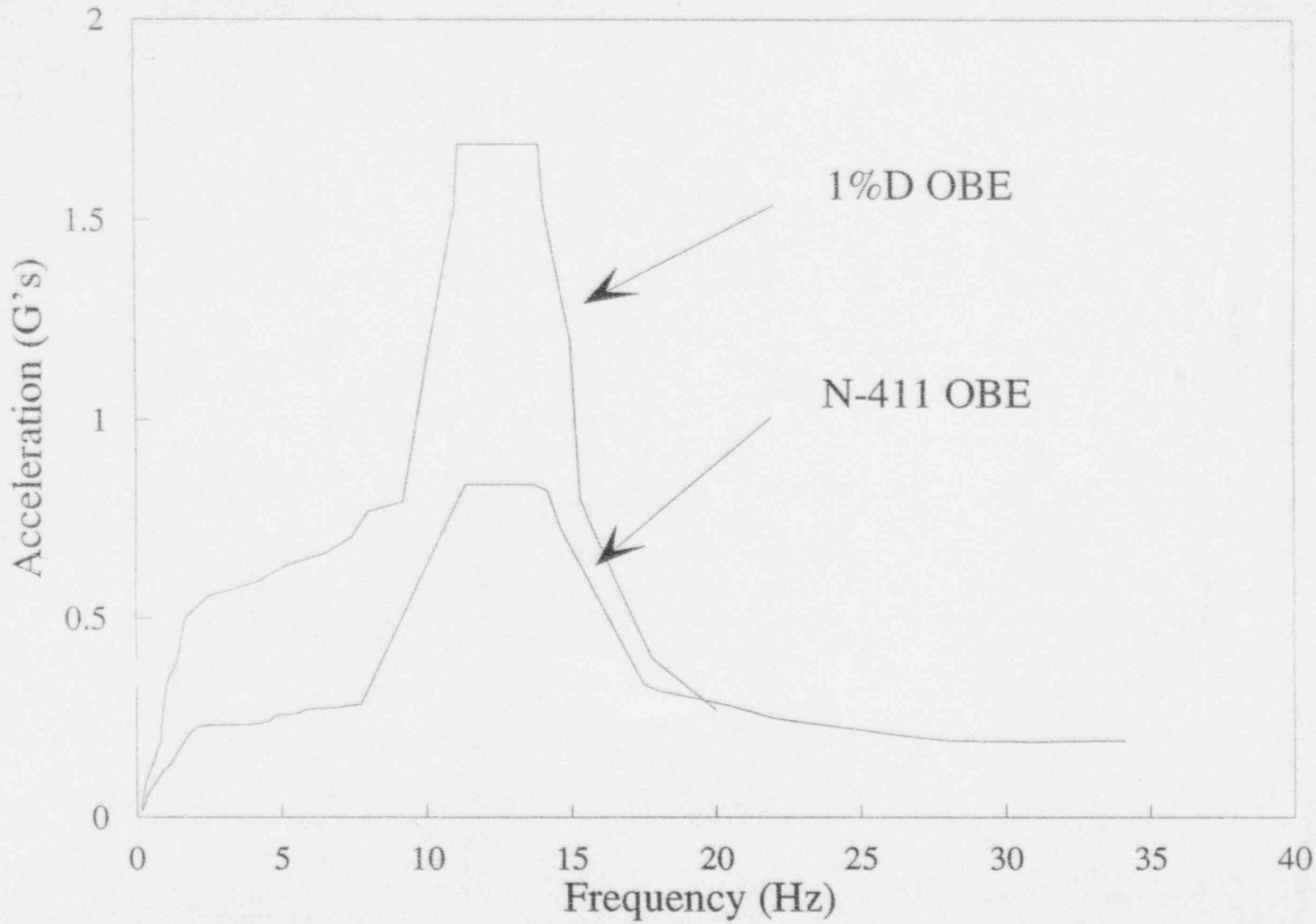


Figure 4.3: Comparison of Typical Reg. Guide 1.61 and ASME Code Case N-411 Damping Spectra at McGuire

