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ATTENTION: R. W. BORCHARDT

Subject: ADVANCED REACTOR CORPORATION TECHNICAL CORE GROUP REPORT ON PIPING INITIATIVES, APPENDIX G

Dear Mr. Borchardt:

This letter provides three copies of the Advanced Reactor Corporation Technical Core Group Report on Piping Initiatives, Appendix G, Piping Design/Analyst Users Guide. This appendix was referenced by Westinghouse during the May, 1994 piping audit and is provided here as information to support review of the AP600 application for design certification.

Please contact Brian A. McIntyre on (412) 374-4334 if you have any questions concerning this transmittal.

N. J. Liparulo, Manager
Nuclear Safety Regulatory and Licensing Activities

/nja

Attachment

Enclosure

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APPENDIX G

PIPING DESIGNER/ANALYST USER GUIDE

Prepared by Sargent & Lundy Engineers

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PURPOSE

The purpose of this Piping Analyst/Designer User's Guide is to provide general description of the technical aspects of design and analysis, as well as the process and design control basic elements necessary to ensure high quality and optimum engineering output. The preparation of this document reflects Sargent & Lundy's recent experience in the engineering of the Korean Yonggwang 1000-MWe Nuclear Units 3 & 4 (1988-1993). The Nuclear Steam Supply System (NSSS) was supplied by Combustion Engineering downsized System 80 and the turbine-generator by General Electric.

This document may be used as a model for the development of project unique administrative procedures and Piping Analyst/Designer Manual. This document also provides detailed discussions of the process requirements to assist managers in defining a given project's quality goals and determine the tools, procedures and resources necessary to achieve them.

OVERVIEW

INTRODUCTION

The engineering of a new nuclear power plant must result in an optimum and reliable plant design and be completed to a fast construction schedule. The piping and pipe support scope is a large design activity affecting most aspects of the overall plant design and has a significant effect on the entire project success. The piping/support design philosophy should be based on the following goals:

- Develop an optimum and reliable design
- Minimize installation time and construction cost
- Minimize plant maintenance cost

In order to achieve these goals, the piping and pipe support design process must be implemented to meet the following quality objectives:

- Minimize or eliminate pipe and support installation interferences
- Minimize the total number of supports
- Simplify pipe support configurations
- Maximize standard support design
- Maximize pipe routing symmetry
- Maintain adequate design margin against future design changes
- Minimize or eliminate the use of snubbers (active devices)
- Minimize the use of welded attachments to the piping pressure boundary
- Establish support embedment plate and penetration locations and sizes before concrete placement
- Allow adequate installation tolerance
- Ensure proper compliance and adequate interaction with other design considerations such as ALARA, Fire Hazards, Radiation and Shielding, Equipment Removal, Personnel Access walkways, plant maintainability, inspection and surveillance, pipe whip, jet impingement and Seismic Category II/I.
- Anticipate operational and maintenance additional needs, such as lead blankets, scaffolding and rigging.

PROCESS

The piping and pipe support engineering scope snould be completed in two design cycles:

1. Preliminary Design Cycle

   Material procurement for piping and supports should use input from preliminary piping layout and stress analysis cycle (weight, thermal and seismic). The preliminary design cycle should utilize to the maximum extent possible a space control mechanism, such as a physical plastic model or a computerized plant layout graphic model. The inclusion of the seismic analysis at this early stage results in enhanced ability to reduce support hardware during this preliminary analysis cycle and the following certified analysis cycle. In addition, equipment bid evaluation should use input from the preliminary cycle results to obtain adequate equipment nozzle allowable loads from the vendors. (Equip specifications should contain "target" values for the vendors to meet with the equipment design).