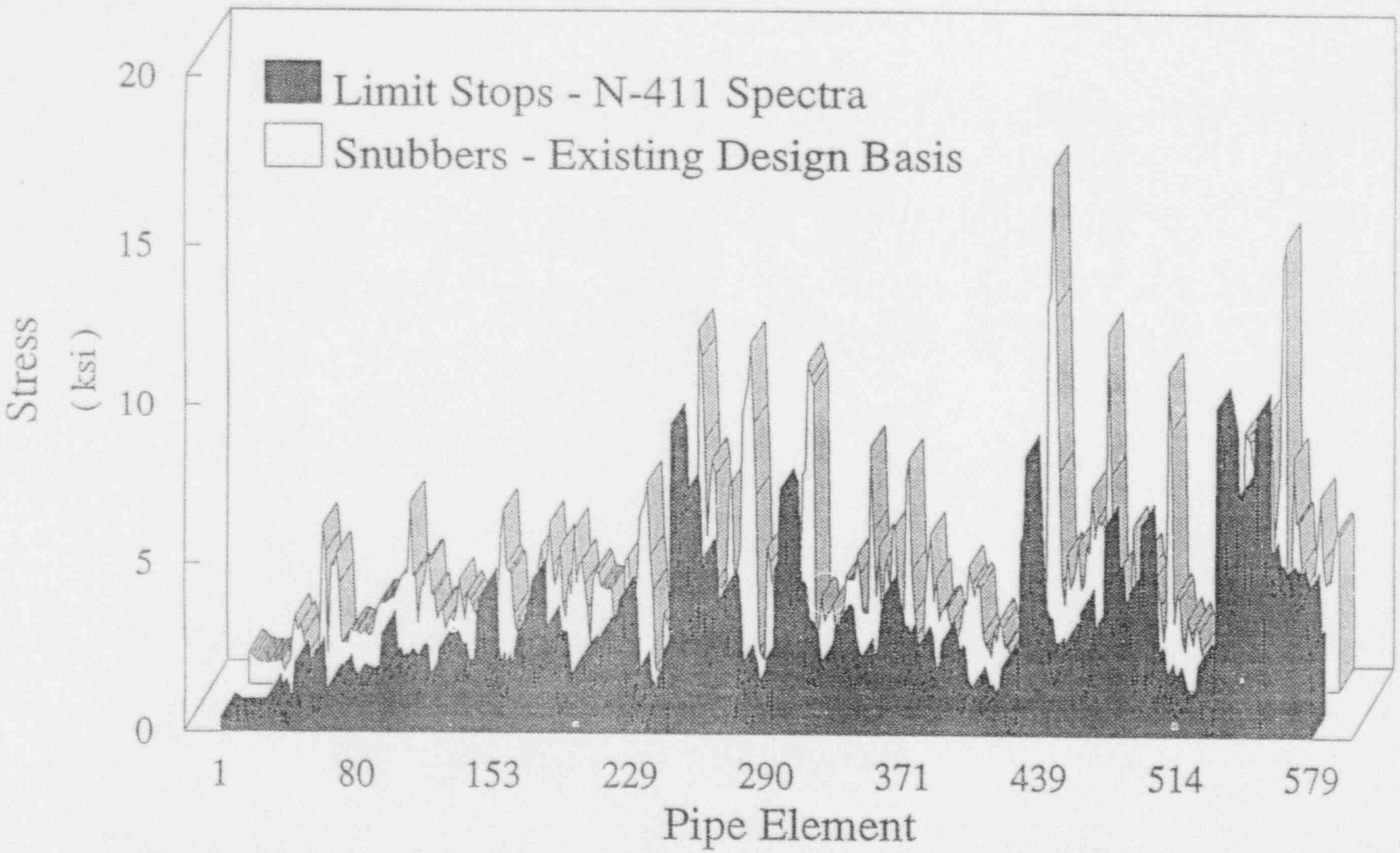


Figure 4.4: Comparison of Pipe Stresses for Refueling Water System

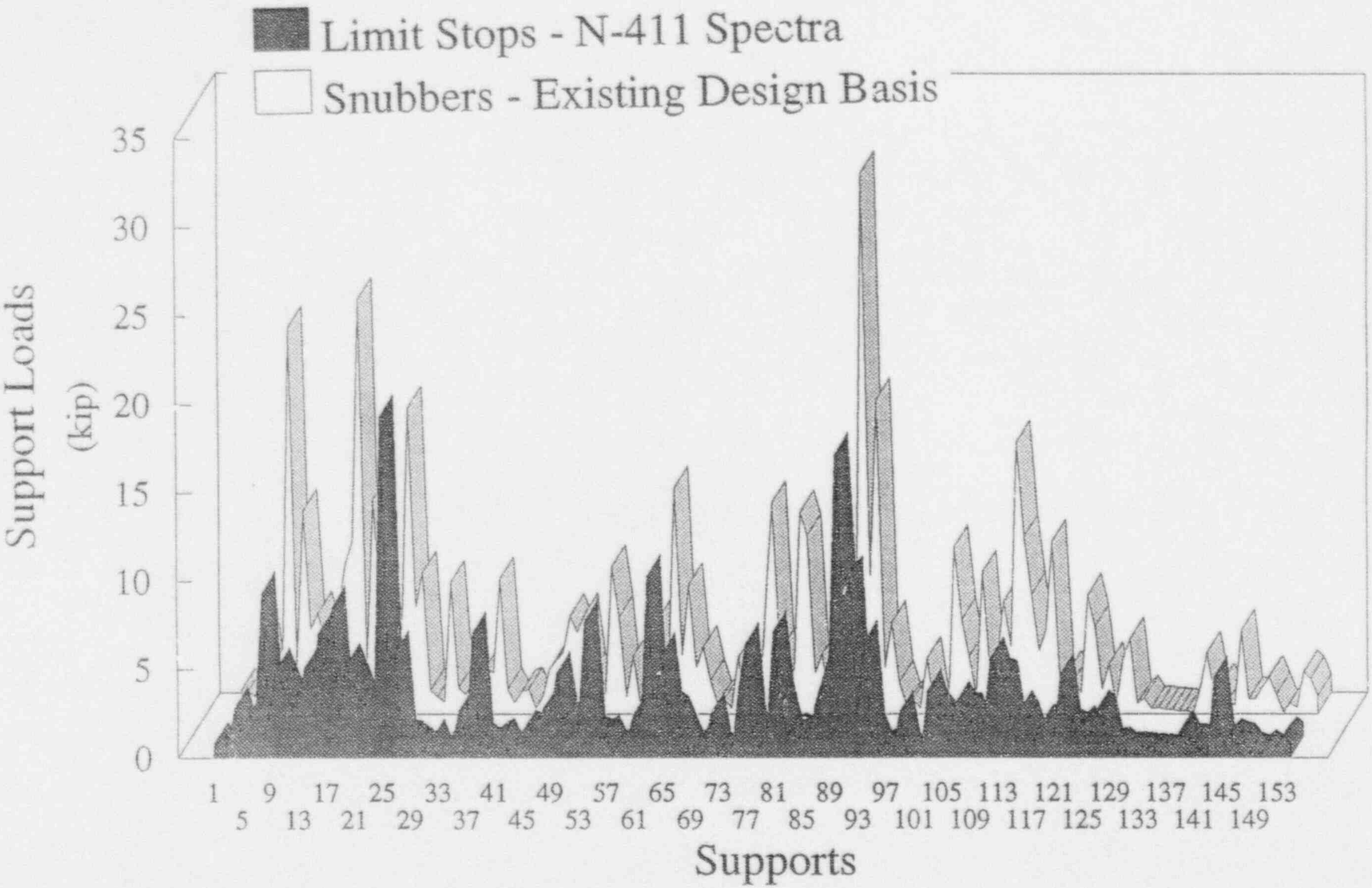


Figure 4.5: Comparison of Support Loads for Refueling Water System

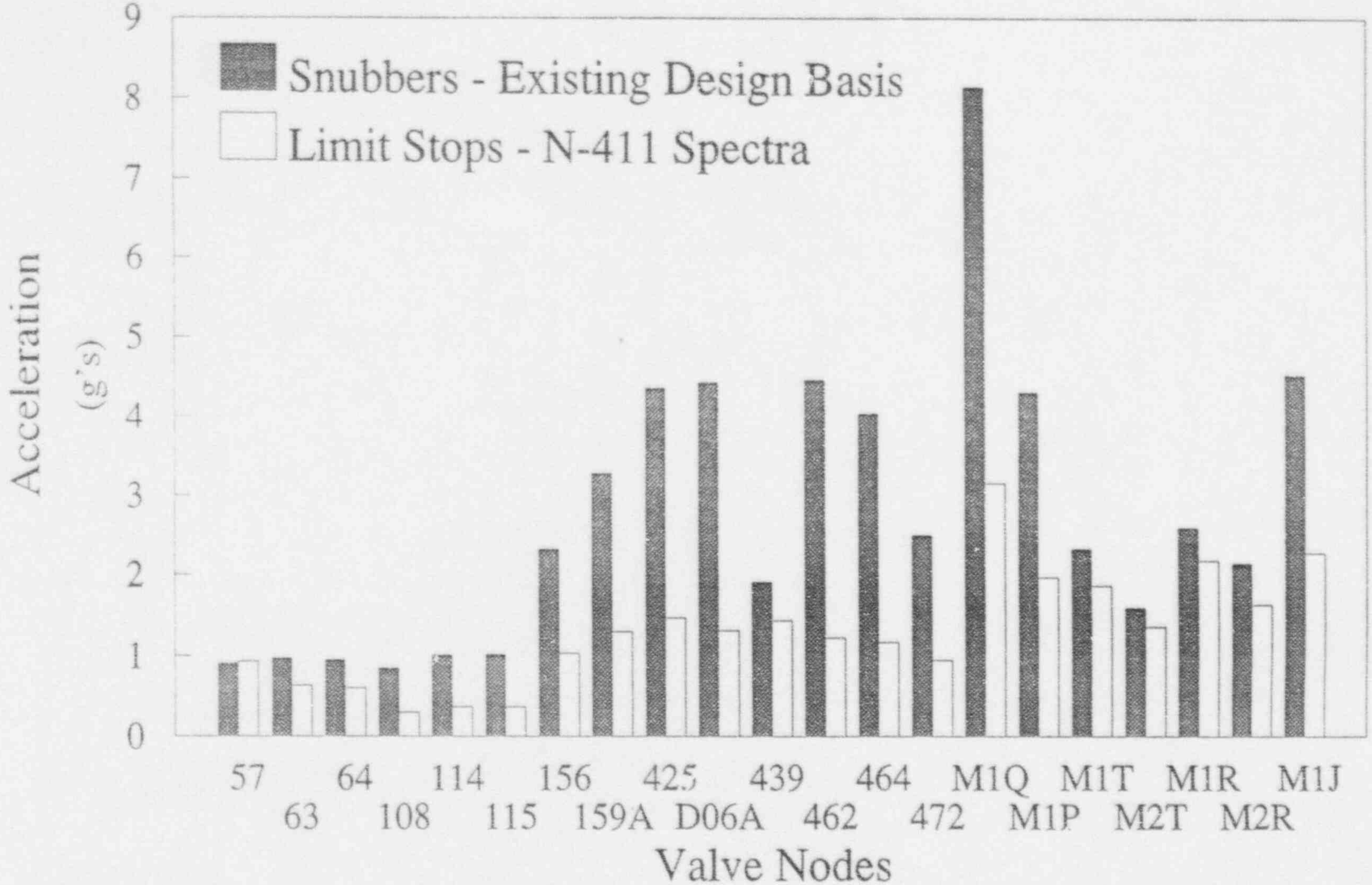


Figure 4.6: Comparison of Pipe Accelerations for Refueling Water System

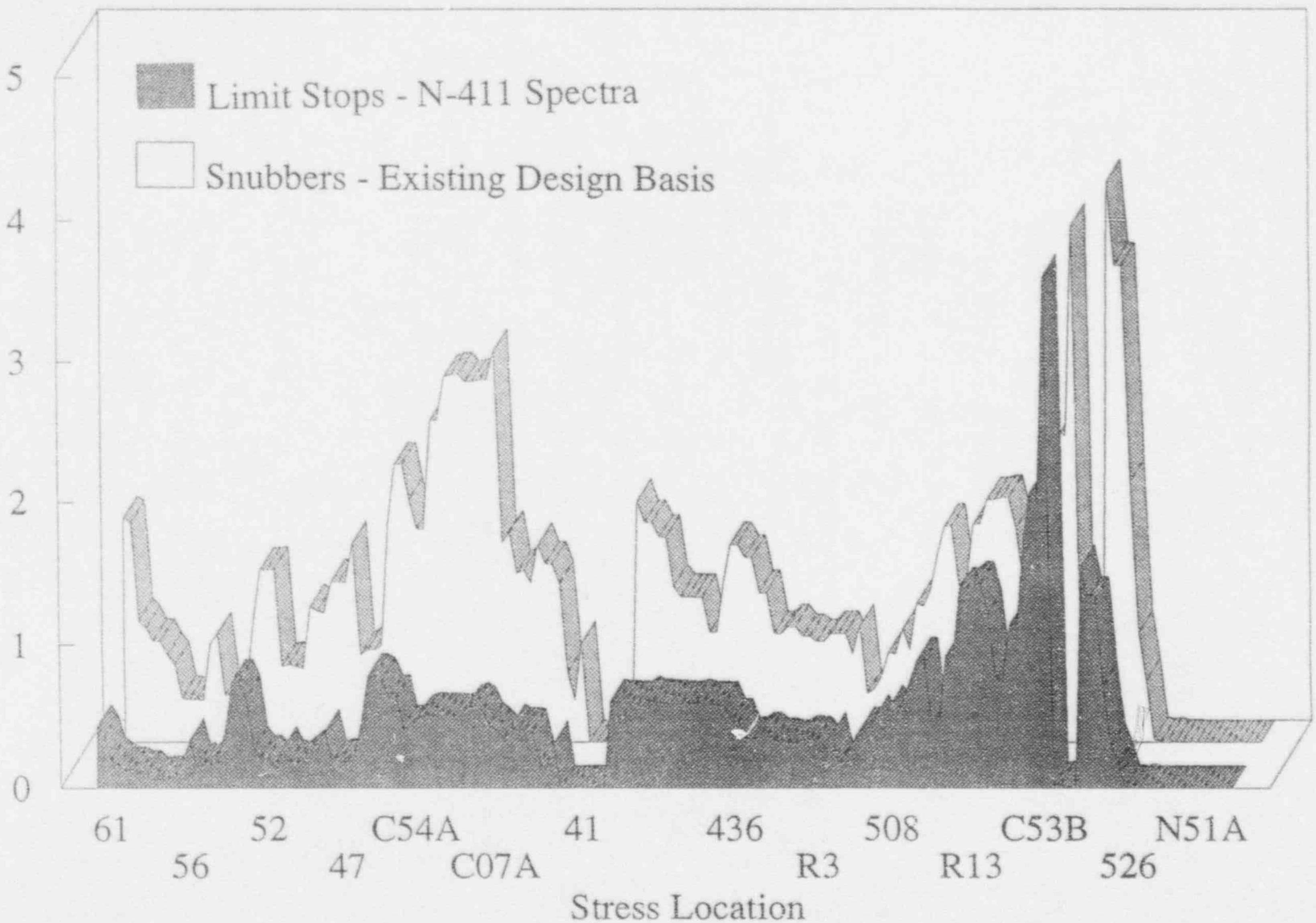


Figure 4.7: Comparison of Pipe Stresses for Auxiliary Feedwater System

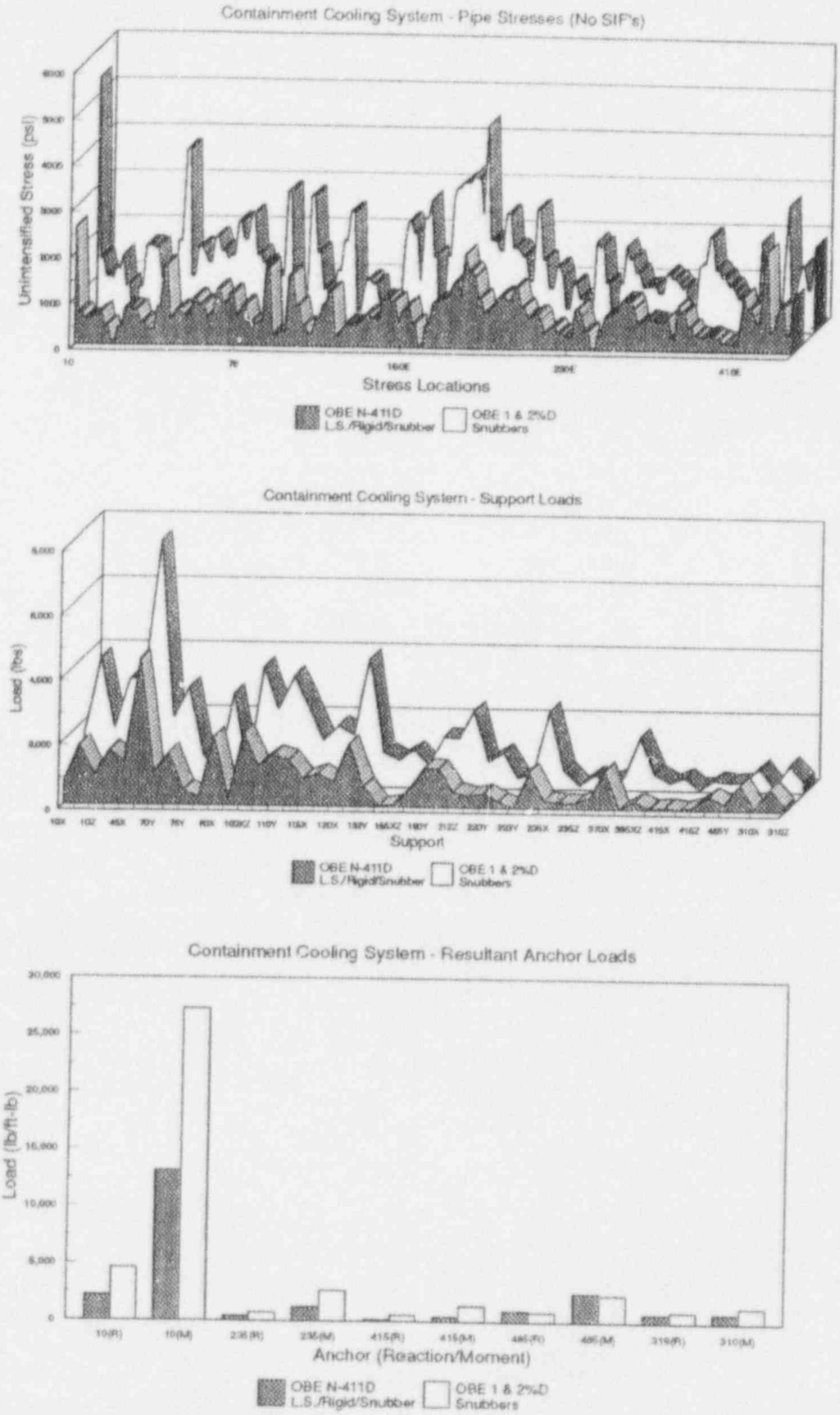


Figure 4.8: Comparison of Results for Containment Cooling Piping System at Wolf Creek

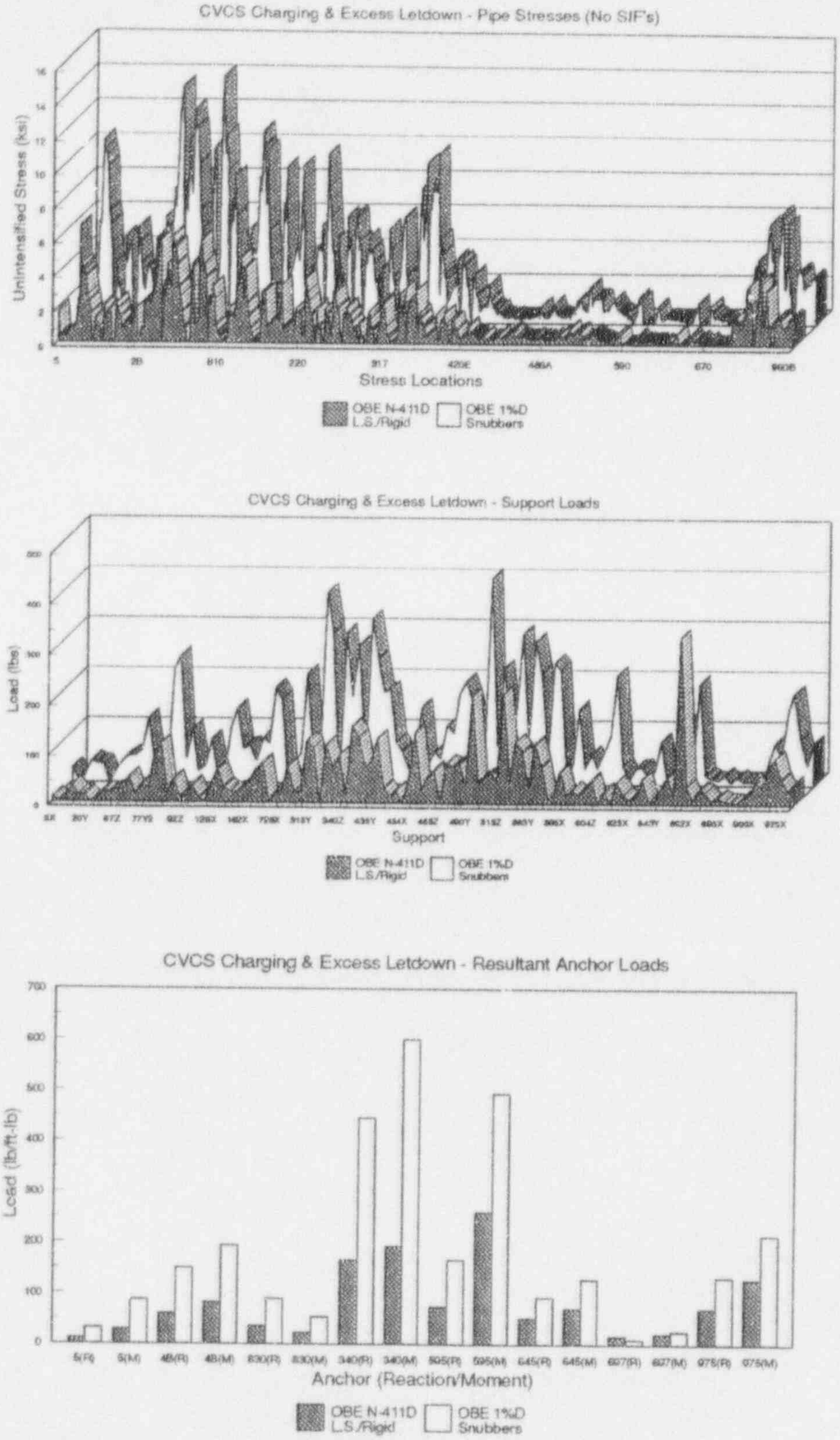


Figure 4.9: Comparison of Results for CVCS Charging and Excess Letdown Piping at Wolf Creek

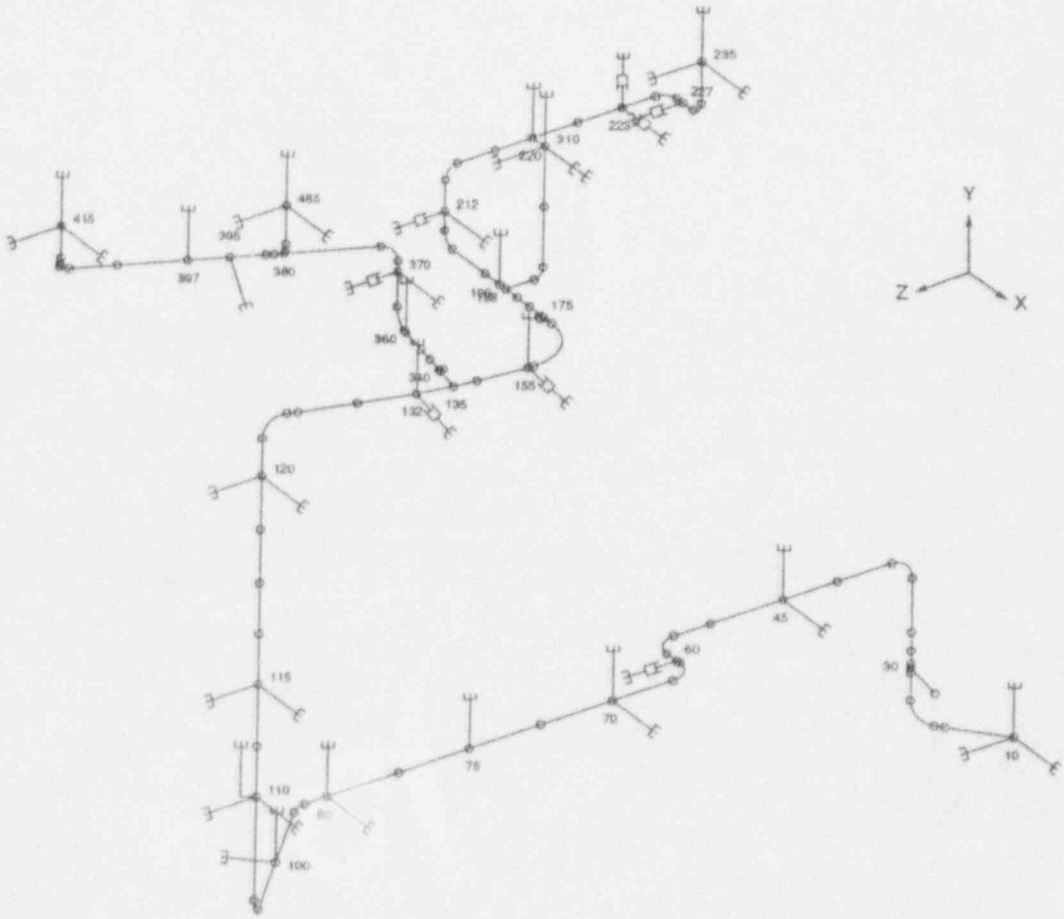


Figure 4.10: Containment Cooling Piping System at Wolf Creek

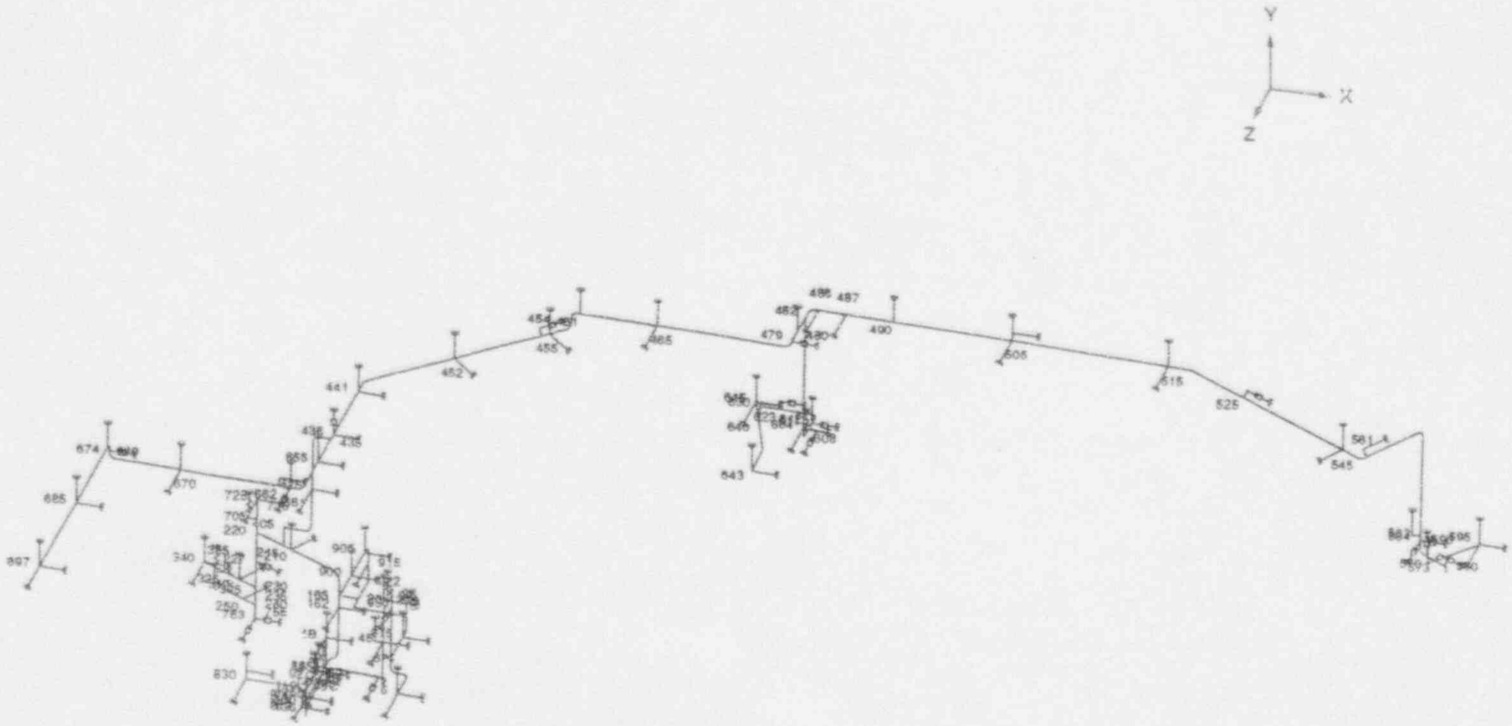


Figure 4.11: CVCS Piping System at Wolf Creek

APPENDIX A

SAMPLE COMPARISON SUMMARY OF NRC BENCHMARK PROBLEMS:

UNIFORM SPECTRA PROBLEM NO. 7

BENCHMARK PROBLEM NO.7
GAPPIPE VERSION 2.0

NATURAL FREQUENCIES

MODE NO.	NUREG (1)	GAPPIPE (2)	% DIFFERENCE ((2)-(1))/(1)*100%
1	5.034	5.034	0.00%
2	7.813	7.813	0.00%
3	8.193	8.193	0.00%
4	8.977	8.977	0.00%
5	9.312	9.312	0.00%
6	9.895	9.895	0.00%
7	13.22	13.222	0.02%
8	14.96	14.957	-0.02%
9	15.07	15.067	-0.02%
10	17.75	17.755	0.03%
11	18.21	18.209	-0.01%
12	22.9	22.9	0.00%
13	25.02	25.023	0.01%
14	25.85	25.855	0.02%
15	26.94	26.943	0.01%
16	28.13	28.133	0.01%
17	30.3	30.299	-0.00%
18	35.22	35.218	-0.01%
19	37.1	37.096	-0.01%
20	42.61	42.614	0.01%
21	44.42	44.418	-0.00%
22	48.09	48.09	0.00%

---- MODAL PARTICIPATION FACTORS ----

	X-DIRECTION		
MODE NO.	NUREG (1)	GAPPIPE (2)	% DIFFERENCE ((2)-(1))/(1)*100%
1	1.7670E-01	0.17674	0.02%
2	2.6400E-02	0.0264	0.00%
3	1.0750E-01	0.10748	-0.02%
4	8.7500E-01	0.87504	0.00%
5	2.0130E-01	0.20134	0.02%
6	2.3130E-01	-0.23135	0.02%
7	5.1610E-01	0.5161	0.00%
8	2.3760E-02	-0.02376	0.00%
9	1.0170E-01	-0.10168	-0.02%
10	-1.0310E-01	-0.10312	0.02%
11	8.2670E-02	0.08267	0.00%
12	-7.4940E-01	-0.74936	-0.01%
13	-5.7780E-01	-0.57776	-0.01%
14	2.9970E-01	-0.29972	0.01%
15	-1.2100E-02	0.0121	0.00%
16	5.2590E-01	-0.52594	0.01%
17	-8.3140E-01	-0.83136	-0.00%
18	-5.6670E-02	-0.05667	0.00%
19	-1.7510E-01	-0.17514	0.02%
20	2.7160E-01	0.27158	-0.01%
21	-1.3[illegible]90E-03	-0.0014	0.07%
22	1.1500E-01	0.11514	0.12%

---- MODAL PARTICIPATION FACTORS ----

	Y-DIRECTION		
MODE NO.	NUREG (1)	GAPPIPE (2)	% DIFFERENCE ((2)-(1))/(1)*100%
1	-5.8590E-01	-0.58585	-0.01%
2	-2.5090E-01	-0.25089	-0.00%
3	4.3320E-01	0.43324	0.01%
4	-1.6270E-01	-0.16271	0.01%
5	1.1080E+00	1.10845	0.04%
6	9.2980E-01	-0.9298	0.00%
7	4.3290E-01	0.43291	0.00%
8	-4.1440E-02	0.04144	0.00%
9	6.8040E-02	-0.06804	0.00%
10	-3.0960E-01	-0.30959	-0.00%
11	-1.0110E+00	-1.01137	0.04%
12	2.2690E-01	0.22692	0.01%
13	1.3730E-01	0.13725	-0.04%
14	-3.9320E-01	0.39324	0.01%
15	-3.4340E-03	0.00343	-0.12%
16	3.9050E-02	-0.03905	0.00%
17	-1.2320E-01	-0.1232	0.00%
18	-2.9740E-01	-0.29738	-0.01%
19	2.1750E-01	0.21754	0.02%
20	-1.3340E-01	-0.13342	0.01%
21	-2.0310E-01	-0.20315	0.02%
22	1.5090E-01	0.15081	-0.06%

---- MODAL PARTICIPATION FACTORS ----

MODE NO.	Z-DIRECTION NUREG (1)	GAPPIPE (2)	% DIFFERENCE ((2)-(1))/(1)*100%
1	1.1580E+00	1.15771	-0.03%
2	1.0870E+00	1.08672	-0.03%
3	4.4660E-01	0.44656	-0.01%
4	-5.3890E-01	-0.53885	-0.01%
5	3.6630E-02	0.03663	0.00%
6	-6.9300E-03	0.00693	0.00%
7	7.9820E-01	0.79824	0.01%
8	-6.6440E-01	0.66444	0.01%
9	7.4620E-02	-0.07462	0.00%
10	7.9960E-02	0.07996	0.00%
11	-1.5860E-01	-0.15858	-0.01%
12	4.4770E-01	0.4477	0.00%
13	2.7720E-01	0.27725	0.02%
14	1.6930E-01	-0.1693	0.00%
15	2.1380E-01	-0.21383	0.01%
16	-2.9700E-02	0.0297	0.00%
17	-2.2180E-01	-0.22176	-0.02%
18	-1.4530E-01	-0.1453	0.00%
19	-1.0070E-01	-0.10072	0.02%
20	1.6140E-01	0.16143	0.02%
21	-2.2720E-02	-0.02271	-0.04%
22	2.6000E-02	0.0261	0.38%

NODAL DISPLACEMENT

NODE NO.	X-DIR. DISPLACEMENT NUREG (1)	GAPPIPE (2)	% DIFFERENCE ((2)-(1))/(1)*100%
1	0.0000E+00		N/A
2	1.5547E-04	0.0002	28.64%
3	0.0000E+00		N/A
4	3.4377E-03	0.0034	-1.10%
5	2.9812E-02	0.0298	-0.04%
6	4.5900E-02	0.0459	0.00%
7	0.0000E+00		N/A
8	5.5673E-02	0.0557	0.05%
9	0.0000E+00		N/A
10	6.6947E-02	0.0669	-0.07%
11	8.4820E-02	0.0848	-0.02%
12	0.0000E+00		N/A
13	8.0124E-02	0.0801	-0.03%
14	0.0000E+00		N/A
15	5.4967E-02	0.055	0.06%
16	9.7873E-03	0.0098	0.13%
17	0.0000E+00		N/A
18	6.4978E-05	0.0001	53.90%
19	0.0000E+00		N/A
20	6.3349E-05	0.0001	57.86%
21	0.0000E+00		N/A
22	0.0000E+00		N/A
23	0.0000E+00		N/A
24	0.0000E+00		N/A
25	5.2360E-05	0.0001	90.99%
26	0.0000E+00		N/A
27	0.0000E+00		N/A
28	0.0000E+00		N/A
29	0.0000E+00		N/A
30	3.4825E-05	0	N/A
31	3.3013E-02	0.033	-0.04%
32	0.0000E+00		N/A
33	3.5608E-02	0.0356	-0.02%
34	0.0000E+00		N/A
35	4.2436E-02	0.0424	-0.08%
36	0.0000E+00		N/A
37	0.0000E+00		N/A
38	0.0000E+00		N/A
39	0.0000E+00		N/A
40	2.6313E-02	0.0263	-0.05%
41	6.8867E-03	0.0069	0.19%
42	0.0000E+00		N/A
43	0.0000E+00		N/A
44	5.1200E-03	0.0051	-0.39%

45	5.1203E-03	0.0051	-0.40%
46	5.1196E-03	0.0051	-0.38%
47	0.0000E+00		N/A
48	3.3789E-03	0.0034	0.63%
49	C.0000E+00		N/A
50	6.1398E-04	0.0006	-2.28%
51	0.0000E+00		N/A
52	0.0000E+00		N/A
53	0.0000E+00		N/A
54	0.0000E+00		N/A
55	3.4300E-08	0	N/A
56	0.0000E+00		N/A
57	0.0000E+00		N/A
58	0.0000E+00		N/A
59	0.0000E+00		N/A
60	1.7441E-05	0	N/A
61	0.0000E+00		N/A
62	0.0000E+00		N/A
63	0.0000E+00		N/A
64	0.0000E+00		N/A
65	6.9086E-08	0	N/A
66	0.0000E+00		N/A
67	0.0000E+00		N/A
68	0.0000E+00		N/A
69	0.0000E+00		N/A
70	1.7603E-05	0	N/A
71	3.7432E-03	0.0037	-1.15%
72	0.0000E+00		N/A
73	3.9369E-03	0.0039	-0.94%
74	0.0000E+00		N/A
75	4.4190E-03	0.0044	-0.43%
76	0.0000E+00		N/A
77	0.0000E+00		N/A
78	0.0000E+00		N/A
79	0.0000E+00		N/A
80	5.4341E-03	0.0054	-0.63%
81	6.2293E-03	0.0062	-0.47%
82	0.0000E+00		N/A
83	0.0000E+00		N/A
84	6.3786E-03	0.0064	0.34%
85	6.3781E-03	0.0064	0.34%
86	6.3732E-03	0.0064	0.42%
87	0.0000E+00		N/A
88	4.3035E-03	0.0043	-0.08%
89	0.0000E+00		N/A
90	8.1040E-04	0.0008	-1.28%
91	0.0000E+00		N/A
92	0.0000E+00		N/A
93	0.0000E+00		N/A
94	0.0000E+00		N/A
95	2.9319E-08	0	N/A

96	0.0000E+00		N/A
97	0.0000E+00		N/A
98	1.8851E-05	0	N/A
99	0.0000E+00		N/A
100	2.0063E-05	0	N/A
101	0.0000E+00		N/A
102	0.0000E+00		N/A
103	0.0000E+00		N/A
104	0.0000E+00		N/A
105	4.3439E-05	0	N/A
106	0.0000E+00		N/A
107	0.0000E+00		N/A
108	0.0000E+00		N/A
109	0.0000E+00		N/A
110	7.0486E-05	0.0001	41.87%
111	8.7379E-05	0.0001	14.44%
112	0.0000E+00		N/A
113	1.2410E-03	0.0012	-3.31%
114	0.0000E+00		N/A
115	5.5974E-03	0.0056	0.05%
116	0.0000E+00		N/A
117	0.0000E+00		N/A
118	0.0000E+00		N/A
119	0.0000E+00		N/A
120	1.4778E-02	0.0148	0.15%
121	6.8606E-03	0.0069	0.57%
122	0.0000E+00		N/A
123	0.0000E+00		N/A
124	9.8402E-03	0.0098	-0.41%
125	9.8390E-03	0.0098	-0.40%
126	9.8303E-03	0.0098	-0.31%
127	0.0000E+00		N/A
128	6.6620E-03	0.0067	0.57%
129	0.0000E+00		N/A
130	1.2579E-03	0.0013	3.35%
131	0.0000E+00		N/A
132	0.0000E+00		N/A
133	0.0000E+00		N/A
134	0.0000E+00		N/A
135	0.0000E+00		N/A
136	0.0000E+00		N/A
137	0.0000E+00		N/A
138	0.0000E+00		N/A
139	0.0000E+00		N/A
140	3.4767E-08	0	N/A
141	0.0000E+00		N/A
142	0.0000E+00		N/A
143	0.0000E+00		N/A
144	0.0000E+00		N/A
145	0.0000E+00		N/A
146	0.0000E+00		N/A