2. Certified Design Cycle

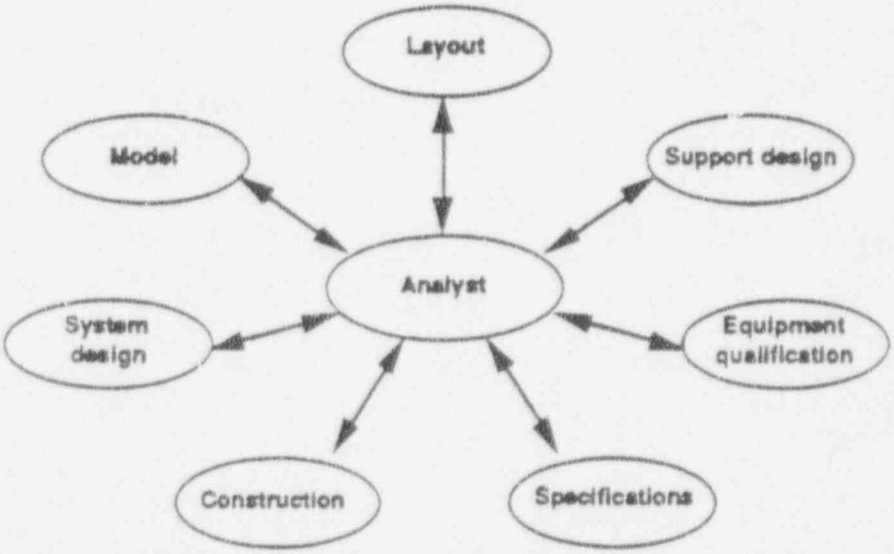
   Pipe and support fabrication and construction shall be based on a certified design specification and approved pipe and support design which are documented by a certified piping analysis using verified vendor data. The design shall not be released for fabrication until verified to be completely free of interferences through the use of a plastic, or computer, model and the engineering documentation reflects the interference free design.

Note: The as-built analysis cycle is a verification rather than an engineering development scope of work and therefore, is not covered in this document. The high quality of the Certified Design Cycle output which includes design margin along with reasonable installation tolerance however, minimizes the cost of the as-built modifications and/or documentation.

IMPLEMENTATION

The project team responsible for implementing the above process should be provided with the following:

- An organizational structure based on a fully integrated design concept



Piping Design Team Integration Concept

- Space control mechanism (either plastic model, computerized layout graphics, or both)
- Integrated Computer aided engineering hardware/software package

DESIGN CONTROLS

Adequate Controls shall be in place for the following aspects of the work:

- Process
- Scope
- Schedule
- Input
- Documents

TECHNICAL GUIDELINES

The design team shall be trained on proper techniques and design approaches to produce technically adequate output. The following topics shall be addressed in detail in this User's Guide.

- Piping layout
- Piping stress analysis
- Support configuration

CRITICAL PATHS/CONFLICTING CONCERNS

A. Plastic Model Versus Electronic Model

The decision to utilize either a plastic model or an electronic model has to be based on the architect engineering (AE) firm's capability and the benefits that are achievable from either systems. The discussion below, however, supports the use of both systems in the engineering of the first wave of new US nuclear power plants in the 1990's.

The following plant model features/usages are required in the design of nuclear power plants in the 1990s:

1. Space control and interference checking
2. Design tool for individual engineers to conceptualize component layout and configurations
3. Team reviews and multi discipline design/interface walkdowns
4. Special design requirement reviews, such as ALARA, system operability, separation, equipment removal, pipe whip, jet impingement and Seismic Category II/I requirements.
5. Management overviews

6. Construction management aid and sequencing
7. Automated drawings and design data generation
8. Automated design interface and electronic data transmittals

While some of the above 8 features, such as items 1 and 2, appear to be equally achievable by both systems (plastic or computer model), the remaining items are not. A project that uses a plastic model to supplement a computerized electronic graphic model realizes the entire spectrum of benefits if it can resolve the apparent overlap or redundancy in capabilities especially in the first two items.

Almost every power engineering firm in the US has both computerized and plastic modelling capabilities. However, it is relatively easier for an engineering firm to achieve proficiency and total coverage in these first two items by using a plastic model rather than a computerized one. On the other hand, the real benefit of using the computer model is concentrated in items 7 and 8. These two capabilities alone (7 and 8) justify the use of the electronic model.

For the features listed in items 3 through 6 one could easily conclude the advantage of using the plastic model over the electronic model. Managers, vendors, contractors and design teams of four or more engineers reviewing the model at the same time, do not need special training to review and reach conclusions on the plastic model, nor do they need an operator to walk them through the model as in the case of a computer graphic model. The importance of conducting such team reviews of the plant model to the quality of the plant engineering outcome cannot be sufficiently emphasized.

Therefore, to realize the total array of benefits listed above, the decision to use both the plastic and the electronic models may be justified by many engineering firms for use on a new nuclear power plant. In the text of this document reference to the type of model used being plastic or electronic is avoided. Reference is made to "Model" only, wherever the use of a space control mechanism is discussed.