147	0.0000E+00	N/A
148	0.0000E+00	N/A
149	0.0000E+00	N/A
150	0.0000E+00	N/A
151	0.0000E+00	N/A
152	0.0000E+00	N/A
153	0.0000E+00	N/A
154	0.0000E+00	N/A
155	0.0000E+00	N/A
156	0.0000E+00	N/A
157	0.0000E+00	N/A
158	0.0000E+00	N/A
159	0.0000E+00	N/A
160	0.0000E+00	N/A
161	0.0000E+00	N/A
162	0.0000E+00	N/A
163	0.0000E+00	N/A
164	0.0000E+00	N/A
165	0.0000E+00	N/A
166	0.0000E+00	N/A
167	0.0000E+00	N/A
168	0.0000E+00	N/A
169	0.0000E+00	N/A
170	0.0000E+00	N/A

NODAL DISPLACEMENT

NODE NO.	Y-DIR. DISPLACEMENT NUREG (1)	GAPPIPE (2)	% DIFFERENCE ((2)-(1))/(1)*100%
1	0.0000E+00		N/A
2	1.1943E-05	0	N/A
3	0.0000E+00		N/A
4	1.2626E-02	0.0126	-0.21%
5	1.3710E-01	0.1371	-0.00%
6	2.1288E-01	0.2129	0.01%
7	0.0000E+00		N/A
8	2.4383E-01	0.2438	-0.01%
9	0.0000E+00		N/A
10	2.4386E-01	0.2438	-0.02%
11	2.4388E-01	0.2438	-0.03%
12	0.0000E+00		N/A
13	2.1412E-01	0.2141	-0.01%
14	0.0000E+00		N/A
15	1.3426E-01	0.1342	-0.04%
16	1.5598E-02	0.0156	0.02%
17	0.0000E+00		N/A
18	4.3568E-03	0.0044	0.99%
19	0.0000E+00		N/A
20	5.4549E-08	0	N/A
21	0.0000E+00		N/A
22	0.0000E+00		N/A
23	0.0000E+00		N/A
24	0.0000E+00		N/A
25	6.6019E-03	0.0066	-0.03%
26	0.0000E+00		N/A
27	0.0000E+00		N/A
28	0.0000E+00		N/A
29	0.0000E+00		N/A
30	9.0729E-03	0.0091	0.30%
31	2.6793E-02	0.0268	0.03%
32	0.0000E+00		N/A
33	2.8586E-02	0.0286	0.05%
34	0.0000E+00		N/A
35	3.5129E-02	0.0351	-0.08%
36	0.0000E+00		N/A
37	0.0000E+00		N/A
38	0.0000E+00		N/A
39	0.0000E+00		N/A
40	3.6328E-02	0.0363	-0.08%
41	3.3668E-02	0.0337	0.10%
42	0.0000E+00		N/A
43	0.0000E+00		N/A
44	2.9760E-02	0.0298	0.14%

45	1.9342E-02	0.0193	-0.22%
46	2.1563E-03	0.0022	2.03%
47	0.0000E+00		N/A
48	1.2546E-05	0	N/A
49	0.0000E+00		N/A
50	3.2359E-06	0	N/A
51	0.0000E+00		N/A
52	0.0000E+00		N/A
53	0.0000E+00		N/A
54	0.0000E+00		N/A
55	4.8784E-08	0	N/A
56	0.0000E+00		N/A
57	0.0000E+00		N/A
58	0.0000E+00		N/A
59	0.0000E+00		N/A
60	4.4227E-03	0.0044	-0.51%
61	0.0000E+00		N/A
62	0.0000E+00		N/A
63	0.0000E+00		N/A
64	0.0000E+00		N/A
65	5.3981E-08	0	N/A
66	0.0000E+00		N/A
67	0.0000E+00		N/A
68	0.0000E+00		N/A
69	0.0000E+00		N/A
70	5.8988E-03	0.0059	0.02%
71	1.7980E-02	0.018	0.11%
72	0.0000E+00		N/A
73	1.9502E-02	0.0195	-0.01%
74	0.0000E+00		N/A
75	2.6305E-02	0.0263	-0.02%
76	0.0000E+00		N/A
77	0.0000E+00		N/A
78	0.0000E+00		N/A
79	0.0000E+00		N/A
80	3.5424E-02	0.0354	-0.07%
81	3.7510E-02	0.0375	-0.03%
82	0.0000E+00		N/A
83	0.0000E+00		N/A
84	3.4077E-02	0.0341	0.07%
85	2.2168E-02	0.0222	0.15%
86	2.5241E-03	0.0025	-0.95%
87	0.0000E+00		N/A
88	1.2952E-05	0	N/A
89	0.0000E+00		N/A
90	3.3406E-06	0	N/A
91	0.0000E+00		N/A
92	0.0000E+00		N/A
93	0.0000E+00		N/A
94	0.0000E+00		N/A
95	5.0365E-08	0	N/A

96	0.0000E+00		N/A
97	0.0000E+00		N/A
98	6.8591E-03	0.0069	0.60%
99	0.0000E+00		N/A
100	7.7882E-03	0.0078	0.15%
101	0.0000E+00		N/A
102	0.0000E+00		N/A
103	0.0000E+00		N/A
104	0.0000E+00		N/A
105	1.6231E-02	0.0162	-0.19%
106	0.0000E+00		N/A
107	0.0000E+00		N/A
108	0.0000E+00		N/A
109	0.0000E+00		N/A
110	5.1417E-08	0	N/A
111	3.2014E-02	0.032	-0.04%
112	0.0000E+00		N/A
113	3.8590E-02	0.0386	0.03%
114	0.0000E+00		N/A
115	4.4797E-02	0.0448	0.01%
116	0.0000E+00		N/A
117	0.0000E+00		N/A
118	0.0000E+00		N/A
119	0.0000E+00		N/A
120	6.0182E-02	0.0602	0.03%
121	5.7435E-02	0.0574	-0.06%
122	0.0000E+00		N/A
123	0.0000E+00		N/A
124	5.0766E-02	0.0508	0.07%
125	3.2820E-02	0.0328	-0.06%
126	3.7553E-03	0.0038	1.19%
127	0.0000E+00		N/A
128	1.5603E-05	0	N/A
129	0.0000E+00		N/A
130	4.0246E-06	0	N/A
131	0.0000E+00		N/A
132	0.0000E+00		N/A
133	0.0000E+00		N/A
134	0.0000E+00		N/A
135	0.0000E+00		N/A
136	0.0000E+00		N/A
137	0.0000E+00		N/A
138	0.0000E+00		N/A
139	0.0000E+00		N/A
140	6.0673E-08	0	N/A
141	0.0000E+00		N/A
142	0.0000E+00		N/A
143	0.0000E+00		N/A
144	0.0000E+00		N/A
145	0.0000E+00		N/A
146	0.0000E+00		N/A

147	0.0000E+00	N/A
148	0.0000E+00	N/A
149	0.0000E+00	N/A
150	0.0000E+00	N/A
151	0.0000E+00	N/A
152	0.0000E+00	N/A
153	0.0000E+00	N/A
154	0.0000E+00	N/A
155	0.0000E+00	N/A
156	0.0000E+00	N/A
157	0.0000E+00	N/A
158	0.0000E+00	N/A
159	0.0000E+00	N/A
160	0.0000E+00	N/A
161	0.0000E+00	N/A
162	0.0000E+00	N/A
163	0.0000E+00	N/A
164	0.0000E+00	N/A
165	0.0000E+00	N/A
166	0.0000E+00	N/A
167	0.0000E+00	N/A
168	0.0000E+00	N/A
169	0.0000E+00	N/A
170	0.0000E+00	N/A

NODAL DISPLACEMENT

	Z-DIR. DISPLACEMENT		
NODE NO.	NUREG (1)	GAPPIPE (2)	% DIFFERENCE ((2)-(1))/(1)*100%
1	0.0000E+00		N/A
2	1.5704E-03	0.0016	1.88%
3	0.0000E+00		N/A
4	1.0175E-02	0.0102	0.24%
5	1.0246E-02	0.0102	-0.45%
6	1.0258E-02	0.0103	0.41%
7	0.0000E+00		N/A
8	4.2529E-02	0.0425	-0.07%
9	0.0000E+00		N/A
10	1.4599E-01	0.146	0.01%
11	3.1155E-01	0.3115	-0.02%
12	0.0000E+00		N/A
13	3.4272E-01	0.3427	-0.00%
14	0.0000E+00		N/A
15	3.4275E-01	0.3427	-0.01%
16	3.4276E-01	0.3427	-0.02%
17	0.0000E+00		N/A
18	3.3296E-01	0.3329	-0.02%
19	0.0000E+00		N/A
20	3.0513E-01	0.3051	-0.01%
21	0.0000E+00		N/A
22	0.0000E+00		N/A
23	0.0000E+00		N/A
24	0.0000E+00		N/A
25	2.3497E-01	0.2349	-0.03%
26	0.0000E+00		N/A
27	0.0000E+00		N/A
28	0.0000E+00		N/A
29	0.0000E+00		N/A
30	1.1216E-01	0.1121	-0.05%
31	7.9233E-02	0.0792	-0.04%
32	0.0000E+00		N/A
33	7.8076E-02	0.0781	0.03%
34	0.0000E+00		N/A
35	7.8062E-02	0.0781	0.05%
36	0.0000E+00		N/A
37	0.0000E+00		N/A
38	0.0000E+00		N/A
39	0.0000E+00		N/A
40	7.8033E-02	0.078	-0.04%
41	7.8011E-02	0.078	-0.01%
42	0.0000E+00		N/A
43	0.0000E+00		N/A
44	7.1388E-02	0.0714	0.02%

45	4.9073E-02	0.0491	0.05%
46	1.1821E-02	0.0118	-0.18%
47	0.0000E+00		N/A
48	5.2949E-03	0.0053	0.10%
49	0.0000E+00		N/A
50	1.2978E-03	0.0013	0.17%
51	0.0000E+00		N/A
52	0.0000E+00		N/A
53	0.0000E+00		N/A
54	0.0000E+00		N/A
55	1.0634E-07	0	N/A
56	0.0000E+00		N/A
57	0.0000E+00		N/A
58	0.0000E+00		N/A
59	0.0000E+00		N/A
60	3.3988E-02	0.034	0.03%
61	0.0000E+00		N/A
62	0.0000E+00		N/A
63	0.0000E+00		N/A
64	0.0000E+00		N/A
65	9.6922E-08	0	N/A
66	0.0000E+00		N/A
67	0.0000E+00		N/A
68	0.0000E+00		N/A
69	0.0000E+00		N/A
70	6.6275E-03	0.0066	-0.41%
71	1.0294E-02	0.0103	0.06%
72	0.0000E+00		N/A
73	1.0368E-02	0.0104	0.31%
74	0.0000E+00		N/A
75	1.0367E-02	0.0104	0.32%
76	0.0000E+00		N/A
77	0.0000E+00		N/A
78	0.0000E+00		N/A
79	0.0000E+00		N/A
80	1.0364E-02	0.0104	0.35%
81	1.0360E-02	0.0104	0.39%
82	0.0000E+00		N/A
83	0.0000E+00		N/A
84	9.7800E-03	0.0098	0.20%
85	7.2066E-03	0.0072	-0.09%
86	2.1734E-03	0.0022	1.22%
87	0.0000E+00		N/A
88	1.1610E-03	0.0012	3.36%
89	0.0000E+00		N/A
90	2.9753E-04	0.0003	0.83%
91	0.0000E+00		N/A
92	0.0000E+00		N/A
93	0.0000E+00		N/A
94	0.0000E+00		N/A
95	2.7215E-08	0	N/A

96	0.0000E+00		N/A
97	0.0000E+00		N/A
98	7.7922E-03	0.0078	0.10%
99	0.0000E+00		N/A
100	9.0227E-03	0.009	-0.25%
101	0.0000E+00		N/A
102	0.0000E+00		N/A
103	0.0000E+00		N/A
104	0.0000E+00		N/A
105	3.7942E-02	0.0379	-0.11%
106	0.0000E+00		N/A
107	0.0000E+00		N/A
108	0.0000E+00		N/A
109	0.0000E+00		N/A
110	6.6414E-02	0.0664	-0.02%
111	6.7065E-02	0.0671	0.05%
112	0.0000E+00		N/A
113	6.6159E-02	0.0662	0.06%
114	0.0000E+00		N/A
115	6.6157E-02	0.0661	-0.09%
116	0.0000E+00		N/A
117	0.0000E+00		N/A
118	0.0000E+00		N/A
119	0.0000E+00		N/A
120	6.6125E-02	0.0661	-0.04%
121	6.6097E-02	0.0661	0.00%
122	0.0000E+00		N/A
123	0.0000E+00		N/A
124	6.1337E-02	0.0613	-0.06%
125	4.3511E-02	0.0435	-0.02%
126	1.1506E-02	0.0115	-0.05%
127	0.0000E+00		N/A
128	5.5821E-03	0.0056	0.32%
129	0.0000E+00		N/A
130	1.4202E-03	0.0014	-1.43%
131	0.0000E+00		N/A
132	0.0000E+00		N/A
133	0.0000E+00		N/A
134	0.0000E+00		N/A
135	0.0000E+00		N/A
136	0.0000E+00		N/A
137	0.0000E+00		N/A
138	0.0000E+00		N/A
139	0.0000E+00		N/A
140	1.2653E-07	0	N/A
141	0.0000E+00		N/A
142	0.0000E+00		N/A
143	0.0000E+00		N/A
144	0.0000E+00		N/A
145	0.0000E+00		N/A
146	0.0000E+00		N/A

147	0.0000E+00	N/A
148	0.0000E+00	N/A
149	0.0000E+00	N/A
150	0.0000E+00	N/A
151	0.0000E+00	N/A
152	0.0000E+00	N/A
153	0.0000E+00	N/A
154	0.0000E+00	N/A
155	0.0000E+00	N/A
156	0.0000E+00	N/A
157	0.0000E+00	N/A
158	0.0000E+00	N/A
159	0.0000E+00	N/A
160	0.0000E+00	N/A
161	0.0000E+00	N/A
162	0.0000E+00	N/A
163	0.0000E+00	N/A
164	0.0000E+00	N/A
165	0.0000E+00	N/A
166	0.0000E+00	N/A
167	0.0000E+00	N/A
168	0.0000E+00	N/A
169	0.0000E+00	N/A
170	0.0000E+00	N/A

NODAL ROTATION

NODE NO.	X-DIR. ROTATION NUREG (1)	GAPPIPE (2)	% DIFFERENCE ((2)-(1))/(1)*100%
1	0.0000E+00		N/A
2	4.9439E-04	0.0005	1.13%
3	0.0000E+00		N/A
4	2.9433E-03	0.0029	-1.47%
5	4.6516E-03	0.0047	1.04%
6	4.8306E-03	0.0048	-0.63%
7	0.0000E+00		N/A
8	5.6235E-03	0.0056	-0.42%
9	0.0000E+00		N/A
10	5.7956E-03	0.0058	0.08%
11	5.4779E-03	0.0055	0.40%
12	0.0000E+00		N/A
13	4.6526E-03	0.0047	1.02%
14	0.0000E+00		N/A
15	4.2457E-03	0.0042	-1.08%
16	3.6891E-03	0.0037	0.29%
17	0.0000E+00		N/A
18	3.3305E-03	0.0033	-0.92%
19	0.0000E+00		N/A
20	3.2150E-03	0.0032	-0.47%
21	0.0000E+00		N/A
22	0.0000E+00		N/A
23	0.0000E+00		N/A
24	0.0000E+00		N/A
25	2.4341E-03	0.0024	-1.40%
26	0.0000E+00		N/A
27	0.0000E+00		N/A
28	0.0000E+00		N/A
29	0.0000E+00		N/A
30	1.1605E-03	0.0012	3.40%
31	5.7443E-04	0.0006	4.45%
32	0.0000E+00		N/A
33	4.5943E-04	0.0005	8.83%
34	0.0000E+00		N/A
35	2.7554E-04	0.0003	8.88%
36	0.0000E+00		N/A
37	0.0000E+00		N/A
38	0.0000E+00		N/A
39	0.0000E+00		N/A
40	3.0980E-04	0.0003	-3.16%
41	3.7324E-04	0.0004	7.17%
42	0.0000E+00		N/A
43	0.0000E+00		N/A
44	4.0394E-04	0.0004	-0.98%

45	4.1044E-04	0.0004	-2.54%
46	4.4760E-04	0.0004	-10.63%
47	0.0000E+00		N/A
48	3.1672E-04	0.0003	-5.28%
49	0.0000E+00		N/A
50	1.4378E-04	0.0001	-30.45%
51	0.0000E+00		N/A
52	0.0000E+00		N/A
53	0.0000E+00		N/A
54	0.0000E+00		N/A
55	3.6891E-08	0	N/A
56	0.0000E+00		N/A
57	0.0000E+00		N/A
58	0.0000E+00		N/A
59	0.0000E+00		N/A
60	5.8029E-04	0.0006	3.40%
61	0.0000E+00		N/A
62	0.0000E+00		N/A
63	0.0000E+00		N/A
64	0.0000E+00		N/A
65	2.5646E-08	0	N/A
66	0.0000E+00		N/A
67	0.0000E+00		N/A
68	0.0000E+00		N/A
69	0.0000E+00		N/A
70	1.7154E-04	0.0002	16.59%
71	3.3022E-04	0.0003	-9.15%
72	0.0000E+00		N/A
73	3.6026E-04	0.0004	11.03%
74	0.0000E+00		N/A
75	3.4994E-04	0.0003	-14.27%
76	0.0000E+00		N/A
77	0.0000E+00		N/A
78	0.0000E+00		N/A
79	0.0000E+00		N/A
80	1.7775E-04	0.0002	12.52%
81	9.8463E-05	0.0001	1.56%
82	0.0000E+00		N/A
83	0.0000E+00		N/A
84	7.0382E-05	0.0001	42.08%
85	6.8260E-05	0.0001	46.50%
86	7.6284E-05	0.0001	31.09%
87	0.0000E+00		N/A
88	6.5462E-05	0.0001	52.76%
89	0.0000E+00		N/A
90	3.2497E-05	0	N/A
91	0.0000E+00		N/A
92	0.0000E+00		N/A
93	0.0000E+00		N/A
94	0.0000E+00		N/A
95	8.5776E-09	0	N/A

96	0.0000E+00		N/A
97	0.0000E+00		N/A
98	1.7147E-04	0.0002	16.64%
99	0.0000E+00		N/A
100	1.7140E-04	0.0002	16.69%
101	0.0000E+00		N/A
102	0.0000E+00		N/A
103	0.0000E+00		N/A
104	0.0000E+00		N/A
105	2.2970E-04	0.0002	-12.93%
106	0.0000E+00		N/A
107	0.0000E+00		N/A
108	0.0000E+00		N/A
109	0.0000E+00		N/A
110	3.6095E-04	0.0004	10.82%
111	4.5364E-04	0.0005	10.22%
112	0.0000E+00		N/A
113	4.8421E-04	0.0005	3.26%
114	0.0000E+00		N/A
115	4.6192E-04	0.0005	8.24%
116	0.0000E+00		N/A
117	0.0000E+00		N/A
118	0.0000E+00		N/A
119	0.0000E+00		N/A
120	1.1193E-04	0.0001	-10.66%
121	2.0558E-04	0.0002	-2.71%
122	0.0000E+00		N/A
123	0.0000E+00		N/A
124	2.4733E-04	0.0002	-19.14%
125	2.5894E-04	0.0003	15.86%
126	3.9052E-04	0.0004	2.43%
127	0.0000E+00		N/A
128	3.1589E-04	0.0003	-5.03%
129	0.0000E+00		N/A
130	1.5554E-04	0.0002	28.59%
131	0.0000E+00		N/A
132	0.0000E+00		N/A
133	0.0000E+00		N/A
134	0.0000E+00		N/A
135	0.0000E+00		N/A
136	0.0000E+00		N/A
137	0.0000E+00		N/A
138	0.0000E+00		N/A
139	0.0000E+00		N/A
140	4.0828E-08	0	N/A
141	0.0000E+00		N/A
142	0.0000E+00		N/A
143	0.0000E+00		N/A
144	0.0000E+00		N/A
145	0.0000E+00		N/A
146	0.0000E+00		N/A

147	0.0000E+00	N/A
148	0.0000E+00	N/A
149	0.0000E+00	N/A
150	0.0000E+00	N/A
151	0.0000E+00	N/A
152	0.0000E+00	N/A
153	0.0000E+00	N/A
154	0.0000E+00	N/A
155	0.0000E+00	N/A
156	0.0000E+00	N/A
157	0.0000E+00	N/A
158	0.0000E+00	N/A
159	0.0000E+00	N/A
160	0.0000E+00	N/A
161	0.0000E+00	N/A
162	0.0000E+00	N/A
163	0.0000E+00	N/A
164	0.0000E+00	N/A
165	0.0000E+00	N/A
166	0.0000E+00	N/A
167	0.0000E+00	N/A
168	0.0000E+00	N/A
169	0.0000E+00	N/A
170	0.0000E+00	N/A

NODAL ROTATION

	Y-DIR. ROTATION		
NODE NO.	NUREG (1)	GAPPIPE (2)	% DIFFERENCE ((2)-(1))/(1)*100%
1	0.0000E+00		N/A
2	1.4871E-04	0.0001	-32.75%
3	0.0000E+00		N/A
4	5.9654E-04	0.0006	0.58%
5	9.9068E-04	0.0010	0.94%
6	1.0207E-03	0.0010	-2.03%
7	0.0000E+00		N/A
8	1.1197E-03	0.0011	-1.76%
9	0.0000E+00		N/A
10	1.1803E-03	0.0012	1.67%
11	1.2787E-03	0.0013	1.67%
12	0.0000E+00		N/A
13	1.3679E-03	0.0014	2.35%
14	0.0000E+00		N/A
15	1.4385E-03	0.0014	-2.68%
16	1.5752E-03	0.0016	1.58%
17	0.0000E+00		N/A
18	1.7575E-03	0.0018	2.42%
19	0.0000E+00		N/A
20	1.8046E-03	0.0018	-0.26%
21	0.0000E+00		N/A
22	0.0000E+00		N/A
23	0.0000E+00		N/A
24	0.0000E+00		N/A
25	2.1106E-03	0.0021	-0.50%
26	0.0000E+00		N/A
27	0.0000E+00		N/A
28	0.0000E+00		N/A
29	0.0000E+00		N/A
30	1.8626E-03	0.0019	2.01%
31	9.9997E-04	0.0010	0.00%
32	0.0000E+00		N/A
33	6.5024E-04	0.0007	7.65%
34	0.0000E+00		N/A
35	7.6983E-05	0.0001	29.90%
36	0.0000E+00		N/A
37	0.0000E+00		N/A
38	0.0000E+00		N/A
39	0.0000E+00		N/A
40	8.8744E-04	0.0009	1.42%
41	1.2562E-03	0.0013	3.48%
42	0.0000E+00		N/A
43	0.0000E+00		N/A
44	1.5708E-03	0.0016	1.86%

97	0.0000E+00		N/A
98	2.9814E-04	0.0003	0.62%
99	0.0000E+00		N/A
100	3.2251E-04	0.0003	-6.98%
101	0.0000E+00		N/A
102	0.0000E+00		N/A
103	0.0000E+00		N/A
104	0.0000E+00		N/A
105	6.4667E-04	0.0006	-7.22%
106	0.0000E+00		N/A
107	0.0000E+00		N/A
108	0.0000E+00		N/A
109	0.0000E+00		N/A
110	2.3777E-04	0.0002	-15.89%
111	1.8081E-04	0.0002	10.61%
112	0.0000E+00		N/A
113	2.9634E-04	0.0003	1.24%
114	0.0000E+00		N/A
115	3.3064E-04	0.0003	-9.27%
116	0.0000E+00		N/A
117	0.0000E+00		N/A
118	0.0000E+00		N/A
119	0.0000E+00		N/A
120	2.2842E-04	0.0002	-12.44%
121	7.2680E-04	0.0007	-3.69%
122	0.0000E+00		N/A
123	0.0000E+00		N/A
124	1.2296E-03	0.0012	-2.41%
125	1.2964E-03	0.0013	0.28%
126	1.1215E-03	0.0011	-1.92%
127	0.0000E+00		N/A
128	7.4204E-04	0.0007	-5.66%
129	0.0000E+00		N/A
130	1.8927E-04	0.0002	5.67%
131	0.0000E+00		N/A
132	0.0000E+00		N/A
133	0.0000E+00		N/A
134	0.0000E+00		N/A
135	0.0000E+00		N/A
136	0.0000E+00		N/A
137	0.0000E+00		N/A
138	0.0000E+00	0.0000	N/A
139	0.0000E+00		N/A
140	2.8770E-08		N/A
141	0.0000E+00		N/A
142	0.0000E+00		N/A
143	0.0000E+00		N/A
144	0.0000E+00		N/A
145	0.0000E+00		N/A
146	0.0000E+00		N/A
147	0.0000E+00		N/A
148	0.0000E+00		N/A

149	0.0000E+00	N/A
150	0.0000E+00	N/A
151	0.0000E+00	N/A
152	0.0000E+00	N/A
153	0.0000E+00	N/A
154	0.0000E+00	N/A
155	0.0000E+00	N/A
156	0.0000E+00	N/A
157	0.0000E+00	N/A
158	0.0000E+00	N/A
159	0.0000E+00	N/A
160	0.0000E+00	N/A
161	0.0000E+00	N/A
162	0.0000E+00	N/A
163	0.0000E+00	N/A
164	0.0000E+00	N/A
165	0.0000E+00	N/A
166	0.0000E+00	N/A
167	0.0000E+00	N/A
168	0.0000E+00	N/A
169	0.0000E+00	N/A
170	0.0000E+00	N/A

NODAL ROTATION

	Z-DIR. ROTATION		
NODE NO.	NUREG (1)	GAPPIPE (2)	% DIFFERENCE ((2)-(1))/(1)*100%
1	0.0000E+00		N/A
2	4.3453E-05	0	N/A
3	0.0000E+00		N/A
4	2.8785E-04	0.0003	4.22%
5	4.8167E-04	0.0005	3.81%
6	5.1415E-04	0.0005	-2.75%
7	0.0000E+00		N/A
8	6.2890E-04	0.0006	-4.60%
9	0.0000E+00		N/A
10	6.5629E-04	0.0007	6.66%
11	6.0289E-04	0.0006	-0.48%
12	0.0000E+00		N/A
13	4.9990E-04	0.0005	0.02%
14	0.0000E+00		N/A
15	4.0873E-04	0.0004	-2.14%
16	2.6385E-04	0.0003	13.70%
17	0.0000E+00		N/A
18	2.8414E-04	0.0003	5.58%
19	0.0000E+00		N/A
20	2.6031E-04	0.0003	15.25%
21	0.0000E+00		N/A
22	0.0000E+00		N/A
23	0.0000E+00		N/A
24	0.0000E+00		N/A
25	1.2807E-04	0.0001	-21.92%
26	0.0000E+00		N/A
27	0.0000E+00		N/A
28	0.0000E+00		N/A
29	0.0000E+00		N/A
30	6.5295E-05	0.0001	53.15%
31	2.2404E-04	0.0002	-10.73%
32	0.0000E+00		N/A
33	2.4192E-04	0.0002	-17.33%
34	0.0000E+00		N/A
35	3.5426E-04	0.0004	12.91%
36	0.0000E+00		N/A
37	0.0000E+00		N/A
38	0.0000E+00		N/A
39	0.0000E+00		N/A
40	5.5886E-04	0.0006	7.36%
41	6.7143E-04	0.0007	4.25%
42	0.0000E+00		N/A
43	0.0000E+00		N/A
44	7.3746E-04	0.0007	-5.08%
45	7.4283E-04	0.0007	-5.77%