B. Procurement Schedule

Vendors develop their component documentation (drawings and data sheets), transmit them to the owner for review, and proceed to manufacture the component as soon as the owner accepts or approves the submitted documentation. Shipment and delivery of the component proceeds henceforth with on-site storage and the related owner's payments to follow. The vendor documents and data sheets are needed early to support engineering, while manufacturing and shipment are needed much later in time to support construction. If the development of procurement schedule is construction driven, engineering progress would lack timely vendor input and, consequently, suffer costly delays. If the procurement schedule is advanced to have the vendor documentation support engineering development, owner's payment and on-site storage costs will be incurred early thus increasing the financial burden of the plant owner. As far as engineering development is concerned, vendor input is usually late on two accounts; schedule is based on construction needs in the first place, plus actual schedule delays of the procurement process. Therefore, a compromise schedule should be developed that is basically construction driven, but at the same time accommodating to engineering development needs as well as allowing adequate margin for the usual bidding and procurement process delays.

C. Equipment Allowable Nozzle Loads

Vendors prefer to limit piping loads on their equipment nozzles, to preserve ample design margin and reduce both manufacturing and documentation cost. Unreasonably low nozzle allowable loads increase the cost of analysis and may necessitate that the first support on the pipe be too close to the nozzle. This results on two adverse conditions:

1. It increases the total number of supports required for supporting the pipe, which in turn increases the cost of both engineering and construction, and

2. When the support is placed too close to the nozzle, the gaps within the support hardware, such as in the pipe clamps, rear end brackets or box supports, result in the equipment nozzle carrying loads even though the analysis model predicts otherwise.

Therefore, from the onset of the project engineering work the piping analyst/engineer should aggressively interface with the procurement process along two lines: 1) by establishing target nozzle load allowables to be incorporated into the procurement specification, and 2) by carefully reviewing the vendor supplied allowable nozzle loads against the preliminary analysis loads and challenge the vendor where unreasonably low nozzle allowable loads would result in the addition of unnecessary supports or increased analysis effort.

D. Small Bore Design - Field Versus Office

Nuclear Power plants commissioned in the 1980's utilized significant field engineering support staff. Major components and large bore piping were installed in the plant before the detailed design for small bore piping and instrument lines began. Field engineering groups were needed to use the plant as a full scale model and develop the small bore piping and instrument line designs.

The new wave of US nuclear power plants to be engineered in the 1990's, will march to a significantly faster schedule and, therefore, must have the small bore piping and instrument line design scope of work done in the office using the design model. There should be an overlap, not a gap like in the 1980s, between the engineering schedules of the large bore and the small bore piping, and likewise with instrument lines.

E. Instrument Lines Design Responsibility

To maintain design consistency, optimum plant arrangement and high level of proficiency, the responsibility of the instrument lines should be assigned to the same team responsible for the large and small bore piping scope.

F. Pipe Wall Thickness

Increasing the pipe wall thickness, over the minimum requirements determined by system engineering for operating conditions including erosion and corrosion, reduces the pipe stresses and in turn the number of supports required to support the pipe. On the other hand, increasing the pipe wall thickness impacts the overall cost of the pipe. Therefore, the approach to this concept should be carefully reviewed and established early in the design stage of the project.

G. Component Support Procurement

Careful preparation and setup of the component support procurement specification provide greater flexibility to the support designers to select appropriate components to meet optimum engineering, construction and operational requirements. The following points are a few examples:

1. The vendor should be made aware of the fact that engineering would strive to minimize or eliminate the use of expensive active devices such as snubbers and constant supports. The procurement contract should be set up to allow engineering absolute flexibility to optimize the design and minimize, if not eliminate, the use of such components without any contractual penalties or constraints. Also, lead time for such components if and when ordered should be optimized to the

maximum extent possible, or provisions should be established for smooth construction progress and enhanced installation time including the use of temporary components.

2. Reduce or eliminate from the procurement specification components with high degree of sensitivity to operational vibration concerns, such as welded beam attachment and U-bolts.

   Welded beam attachment allow the sliding of the eye-rods or variable spring attachments from its center to the sides thus increasing load offsets or introducing undesirable moments that should be accounted for in the design calculation. To avoid this phenomena, these components may be completely replaced by welding lugs.

   The nuts of the U-bolts cause several technical problems, such as ability to maintain the design gaps, torque specification/control, interference with the pipe itself, limited load capacity, and loss of stability induced by friction with the pipe side walls or steady state vibrations. Welded straps provide effective replacement of U-bolts for use as one- or two-directional restraints for pipes up to 8" in diameter.

3. Special clamps with dual pipe attachment @ 90° angle for use with struts provide several advantages for pairs of struts used as pipe guides. These clamps have higher stability and can fit easier in short pipe segments than in the case of two clamps for two strats @ 90° angle.

SECTION G.1

1.0 PROCESS REQUIREMENTS

The piping and pipe support engineering scope of work shall be completed in two design cycles; the Preliminary and the Certified Design/Analysis cycles. The preliminary design is used for material procurement and the certified analysis is used for fabrication and construction releases.

The scope of the piping design, analysis and pipe support design comprises piping layout, support location, functions and configuration determination as well as the piping weight, thermal and seismic analysis. These three design activities (piping design, analysis, and support design) will require several iterations over a short period of time. One engineer proficient in all three design activities is the ideal candidate to lead this work. However, two or three engineers/designers, or groups, may do this work to the desired quality provided the interface arrangement among the entire design/analysis work is optimum and efficient, i.e., an integrated team under a single leadership responsibility.

1.1 Preliminary Design Cycle

The outcome of the preliminary analysis/design cycle is used: 1) in the pipe and support material procurement, 2) to provide nozzle load input to the equipment procurement scope, and 3) to provide realistic support loads to the structural building design.

1.1.1 Input

The input required for this cycle, is preliminary by definition and uses the best available information from the following:

a. General Arrangement Drawings

b. Design Criteria & Piping Design Specification

c. Process/Flow Diagrams and System Design Specification

d. Equipment Procurement Specification and Catalog/Reference Data

1.1.2 **Process Steps** - See Figure 1 (Page 1-10)

The preliminary design cycle for major piping systems, such as main steam and feedwater, actually starts in concert with the development of the plant general arrangement and the configuration of the major equipment of the NSSS and Turbine Generator.

Step 1: Conceptual Routing

Preliminary system process and instrumentation diagrams (P&IDs) are used to start the conceptual pipe layout using standard catalog data for equipment/components such as, pumps and valves and previous reference projects data for heat exchangers, tanks etc. Routing of major systems, such as main steam and feedwater is given priority to ensure appropriate space allocation, optimum layout configuration (minimum number of tees, laterals and elbows), and to provide identification of the building areas or structural components that will accommodate and support the loading of these major piping system. Optimal support configurations are an essential consideration in the conceptual routing activity. Piping should be routed such as simple standard supports may be used without the need to add auxiliary steel.

Step 2: Initial Analysis, Support Location and Configuration Determination

Piping weight, thermal and seismic stress analysis of the preliminary routing provide early indication of the acceptability of the routing, supporting arrangement, nozzle loads and pipe stresses. The pipe wall thickness for certain locations under certain operating conditions, may require some increases based on the stress levels indicated by the analysis. Areas of high stress concentration such as at tees, laterals and reducers are reviewed and the findings resolved in this cycle. Depending on the timing, equipment nozzle loads developed by the analysis, plus margin, are either used as input to the process of preparing of the procurement specification or to evaluate bid proposals from prospective vendors.

Step 3: Piping Code Check

The pipe stresses should be maintained below the code allowables by an adequate margin throughout the engineering of the project (e.g., 20 - 30%). This may be achieved for piping areas found with less margin by relocating supports, rerouting the pipe or both, and as a last resort by increasing pipe wall thickness.

Step 4: Piping and Support Configuration on the Model

The conceptual piping and supports should be installed (or loaded) on the Model to identify and resolve interference and clearance problems and to reserve space. In this process, piping layout and support locations and configurations receive special review for simplification, optimization and reduction of auxiliary support steel. The goal during this activity is to optimize the pipe and support configuration such tht the use of standard support hardware is maximized and auxiliary steel is minimized. The review shall be conducted by the integrated piping analyst/designer and the support designer team.

Step 5: Preliminary Support and Nozzle Loads

The changes in pipe routing and support arrangement resulting from the model review should be verified by analysis.

Step 6: Preliminary Support Design

The preliminary analysis support loads are used with adequate margins to develop preliminary support designs. The level of detail of the support design required in this step should be adequate to at least define embedded plate requirements, provide support reaction loads to the building structure and to verify that the support hardware sizes required for the design loads fit in the space available. The design load margin (e.g. 30%) in this stage is dependant on the confidence and completeness of the input. During the certified analysis, the load margin may be slightly reduced (e.g. 20%) to allow for the final as-built analysis.