46	5.7791E-04	0.0006	3.82%
47	0.0000E+00		N/A
48	2.8368E-04	0.0003	5.75%
49	0.0000E+00		N/A
50	7.5058E-05	0.0001	33.23%
51	0.0000E+00		N/A
52	0.0000E+00		N/A
53	0.0000E+00		N/A
54	0.0000E+00		N/A
55	1.5794E-08	0	N/A
56	0.0000E+00		N/A
57	0.0000E+00		N/A
58	0.0000E+00		N/A
59	0.0000E+00		N/A
60	1.3447E-04	0.0001	-25.63%
61	0.0000E+00		N/A
62	0.0000E+00		N/A
63	0.0000E+00		N/A
64	0.0000E+00		N/A
65	2.8675E-08	0	N/A
66	0.0000E+00		N/A
67	0.0000E+00		N/A
68	0.0000E+00		N/A
69	0.0000E+00		N/A
70	2.3499E-04	0.0002	-14.89%
71	4.1539E-04	0.0004	-3.70%
72	0.0000E+00		N/A
73	4.3969E-04	0.0004	-9.03%
74	0.0000E+00		N/A
75	5.3226E-04	0.0005	-6.06%
76	0.0000E+00		N/A
77	0.0000E+00		N/A
78	0.0000E+00		N/A
79	0.0000E+00		N/A
80	6.9980E-04	0.0007	0.03%
81	7.9250E-04	0.0008	0.95%
82	0.0000E+00		N/A
83	0.0000E+00		N/A
84	8.4502E-04	0.0008	-5.33%
85	8.4779E-04	0.0008	-5.64%
86	6.6708E-04	0.0007	4.94%
87	0.0000E+00		N/A
88	3.4554E-04	0.0003	-13.18%
89	0.0000E+00		N/A
90	9.8093E-05	0.0001	1.94%
91	0.0000E+00		N/A
92	0.0000E+00		N/A
93	0.0000E+00		N/A
94	0.0000E+00		N/A
95	2.0975E-08	0	N/A
96	0.0000E+00		N/A
97	0.0000E+00		N/A

98	2.3482E-04	0.0002	-14.83%
99	0.0000E+00		N/A
100	2.3419E-04	0.0002	-14.60%
101	0.0000E+00		N/A
102	0.0000E+00		N/A
103	0.0000E+00		N/A
104	0.0000E+00		N/A
105	9.1896E-05	0.0001	8.82%
106	0.0000E+00		N/A
107	0.0000E+00		N/A
108	0.0000E+00		N/A
109	0.0000E+00		N/A
110	6.4295E-04	0.0006	-6.68%
111	9.8722E-04	0.001	1.30%
112	0.0000E+00		N/A
113	1.0294E-03	0.001	-2.85%
114	0.0000E+00		N/A
115	1.0585E-03	0.0011	3.92%
116	0.0000E+00		N/A
117	0.0000E+00		N/A
118	0.0000E+00		N/A
119	0.0000E+00		N/A
120	1.1943E-03	0.0012	0.47%
121	1.2515E-03	0.0013	3.88%
122	0.0000E+00		N/A
123	0.0000E+00		N/A
124	1.2803E-03	0.0013	1.54%
125	1.2712E-03	0.0013	2.27%
126	9.8498E-04	0.001	1.52%
127	0.0000E+00		N/A
128	5.2935E-04	0.0005	-5.54%
129	0.0000E+00		N/A
130	1.5226E-04	0.0002	31.35%
131	0.0000E+00		N/A
132	0.0000E+00		N/A
133	0.0000E+00		N/A
134	0.0000E+00		N/A
135	0.0000E+00		N/A
136	0.0000E+00		N/A
137	0.0000E+00		N/A
138	0.0000E+00		N/A
139	0.0000E+00		N/A
140	3.2507E-08	0	N/A
141	0.0000E+00		N/A
142	0.0000E+00		N/A
143	0.0000E+00		N/A
144	0.0000E+00		N/A
145	0.0000E+00		N/A
146	0.0000E+00		N/A
147	0.0000E+00		N/A
148	0.0000E+00		N/A
149	0.0000E+00		N/A

150	0.0000E+00	N/A
151	0.0000E+00	N/A
152	0.0000E+00	N/A
153	0.0000E+00	N/A
154	0.0000E+00	N/A
155	0.0000E+00	N/A
156	0.0000E+00	N/A
157	0.0000E+00	N/A
158	0.0000E+00	N/A
159	0.0000E+00	N/A
160	0.0000E+00	N/A
161	0.0000E+00	N/A
162	0.0000E+00	N/A
163	0.0000E+00	N/A
164	0.0000E+00	N/A
165	0.0000E+00	N/A
166	0.0000E+00	N/A
167	0.0000E+00	N/A
168	0.0000E+00	N/A
169	0.0000E+00	N/A
170	0.0000E+00	N/A

BENCHMARK PROBLEM NO.7, ELEMENT STRESSES

GAPPIPE VERSION 2.0

NUREG RESULTS

ELEM NO.	PX(I) PX(J)	VY(I) VY(J)	VZ(I) VZ(J)	TX(I) TX(J)	MY(I) MY(J)	MZ(I) MZ(J)	PX(J/C)	VY(J/C)	VZ(J/C)	TX(J/C)	MY(J/C)	MZ(J/C)
1	2.369E+02	2.665E+02	8.072E+01	4.947E+03	2.106E+03	2.217E+04	2.369E+02	2.665E+02	8.072E+01	4.947E+03	1.656E+03	2.059E+04
2	2.369E+02	2.665E+02	8.072E+01	4.947E+03	1.656E+03	2.059E+04	5.266E+01	3.527E+02	8.072E+01	2.546E+03	4.295E+03	1.906E+04
	2.665E+02	2.369E+02	8.072E+01	1.233E+03	4.468E+03	1.760E+04						
3	2.665E+02	2.369E+02	8.072E+01	1.233E+03	4.468E+03	1.760E+04	2.665E+02	2.369E+02	8.072E+01	1.233E+03	1.947E+03	1.011E+04
4	2.619E+02	1.701E+02	5.751E+01	1.233E+03	1.947E+03	1.011E+04	2.619E+02	1.701E+02	5.751E+01	1.233E+03	1.038E+03	7.444E+03
5	2.619E 02	1.701E+02	5.751E+01	1.233E+03	1.038E+03	7.444E+03	7.292E+01	3.057E+02	5.751E+01	2.637E+02	1.367E+03	6.282E+03
	1.701E+02	2.619E+02	5.751E+01	7.031E+02	9.182E+02	4.882E+03						
6	1.701E+02	2.619E+02	5.751E+01	7.031E+02	9.182E+02	4.882E+03	1.701E+02	2.619E+02	5.751E+01	7.031E+02	4.899E+02	2.753E+02
7	7.799E+01	2.070E+02	3.153E+01	7.031E+02	4.899E+02	2.753E+02	7.799E+01	2.070E+02	3.153E+01	7.031E+02	8.940E+02	5.847E+03
8	7.799E+01	2.070E+02	3.153E+01	7.031E+02	8.940E+02	5.847E+03	2.014E+02	9.151E+01	3.153E+01	2.465E+02	1.234E+03	6.588E+03
	2.070E+02	7.799E+01	3.153E+01	1.060E+03	8.666E+02	6.621E+03						
9	2.070E+02	7.799E+01	3.153E+01	1.060E+03	8.666E+02	6.621E+03	2.070E+02	7.799E+01	3.153E+01	1.060E+03	1.397E+03	5.221E+03
10	6.936E+01	3.331E+01	3.743E+01	1.060E+03	1.397E+03	5.221E+03	6.936E+01	3.331E+01	3.743E+01	1.060E+03	2.008E+03	4.479E+03
11	6.936E+01	3.743E+01	3.331E+01	1.060E+03	4.479E+03	2.008E+03	5.133E+01	5.980E+01	3.331E+01	3.856E+03	2.355E+03	2.215E+03
	3.743E+01	6.936E+01	3.331E+01	4.343E+03	1.198E+03	2.485E+03						
12	3.743E+01	3.331E+01	6.936E+01	4.343E+03	2.485E+03	1.198E+03	3.743E+01	3.331E+01	6.936E+01	4.343E+03	3.413E+03	1.628E+03
13	3.755E+01	2.386E+01	4.334E+01	4.343E+03	3.413E+03	1.628E+03	3.755E+01	2.386E+01	4.334E+01	4.343E+03	2.144E+03	1.038E+03
14	3.761E+01	1.923E+01	9.375E+01	4.343E+03	2.144E+03	1.038E+03	3.761E+01	1.923E+01	9.375E+01	4.343E+03	3.974E+03	8.064E+02
15	5.376E+01	2.267E+01	3.160E+01	1.378E+03	2.377E+03	1.687E+03	5.376E+01	2.267E+01	3.160E+01	1.378E+03	3.316E+03	1.038E+03
16	5.376E+01	3.160E+01	2.267E+01	1.378E+03	1.038E+03	3.316E+03	6.131E+01	1.143E+01	2.267E+01	9.453E+02	1.417E+03	3.350E+03
	5.968E+01	1.811E+01	2.267E+01	4.738E+02	1.611E+03	3.344E+03						
17	5.969E+01	2.267E+01	1.805E+01	4.748E+02	3.344E+03	1.611E+03	5.969E+01	2.267E+01	1.805E+01	4.748E+02	3.032E+03	1.371E+03
18	6.928E+01	1.949E+01	2.251E+01	4.748E+02	3.032E+03	1.371E+03	6.928E+01	1.949E+01	2.251E+01	4.748E+02	2.281E+03	8.857E+02
19	9.030E+01	3.228E+01	3.068E+01	4.748E+02	2.281E+03	8.857E+02	9.030E+01	3.228E+01	3.068E+01	4.748E+02	1.742E+03	2.852E+02
20	9.030E+01	3.068E+01	3.228E+01	4.748E+02	2.852E+02	1.742E+03	4.509E+01	8.403E+01	3.228E+01	2.283E+02	4.217E+02	1.540E+03
	3.068E+01	9.030E+01	3.228E+01	1.778E+02	3.362E+02	1.223E+03						
21	3.068E+01	3.228E+01	9.030E+01	1.778E+02	1.223E+03	3.362E+02	3.068E+01	3.228E+01	9.030E+01	1.778E+02	2.567E+02	1.825E+02
22	3.387E+01	4.878E+01	1.061E+02	1.778E+02	2.567E+02	1.825E+02	3.387E+01	4.878E+01	1.061E+02	1.778E+02	2.711E+03	1.319E+03
23	3.387E+01	4.878E+01	1.061E+02	1.778E+02	2.711E+03	1.319E+03	4.744E+01	3.573E+01	1.061E+02	2.154E+03	2.159E+03	1.457E+03
	4.878E+01	3.387E+01	1.061E+02	3.187E+03	3.593E+02	1.488E+03						
24	4.878E+01	1.061E+02	3.387E+01	3.187E+03	1.488E+03	3.593E+02	4.878E+01	1.061E+02	3.387E+01	3.187E+03	1.433E+03	1.993E+03
25	4.878E+01	1.063E+02	3.430E+01	3.187E+03	1.433E+03	1.993E+03	4.878E+01	1.063E+02	3.430E+01	3.187E+03	1.579E+03	3.689"+03
26	4.310E+01	2.587E+01	7.841E+01	2.413E+03	1.919E+03	1.323E+03	4.310E+01	2.587E+01	7.841E+01	2.413E+03	4.943E+03	1.888E+02
27	4.312E+01	3.246E+01	8.771E+01	2.413E+03	4.943E+03	1.888E+02	4.312E+01	3.246E+01	8.771E+01	2.413E+03	8.982E+03	1.495E+03
28	4.972E+01	3.809E+01	3.950E+01	8.152E+02	2.453E+03	2.244E+03	4.972E+01	3.809E+01	3.950E+01	8.152E+02	9.842E+02	6.787E+02
29	1.776E+01	2.457E+01	1.905E+01	1.152E+02	9.710E+02	1.276E+03	1.776E+01	2.457E+01	1.905E+01	1.152E+02	5.172E+02	5.011E+02
30	1.776E+01	1.905E+01	2.457E+01	1.152E+02	5.011E+02	5.172E+02	2.022E+01	1.641E+01	2.457E+01	2.881E+02	3.806E+02	4.989E+02
	2.143E+01	1.453E+01	2.457E+01	4.027E+02	2.060E+02	4.772E+02						
31	2.143E+01	2.457E+01	1.454E+01	4.025E+02	4.772E+02	2.064E+02	2.143E+01	2.457E+01	1.454E+01	4.025E+02	2.592E+02	3.385E+02
32	1.781E+01	1.264E+01	1.448E+01	4.025E+02	2.592E+02	3.385E+02	1.781E+01	1.264E+01	1.448E+01	4.025E+02	3.579E+02	7.475E+02
33	1.970E+01	2.881E+01	2.063E+01	4.025E+02	3.579E+02	7.475E+02	1.970E+01	2.881E+01	2.063E+01	4.025E+02	5.930E+02	2.395E+02
34	1.970E+01	2.063E+01	2.881E+01	4.025E+02	2.395E+02	5.930E+02	2.685E+01	9.677E+00	2.881E+01	1.941E+02	3.625E+02	6.225E+02
	2.063E+01	1.970E+01	2.881E+01	1.551E+02	2.840E+02	5.860E+02						
35	2.063E+01	2.881E+01	1.970E+01	1.551E+02	5.860E+02	2.840E+02	2.063E+01	2.881E+01	1.970E+01	1.551E+02	3.360E+02	2.026E+02
36	2.853E+01	5.036E+01	2.702E+01	1.551E+02	3.360E+02	2.026E+02	2.853E+01	5.036E+01	2.702E+01	1.551E+02	3.632E+02	1.397E+03