Step 7: Freeze Piping Layout

The piping layouts and supporting arrangement shall be frozen. Any subsequent change requests should be filed in pending action files till the next analysis cycle. The frozen pipe should be identified as such on the appropriate system, such as the Model, piping computer master drawing file or the system P&IDs.

1.1.3 Output

The result of the preliminary analysis/design of the pipe and supports are used to:

a. Provide comments to equipment procurement specifications based on preliminary analysis nozzle loads (bidding and awarding of procurement contracts should be in progress at this stage) to obtain reasonable and adequate nozzle allowable loads from the vendors.

b. Identify concrete penetration locations and sizes.

c. Request concrete embedment plates and structural steel.

d. Provide preliminary support loads to building design.

e. Prepare preliminary piping and support design drawings and/or sketches and provide input to pipe and support procurement and material takeoff.

f. Provide comments to system engineering on pipe schedule, sizes, and fittings (tees, laterals, etc.) where necessary to reduce stress levels at locations of high stress concentration on the piping system.

g. Provide interface input to NSSS, turbine generator and any subsystem or equipment packages supplied by others.

h. Define the subsystem (analysis problem) boundaries on system P&IDs or any other appropriate media.

1.2 Certified Analysis Cycle

The purpose of the certified analysis cycle is to release safety and non-safety related pipe and support design for fabrication and construction. As such, all input or interface documentation have to be finalized, verified, certified and/or approved for use.

1.2.1 Input

The following is the required input for the certified analysis cycle.

a. Certified or verified vendor data.

b. Finalzed system engineering input.

c. Preliminary pipe and supports configuration installed on the Model (plastic or electronic).

d. Certified design specification.

e. Structural steel, embedment plate and penetration sleeve designs.

1.2.2 Pre-Requisites

a. Area Reviews

The time span between the preliminary and the certified analysis cycles should be utilized to make area reviews to resolve and/or make allowances for the design issues or design features as discussed below. Some of those reviews will be conducted by the piping designer/analyst team and some are by other groups, such as safety analysis, nuclear safeguard and licensing groups.

a1. Optimize Design:

The reviewer shall conduct systematic area reviews on the Model for all supports using latest support drawings or sketches. The actions resulting of this review may be categorized as follows:

- Supports required to be revised, relocated or reoriented to enhance their design, or to combine more than one support on one single auxiliary structural steel (gang supports) without impact to pipe routing.
- Supports that may be deleted. This may require the relocation of neighboring supports.
- Pipe rerouting to simplify complicated, uneconomical or unconstructable supports.
- Relocation of other components such as electrical cable trays and HVAC ducts to improve the supportability of the piping.

a2. Design Issues:

The teams responsible for radiation protection and shielding, ALARA, vibrations induced from flow or equipment operation, safety analysis, jet impingement and pipe whip design issues, maintainability, constructability, etc., shall complete their area reviews at this time to identify and resolve component arrangements that cause conflict with these issues.

b. Incorporate Vendor Data:

As the certified vendor data are received and incorporated on the piping design, piping and supports are adjusted and the Model updated. In parallel, system flow diagrams incorporate the vendor input and new lines (mainly equipment vents and drains) shall be routed and added to the scope. Supports for these new lines may be located and conceptualized using either approximate load determination methods or stress analysis. Equipment pull space and maintenance clearance requirements as specified by the vendor should be verified and any problems resolved. Equipment drain and foundation requirement as well as the nozzle location may result in piping layout changes. Consideration to avoid hydraulic turbulences, especially at major pumps should also be identified and incorporated.

c. System Freeze:

The subsystem boundaries identifying the analysis problem (discussed in Section 1.1.3h) shall be used to inform system engineering of the schedule of beginning the certified analysis cycle for a given subsystem (analysis problem) and to request system engineering freeze for that subsystem. System engineering shall freeze the subsystem or respond by indicating any open items within the specific analysis problem boundary, the schedule for resolving the open items, and if significant changes are anticipated, shall request a hold on the analysis.

d. Gallery Layout:

Access gallery conceptual layout based on the piping layout should commence in this stage between the preliminary and certified analysis cycles. Galleries consume considerable plant space. As their layout design progresses, interferences with pipe and pipe supports should be resolved. Many of the interfering supports may be reattached to the gallery supporting steel depending on the magnitude of their loads. This will result in simplified gallery and support design, which enhances personnel access (ALARA) and improves the engineering outlook of the plant arrangement.