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37 2.853E+01 5.036E+01 2.702E+01 1.551E+02 3.632E+02 1.397E+03 3.619E+01 4.546E+01 2.702E+01 3.874E+02 2.574E+02 1.562E+03
   5.036E+01 2.853E+01 2.702E+01 4.820E+02 9.669E+01 1.645E+03
38 5.036E+01 2.702E+01 2.853E+01 4.820E+02 1.645E+03 9.669E+01 5.036E+01 2.702E+01 2.853E+01 4.820E+02 1.796E+03 4.280E+02
39 5.036E+01 2.721E+01 2.932E+01 4.820E+02 1.796E+03 4.280E+02 5.036E+01 2.721E+01 2.932E+01 4.820E+02 2.097E+03 8.578E+02
40 3.678E+01 2.209E+01 3.661E+01 2.200E+02 1.906E+03 7.219E+02 3.678E+01 2.209E+01 3.661E+01 2.200E+02 1.758E+03 6.544E+02
41 3.678E+01 2.209E+01 3.661E+01 2.200E+02 1.758E+03 6.544E+02 3.678E+01 2.209E+01 3.661E+01 2.200E+02 1.615E+03 5.947E+02
42 3.678E+01 2.209E+01 3.661E+01 2.200E+02 1.615E+03 5.947E+02 3.678E+01 2.209E+01 3.661E+01 2.200E+02 3.850E+02 8.880E+02
43 3.675E+01 1.759E+01 1.754E+01 2.200E+02 3.850E+02 8.880E+02 3.675E+01 1.759E+01 1.754E+01 2.200E+02 1.287E+03 1.663E+03
44 3.671E+01 3.550E+01 1.696E+01 2.200E+02 1.287E+03 1.663E+03 3.671E+01 3.550E+01 1.696E+01 2.200E+02 7.923E+02 3.647E+02
45 3.671E+01 1.696E+01 3.550E+01 2.200E+02 3.647E+02 7.923E+02 1.886E+01 3.582E+01 3.550E+01 1.226E+02 2.995E+02 7.135E+02
   1.696E+01 3.671E+01 3.550E+01 2.354E+02 8.521E+01 5.907E+02
46 1.696E+01 3.550E+01 3.671E+01 2.354E+02 5.907E+02 8.521E+01 1.696E+01 3.550E+01 3.671E+01 2.354E+02 2.159E+02 4.403E+02
47 4.405E+01 1.377E+01 3.383E+01 2.354E+02 2.159E+02 4.403E+02 4.405E+01 1.377E+01 3.383E+01 2.354E+02 1.968E+03 1.212E+03
48 9.427E+01 3.529E+01 2.607E+01 2.354E+02 1.968E+03 1.212E+03 9.427E+01 3.529E+01 2.607E+01 2.354E+02 2.491E+03 4.466E+02
49 9.427E+01 2.607E+01 3.529E+01 2.354E+02 4.466E+02 2.491E+03 8.305E+01 5.167E+01 3.529E+01 3.697E+02 3.209E+02 2.439E+03
   2.607E+01 9.427E+01 3.529E+01 4.692E+02 1.390E+02 2.170E+03
50 2.607E+01 3.529E+01 9.427E+01 4.692E+02 2.170E+03 1.390E+02 2.607E+01 3.529E+01 9.427E+01 4.692E+02 8.539E+02 4.759E+02
51 3.400E+01 6.067E+01 1.261E+02 4.692E+02 8.539E+02 4.759E+02 3.400E+01 6.067E+01 1.261E+02 4.692E+02 2.310E+03 1.961E+03
52 3.400E+01 6.067E+01 1.261E+02 4.692E+02 2.310E+03 1.961E+03 2.955E+01 6.285E+01 1.261E+02 2.128E+03 1.707E+03 2.187E+03
   6.067E+01 3.400E+01 1.261E+02 2.877E+03 2.027E+02 2.348E+03
53 6.067E+01 1.261E+02 3.400E+01 2.877E+03 2.348E+03 2.027E+02 6.067E+01 1.261E+02 3.400E+01 2.877E+03 2.773E+03 2.064E+03
54 6.067E+01 1.265E+02 3.477E+01 2.877E+03 2.773E+03 2.064E+03 6.067E+01 1.265E+02 3.477E+01 2.877E+03 3.251E+03 4.083E+03
 1 2.439E-01 0.000E+00
 2 3.633E-02 0.000E+00
 3 3.542E-02 0.000E+00
 4 6.018E-02 0.000E+00
 5 5.455E+01 0.000E+00
 6 5.142E+01 0.000E+00
 7 3.430E+01 0.000E+00
 8 4.878E+01 0.000E+00
 9 1.063E+02 0.000E+00
10 6.909E+01 0.000E+00
11 5.398E+01 0.000E+00
12 9.692E+01 0.000E+00
13 2.932E+01 0.000E+00
14 5.036E+01 0.000E+00
15 2.721E+01 0.000E+00
16 3.477E+01 0.000E+00
17 6.067E+01 0.000E+00
18 1.265E+02 0.000E+00
19 3.689E+03 0.000E+00
20 3.187E+03 0.000E+00
21 1.579E+03 0.000E+00
22 2.565E+03 0.000E+00
23 9.334E+03 0.000E+00
24 2.867E+03 0.000E+00
25 8.578E+02 0.000E+00
26 4.820E+02 0.000E+00
27 2.097E+03 0.000E+00
28 4.083E+03 0.000E+00
29 2.877E+03 0.000E+00
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30 3.251E+03 0.000E+00

1 GAPPIPE VERSION 2.0 RESULTS

ELEM NO.	PX(I) PX(J)	VY(I) VY(J)	VZ(I) VZ(J)	TX(I) TX(J)	MY(I) MY(J)	MZ(I) MZ(J)	PX(J/C)	VY(J/C)	VZ(J/C)	TX(J/C)	MY(J/C)	MZ(J/C)
1	2.368E+02	2.665E+02	8.070E+01	4.946E+03	2.106E+03	2.217E+04	2.368E+02	2.665E+02	8.070E+01	4.946E+03	1.656E+03	2.059E+04
2	2.368E+02	2.665E+02	8.070E+01	4.946E+03	1.656E+03	2.059E+04	5.270E+01	3.526E+02	8.070E+01	2.546E+03	4.295E+03	1.906E+04
	2.665E+02	2.368E+02	8.070E+01	1.233E+03	4.467E+03	1.760E+04						
3	2.665E+02	2.368E+02	8.070E+01	1.233E+03	4.467E+03	1.760E+04	2.665E+02	2.368E+02	8.070E+01	1.233E+03	1.947E+03	1.011E+04
4	2.619E+02	1.701E+02	5.750E+01	1.233E+03	1.947E+03	1.011E+04	2.619E+02	1.701E+02	5.750E+01	1.233E+03	1.038E+03	7.443E+03
5	2.619E+02	1.701E+02	5.750E+01	1.233E+03	1.038E+03	7.443E+03	7.290E+01	3.036E+02	5.750E+01	2.640E+02	1.367E+03	6.281E+03
	1.701E+02	2.619E+02	5.750E+01	7.030E+02	9.180E+02	4.881E+03						
6	1.701E+02	2.619E+02	5.750E+01	7.030E+02	9.180E+02	4.881E+03	1.701E+02	2.619E+02	5.750E+01	7.030E+02	4.900E+02	2.750E+02
7	7.800E+01	2.070E+02	3.150E+01	7.030E+02	4.900E+02	2.750E+02	7.800E+01	2.070E+02	3.150E+01	7.030E+02	8.940E+02	5.847E+03
8	7.800E+01	2.070E+02	3.150E+01	7.030E+02	8.940E+02	5.847E+03	2.013E+02	9.150E+01	3.150E+01	2.460E+02	1.234E+03	6.587E+03
	2.070E+02	7.800E+01	3.150E+01	1.060E+03	8.670E+02	6.621E+03						
9	2.070E+02	7.800E+01	3.150E+01	1.060E+03	8.670E+02	6.621E+03	2.070E+02	7.800E+01	3.150E+01	1.060E+03	1.396E+03	5.220E+03
10	6.930E+01	3.330E+01	3.740E+01	1.060E+03	1.396E+03	5.220E+03	6.930E+01	3.330E+01	3.740E+01	1.060E+03	2.008E+03	4.479E+03
11	6.930E+01	3.740E+01	3.330E+01	1.060E+03	4.479E+03	2.008E+03	5.130E+01	5.980E+01	3.330E+01	3.855E+03	2.355E+03	2.215E+03
	3.740E+01	6.930E+01	3.330E+01	4.343E+03	1.198E+03	2.485E+03						
12	3.740E+01	3.330E+01	6.930E+01	4.343E+03	2.485E+03	1.198E+03	3.740E+01	3.330E+01	6.930E+01	4.343E+03	3.413E+03	1.628E+03
13	3.750E+01	2.390E+01	4.330E+01	4.343E+03	3.413E+03	1.628E+03	3.750E+01	2.390E+01	4.330E+01	4.343E+03	2.143E+03	1.038E+03
14	3.760E+01	1.920E+01	9.370E+01	4.343E+03	2.143E+03	1.038E+03	3.760E+01	1.920E+01	9.370E+01	4.343E+03	3.974E+03	8.060E+02
15	5.380E+01	2.270E+01	3.160E+01	1.377E+03	2.376E+03	1.687E+03	5.380E+01	2.270E+01	3.160E+01	1.377E+03	3.316E+03	1.038E+03
16	5.380E+01	3.160E+01	2.270E+01	1.377E+03	1.038E+03	3.316E+03	6.130E+01	1.140E+01	2.270E+01	9.450E+02	1.416E+03	3.350E+03
	5.970E+01	1.810E+01	2.270E+01	4.740E+02	1.611E+03	3.343E+03						
17	5.970E+01	2.270E+01	1.810E+01	4.750E+02	3.343E+03	1.610E+03	5.970E+01	2.270E+01	1.810E+01	4.750E+02	3.031E+03	1.371E+03
18	6.930E+01	1.950E+01	2.250E+01	4.750E+02	3.031E+03	1.371E+03	6.930E+01	1.950E+01	2.250E+01	4.750E+02	2.281E+03	8.860E+02
19	9.030E+01	3.230E+01	3.070E+01	4.750E+02	2.281E+03	8.860E+02	9.030E+01	3.230E+01	3.070E+01	4.750E+02	1.742E+03	2.850E+02
20	9.030E+01	3.070E+01	3.230E+01	4.750E+02	2.850E+02	1.742E+03	4.510E+01	8.400E+01	3.230E+01	2.280E+02	4.220E+02	1.540E+03
	3.070E+01	9.030E+01	3.230E+01	1.780E+02	3.360E+02	1.223E+03						
21	3.070E+01	3.230E+01	9.030E+01	1.780E+02	1.223E+03	3.360E+02	3.070E+01	3.230E+01	9.030E+01	1.780E+02	2.570E+02	1.820E+02
22	3.390E+01	4.880E+01	1.061E+02	1.780E+02	2.570E+02	1.820E+02	3.390E+01	4.880E+01	1.061E+02	1.780E+02	2.711E+03	1.319E+03
23	3.390E+01	4.880E+01	1.061E+02	1.780E+02	2.711E+03	1.319E+03	4.740E+01	3.570E+01	1.061E+02	2.154E+03	2.158E+03	1.457E+03
	4.880E+01	3.390E+01	1.061E+02	3.186E+03	3.590E+02	1.488E+03						
24	4.880E+01	1.061E+02	3.390E+01	3.1[illegible]E+03	1.488E+03	3.590E+02	4.880E+01	1.061E+02	3.390E+01	3.186E+03	1.433E+03	1.993E+03
25	4.880E+01	1.063E+02	3.430E+01	3.186E+03	1.433E+03	1.993E+03	4.880E+01	1.063E+02	3.430E+01	3.186E+03	1.579E+03	3.689E+03
26	4.310E+01	2.590E+01	7.840E+01	2.413E+03	1.918E+03	1.323E+03	4.310E+01	2.590E+01	7.840E+01	2.413E+03	4.942E+03	1.890E+02
27	4.310E+01	3.250E+01	8.770E+01	2.413E+03	4.942E+03	1.890E+02	4.310E+01	3.250E+01	8.770E+01	2.413E+03	8.981E+03	1.495E+03
28	4.970E+01	3.810E+01	3.950E+01	8.150E+02	2.453E+03	2.263E+03	4.970E+01	3.810E+01	3.950E+01	8.150E+02	9.840E+02	6.790E+02
29	1.780E+01	2.460E+01	1.900E+01	1.150E+02	9.710E+02	1.276E+03	1.780E+01	2.460E+01	1.900E+01	1.150E+02	5.170E+02	5.010E+02
30	1.780E+01	1.900E+01	2.460E+01	1.150E+02	5.010E+02	5.170E+02	2.020E+01	1.640E+01	2.460E+01	2.880E+02	3.810E+02	4.990E+02
	2.140E+01	1.450E+01	2.460E+01	4.030E+02	2.060E+02	4.770E+02						
31	2.140E+01	2.460E+01	1.450E+01	4.020E+02	4.770E+02	2.060E+02	2.140E+01	2.460E+01	1.450E+01	4.020E+02	2.590E+02	3.380E+02
32	1.780E+01	1.260E+01	1.450E+01	4.020E+02	2.590E+02	3.380E+02	1.780E+01	1.260E+01	1.450E+01	4.020E+02	3.580E+02	7.470E+02
33	1.970E+01	2.880E+01	2.060E+01	4.020E+02	3.580E+02	7.470E+02	1.970E+01	2.880E+01	2.060E+01	4.020E+02	5.930E+02	2.390E+02
34	1.970E+01	2.060E+01	2.880E+01	4.020E+02	2.390E+02	5.930E+02	2.680E+01	9.700E+00	2.880E+01	1.940E+02	3.620E+02	6.220E+02
	2.060E+01	1.970E+01	2.880E+01	1.550E+02	2.840E+02	5.860E+02						
35	2.060E+01	2.880E+01	1.970E+01	1.550E+02	5.860E+02	2.840E+02	2.060E+01	2.880E+01	1.970E+01	1.550E+02	3.360E+02	2.030E+02
36	2.850E+01	5.040E+01	2.700E+01	1.550E+02	3.360E+02	2.030E+02	2.850E+01	5.040E+01	2.700E+01	1.550E+02	3.630E+02	1.397E+03
37	2.850E+01	5.040E+01	2.700E+01	1.550E+02	3.630E+02	1.397E+03	3.620E+01	4.550E+01	2.700E+01	3.870E+02	2.570E+02	1.562E+03
	5.040E+01	2.850E+01	2.700E+01	4.820E+02	9.700E+01	1.645E+03						

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38 5.040E+01 2.700E+01 2.850E+01 4.820E+02 1.645E+03 9.700E+01 5.040E+01 2.700E+01 2.850E+01 4.820E+02 1.795E+03 4.280E+02
39 5.040E+01 2.720E+01 2.930E+01 4.820E+02 1.795E+03 4.280E+02 5.040E+01 2.720E+01 2.930E+01 4.820E+02 2.097E+03 8.580E+02
40 3.680E+01 2.210E+01 3.660E+01 2.200E+02 1.906E+03 7.220E+02 3.680E+01 2.210E+01 3.660E+01 2.200E+02 1.758E+03 6.540E+02
41 3.680E+01 2.210E+01 3.660E+01 2.200E+02 1.758E+03 6.540E+02 3.680E+01 2.210E+01 3.660E+01 2.200E+02 1.614E+03 5.950E+02
42 3.680E+01 2.210E+01 3.660E+01 2.200E+02 1.614E+03 5.950E+02 3.680E+01 2.210E+01 3.660E+01 2.200E+02 3.850E+02 8.880E+02
43 3.670E+01 1.760E+01 1.750E+01 2.200E+02 3.850E+02 8.880E+02 3.670E+01 1.760E+01 1.750E+01 2.200E+02 1.287E+03 1.663E+03
44 3.670E+01 3.550E+01 1.700E+01 2.200E+02 1.287E+03 1.663E+03 3.670E+01 3.550E+01 1.700E+01 2.200E+02 7.920E+02 3.650E+02
45 3.670E+01 1.700E+01 3.550E+01 2.200E+02 3.650E+02 7.920E+02 1.890E+01 3.580E+01 3.550E+01 1.230E+02 2.990E+02 7.130E+02
   1.700E+01 3.670E+01 3.550E+01 2.350E+02 8.500E+01 5.910E+02
46 1.700E+01 3.550E+01 3.670E+01 2.350E+02 5.910E+02 8.500E+01 1.700E+01 3.550E+01 3.670E+01 2.350E+02 2.160E+02 4.400E+02
47 4.400E+01 1.380E+01 3.380E+01 2.350E+02 2.160E+02 4.400E+02 4.400E+01 1.380E+01 3.380E+01 2.350E+02 1.968E+03 1.212E+03
48 9.430E+01 3.530E+01 2.610E+01 2.350E+02 1.968E+03 1.212E+03 9.430E+01 3.530E+01 2.610E+01 2.350E+02 2.490E+03 4.470E+02
49 9.430E+01 2.610E+01 3.530E+01 2.350E+02 4.470E+02 2.490E+03 8.300E+01 5.170E+01 3.530E+01 3.700E+02 3.210E+02 2.439E+03
   2.610E+01 9.430E+01 3.530E+01 4.690E+02 1.390E+02 2.170E+03
50 2.610E+01 3.530E+01 9.430E+01 4.690E+02 2.170E+03 1.390E+02 2.610E+01 3.530E+01 9.430E+01 4.690E+02 8.540E+02 4.760E+02
51 3.400E+01 6.070E+01 1.261E+02 4.690E+02 8.540E+02 4.760E+02 3.400E+01 6.070E+01 1.261E+02 4.690E+02 2.310E+03 1.961E+03
52 3.400E+01 6.070E+01 1.261E+02 4.690E+02 2.310E+03 1.961E+03 2.960E+01 6.280E+01 1.261E+02 2.128E+03 1.707E+03 2.186E+03
   6.070E+01 3.400E+01 1.261E+02 2.877E+03 2.030E+02 2.348E+03
53 6.070E+01 1.261E+02 3.400E+01 2.877E+03 2.348E+03 2.030E+02 6.070E+01 1.261E+02 3.400E+01 2.877E+03 2.773E+03 2.064E+03
54 6.070E+01 1.265E+02 3.480E+01 2.877E+03 2.773E+03 2.064E+03 6.070E+01 1.265E+02 3.480E+01 2.877E+03 3.250E+03 4.082E+03
 1 2.438E-01 0.000E+00
 2 3.632E-02 0.000E+00
 3 3.542E-02 0.000E+00
 4 6.017E-02 0.000E+00
 5 5.454E+01 0.000E+00
 6 5.141E+01 0.000E+00
 7 3.430E+01 0.000E+00
 8 4.878E+01 0.000E+00
 9 1.063E+02 0.000E+00
10 6.908E+01 0.000E+00
11 5.397E+01 0.000E+00
12 9.691E+01 0.000E+00
13 2.932E+01 0.000E+00
14 5.036E+01 0.000E+00
15 2.721E+01 0.000E+00
16 3.476E+01 0.000E+00
17 6.067E+01 0.000E+00
18 1.265E+02 0.000E+00
19 0.000E+00 3.689E+03
20 0.000E+00 3.186E+03
21 0.000E+00 1.579E+03
22 0.000E+00 2.564E+03
23 0.000E+00 9.333E+03
24 0.000E+00 2.867E+03
25 0.000E+00 8.577E+02
26 0.000E+00 4.819E+02
27 0.000E+00 2.097E+03
28 0.000E+00 4.082E+03
29 0.000E+00 2.877E+03
30 0.000E+00 3.250E+03
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1 PERCENTAGE DIFFERENCES BETWEEN NUREG AND GAPPIPE VERSION 2.0 (BASED ON NUREG):

ELEM	PX(I)	VY(I)	VZ(I)	TX(I)	MY(I)	MZ(I)	PX(J/C)	VY(J/C)	VZ(J/C)	TX(J/C)	MY(J/C)	MZ(J/C)
NO.	PX(J)	VY(J)	VZ(J)	TX(J)	MY(J)	MZ(J)						
1	-0.04%	0.00%	-0.02%	-0.02%	0.00%	0.00%	-0.04%	0.00%	-0.02%	-0.02%	0.00%	0.00%
2	-0.04%	0.00%	-0.02%	-0.02%	0.00%	0.00%	0.06%	-0.03%	-0.02%	0.00%	0.00%	0.00%
	0.00%	-0.04%	-0.02%	0.00%	-0.02%	0.00%	N/A	N/A	N/A	N/A	N/A	N/A
3	0.00%	-0.04%	-0.02%	0.00%	-0.02%	0.00%	0.00%	-0.04%	-0.02%	0.00%	0.00%	0.00%
4	0.00%	0.00%	-0.02%	0.00%	0.00%	0.00%	0.00%	0.00%	-0.02%	0.00%	0.00%	-0.01%
5	0.00%	0.00%	-0.02%	0.00%	0.00%	-0.01%	-0.03%	-0.03%	-0.02%	0.11%	0.00%	-0.02%
	0.00%	0.00%	-0.02%	-0.01%	-0.02%	-0.02%	N/A	N/A	N/A	N/A	N/A	N/A
6	0.00%	0.00%	-0.02%	-0.01%	-0.02%	-0.02%	0.00%	0.00%	-0.02%	-0.01%	0.02%	-0.11%
7	0.01%	0.00%	-0.10%	-0.01%	0.02%	-0.11%	0.01%	0.00%	-0.10%	-0.01%	0.00%	0.00%
8	0.01%	0.00%	-0.10%	-0.01%	0.00%	0.00%	-0.05%	-0.01%	-0.10%	-0.20%	0.00%	-0.02%
	0.00%	0.01%	-0.10%	0.00%	0.05%	0.00%	N/A	N/A	N/A	N/A	N/A	N/A
9	0.00%	0.01%	-0.10%	0.00%	0.05%	0.00%	0.00%	0.01%	-0.10%	0.00%	-0.07%	-0.02%
10	-0.09%	-0.03%	-0.08%	0.00%	-0.07%	-0.02%	-0.09%	-0.03%	-0.08%	0.00%	0.00%	0.00%
11	-0.09%	-0.08%	-0.03%	0.00%	0.00%	0.00%	-0.06%	0.00%	-0.03%	-0.03%	0.00%	0.00%
	-0.08%	-0.09%	-0.03%	0.00%	0.00%	0.00%	N/A	N/A	N/A	N/A	N/A	N/A
12	-0.08%	-0.03%	-0.09%	0.00%	0.00%	0.00%	-0.08%	-0.03%	-0.09%	0.00%	0.00%	0.00%
13	-0.13%	0.17%	-0.09%	0.00%	0.00%	0.00%	-0.13%	0.17%	-0.09%	0.00%	-0.05%	0.00%
14	-0.03%	-0.16%	-0.05%	0.00%	-0.05%	0.00%	-0.03%	-0.16%	-0.05%	0.00%	0.00%	-0.05%
15	0.07%	0.13%	0.00%	-0.07%	-0.04%	0.00%	0.07%	0.13%	0.00%	-0.07%	0.00%	0.00%
16	0.07%	0.00%	0.13%	-0.07%	0.00%	0.00%	-0.02%	-0.26%	0.13%	-0.03%	-0.07%	0.00%
	0.03%	-0.06%	0.13%	0.04%	0.00%	-0.03%	N/A	N/A	N/A	N/A	N/A	N/A
17	0.02%	0.13%	0.28%	0.04%	-0.03%	-0.06%	0.02%	0.13%	0.28%	0.04%	-0.03%	0.00%
18	0.03%	0.05%	-0.04%	0.04%	-0.03%	0.00%	0.03%	0.05%	-0.04%	0.04%	0.00%	0.03%
19	0.00%	0.06%	0.07%	0.04%	0.00%	0.03%	0.00%	0.06%	0.07%	0.04%	0.00%	-0.07%
20	0.00%	0.07%	0.06%	0.04%	-0.07%	0.00%	0.02%	-0.04%	0.06%	-0.13%	0.07%	0.00%
	0.07%	0.00%	0.06%	0.11%	-0.06%	0.00%	N/A	N/A	N/A	N/A	N/A	N/A
21	0.07%	0.06%	0.00%	0.11%	0.00%	-0.06%	0.07%	0.06%	0.00%	0.11%	0.12%	-0.27%
22	0.09%	0.04%	0.00%	0.11%	0.12%	-0.27%	0.09%	0.04%	0.00%	0.11%	0.00%	0.00%
23	0.09%	0.04%	0.00%	0.11%	0.00%	0.00%	-0.08%	-0.08%	0.00%	0.00%	-0.05%	0.00%
	0.04%	0.09%	0.00%	-0.03%	-0.08%	0.00%	N/A	N/A	N/A	N/A	N/A	N/A
24	0.04%	0.00%	0.09%	-0.03%	0.00%	-0.08%	0.04%	0.00%	0.09%	-0.03%	0.00%	0.00%
25	0.04%	0.00%	0.00%	-0.03%	0.00%	0.00%	0.04%	0.00%	0.00%	-0.03%	0.00%	0.00%
26	0.00%	0.12%	-0.01%	0.00%	-0.05%	0.00%	0.00%	0.12%	-0.01%	0.00%	-0.02%	0.11%
27	-0.05%	0.12%	-0.01%	0.00%	-0.02%	0.11%	-0.05%	0.12%	-0.01%	0.00%	-0.01%	0.00%
28	-0.04%	0.03%	0.00%	-0.02%	0.00%	-0.04%	-0.04%	0.03%	0.00%	-0.02%	-0.02%	0.04%
29	0.23%	0.12%	-0.26%	-0.17%	0.00%	0.00%	0.23%	0.12%	-0.26%	-0.17%	-0.04%	-0.02%
30	0.23%	-0.26%	0.12%	-0.17%	-0.02%	-0.04%	-0.10%	-0.06%	0.12%	-0.03%	0.11%	0.02%
	-0.14%	-0.21%	0.12%	0.07%	0.00%	-0.04%	N/A	N/A	N/A	N/A	N/A	N/A
31	-0.14%	0.12%	-0.28%	-0.12%	-0.04%	-0.19%	-0.14%	0.12%	-0.28%	-0.12%	-0.08%	-0.15%
32	-0.06%	-0.32%	0.14%	-0.12%	-0.08%	-0.15%	-0.06%	-0.32%	0.14%	-0.12%	0.03%	-0.07%
33	0.00%	-0.03%	-0.15%	-0.12%	0.03%	-0.07%	0.00%	-0.03%	-0.15%	-0.12%	0.00%	-0.21%
34	0.00%	-0.15%	-0.03%	-0.12%	-0.21%	0.00%	-0.19%	0.24%	-0.03%	-0.05%	-0.14%	-0.08%
	-0.15%	0.00%	-0.03%	-0.06%	0.00%	0.00%	N/A	N/A	N/A	N/A	N/A	N/A
35	-0.15%	-0.03%	0.00%	-0.06%	0.00%	0.00%	-0.15%	-0.03%	0.00%	-0.06%	0.00%	0.20%
36	-0.11%	0.08%	-0.07%	-0.06%	0.00%	0.20%	-0.11%	0.08%	-0.07%	-0.06%	-0.06%	0.00%
37	-0.11%	0.08%	-0.07%	-0.06%	-0.06%	0.00%	0.03%	0.09%	-0.07%	-0.10%	-0.16%	0.00%
	0.08%	-0.11%	-0.07%	0.00%	0.32%	0.00%	N/A	N/A	N/A	N/A	N/A	N/A

38	0.08%	-0.07%	-0.11%	0.00%	0.00%	0.32%	0.08%	-0.07%	-0.11%	0.00%	-0.06%	0.00%
39	0.08%	-0.04%	-0.07%	0.00%	-0.06%	0.00%	0.08%	-0.04%	-0.07%	0.00%	0.00%	0.02%
40	0.05%	0.05%	-0.03%	0.00%	0.00%	0.01%	0.05%	0.05%	-0.03%	0.00%	0.00%	-0.06%
41	0.05%	0.05%	-0.03%	0.00%	0.00%	-0.06%	0.05%	0.05%	-0.03%	0.00%	-0.06%	0.05%
42	0.05%	0.05%	-0.03%	0.00%	-0.06%	0.05%	0.05%	0.05%	-0.03%	0.00%	0.00%	0.00%
43	-0.14%	0.06%	-0.23%	0.00%	0.00%	0.00%	-0.14%	0.06%	-0.23%	0.00%	0.00%	0.00%
44	-0.03%	0.00%	0.24%	0.00%	0.00%	0.00%	-0.03%	0.00%	0.24%	0.00%	-0.04%	0.08%
45	-0.03%	0.24%	0.00%	0.00%	0.08%	-0.04%	0.21%	-0.06%	0.00%	0.33%	-0.17%	-0.07%
	0.24%	-0.03%	0.00%	-0.17%	-0.25%	0.05%	N/A	N/A	N/A	N/A	N/A	N/A
46	0.24%	0.00%	-0.03%	-0.17%	0.05%	-0.25%	0.24%	0.00%	-0.03%	-0.17%	0.05%	-0.07%
47	-0.11%	0.22%	-0.09%	-0.17%	0.05%	-0.07%	-0.11%	0.22%	-0.09%	-0.17%	0.00%	0.00%
48	0.03%	0.03%	0.12%	-0.17%	0.00%	0.00%	0.03%	0.03%	0.12%	-0.17%	-0.04%	0.09%
49	0.03%	0.12%	0.03%	-0.17%	0.09%	-0.04%	-0.06%	0.06%	0.03%	0.08%	0.03%	0.00%
	0.12%	0.03%	0.03%	-0.04%	0.00%	0.00%	N/A	N/A	N/A	N/A	N/A	N/A
50	0.12%	0.03%	0.03%	-0.04%	0.00%	0.00%	0.12%	0.03%	0.03%	-0.04%	0.01%	0.02%
51	0.00%	0.05%	0.00%	-0.04%	0.01%	0.02%	0.00%	0.05%	0.00%	-0.04%	0.00%	0.00%
52	0.00%	0.05%	0.00%	-0.04%	0.00%	0.00%	0.17%	-0.08%	0.00%	0.00%	0.00%	-0.05%
	0.05%	0.00%	0.00%	0.00%	0.15%	0.00%	N/A	N/A	N/A	N/A	N/A	N/A
53	0.05%	0.00%	0.00%	0.00%	0.00%	0.15%	0.05%	0.00%	0.00%	0.00%	0.00%	0.00%
54	0.05%	0.00%	0.09%	0.00%	0.00%	0.00%	0.05%	0.00%	0.09%	0.00%	-0.03%	-0.03%
1	-0.03%	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2	-0.02%	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3	0.00%	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
4	-0.01%	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
5	-0.01%	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
6	-0.02%	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
7	-0.01%	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
8	-0.00%	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
9	0.03%	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
10	-0.02%	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
11	-0.01%	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
12	-0.01%	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
13	-0.02%	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
14	-0.00%	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
15	0.00%	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
16	-0.02%	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
17	-0.01%	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
18	0.01%	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
19	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
20	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
21	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
22	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
23	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
24	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
25	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
26	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
27	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
28	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
29	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
30	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A