1.2.3 Certified Analysis/Design Process Steps - See Figure 2 (Page 1-11)

Step 1: Support Design Loads:

Significant modifications of the piping and support arrangement after the preliminary analysis as a result of the pre-requisite activities discussed in Section 1.2.2.a and b above, should be analyzed to develop support design loads. The pipe stresses shall be reviewed for compliance with code allowables.

Step 2: Support Feasibility:

Modified support configuration will be reviewed against the support loads and new support sketches will be prepared for new locations.

Step 3: Model Update:

The subsystem piping and support arrangement will be updated on the Model.

Step 4: Subsystem Freeze:

A team walkdown shall be conducted on the Model for a final configuration review, optimization and acceptance. The final design shall be simple, economic and constructable. The design shall be free of snubbers, welded attachments and with minimum number of constant supports. Supports shall be located such that the use of auxiliary steel and expansion anchor plates are minimal. The support hardware selection shall be geared towards minimizing field construction welds (e.g., by using two 90°- angle struts needing about 20 linear inches of field welds in lieu of a box support that requires over 100 linear inches of field welds).

Step 5: Final Loads:

The frozen piping and pipe support arrangement shall be incorporated into the analysis model. The stress analysis results shall be reviewed and approved. Loads on equipment nozzles, penetrations and supports as well as code allowables shall be reviewed. The approved loads are used as input to develop approved support, penetration and equipment foundation designs. The nozzle loads shall be used to document compliance with equipment vendor allowables. All interface requirements with other entities requiring input from the piping analysis shall receive their input at this step. This is necessary to allow adequate time for returning to the certified analysis group confirmation that the input is incorporated with no exceptions.

Step 6: Approved Piping and Support Design:

- Using the approved support loads the support final design is completed, verified to be free of interference on the Model, and then approved.
- The piping design shall also be approved after incorporation of all certified vendor input, analysis initiated changes, and Model verification of interference free design.

Step 7: Certified (ASME) or Approved (ANSI) Design Report:

The certification or approval of the subsystem design report shall be completed only after acceptable documentation of the satisfaction of all associated and interfacing design requirements such as penetration sleeve design and foundation design are on file.

Step 8: Release to Fabrication and Construction:

Based on the certified or approved design report, the piping and its associated supports are released for fabrication and construction.

1.2.4 Output

The output of the Certified Analysis Cycle is as follows:

a. Pipe design released for fabrication and construction.

b. Support design released for fabrication and construction.

c. Penetration design and associated support reaction loads transmitted to building design.

d. Embedment plate design incorporated on building design drawings.

e. Final support loads input to building structure.

f. Equipment nozzle load compliance documentation.

g. Equipment nozzle final load input for equipment foundation documentation.

h. Finalized interface with NSSS, turbine generator and other interfaces, (loads, stiffnesses, motion time history, etc.)

i. Certified or approved design report.

1.3 Precautions

1.3.1 Space Control

a. Participation and Timing:

The effectiveness, and the benefit to the project, of using the Model for design and space control is commensurate with the number of groups interacting with the system and the time each individual group starts the interaction.

b. Space Reservation/Allocation:

This aspect should be well coordinated from the beginning of the project work, with area responsibilities assigned, and conflicts resolved from an overall plant arrangement perspective.

c. Design Reviews:

The Model should have capabilities to highlight to the users features or aspects that will affect the design decisions reached by viewing the Model. This includes equipment pull space, equipment removal paths, personnel access walkways, radiation zones, fire zones, areas containing safe shutdown equipment (for II/I considerations), pipe whip and jet impingement, etc.

d. Problem Identification/Resolutions:

The space control mechanism should have a feedback mechanism to identify to the responsible group any physical design problems requiring resolution. This includes interference and clearance criteria violation.

1.3.2 Computer Aided Engineering

Engineering groups should develop their design using computer hardware/software packages that are set up to electronically interface with each other. Coordination and interface among the engineering groups shall be controlled such that the design sequence and interface is streamlined and the design status (preliminary, frozen, approved or in revision) of components are highlighted to the interfacing groups in order to assure the quality of engineering interface and exchange of design data.

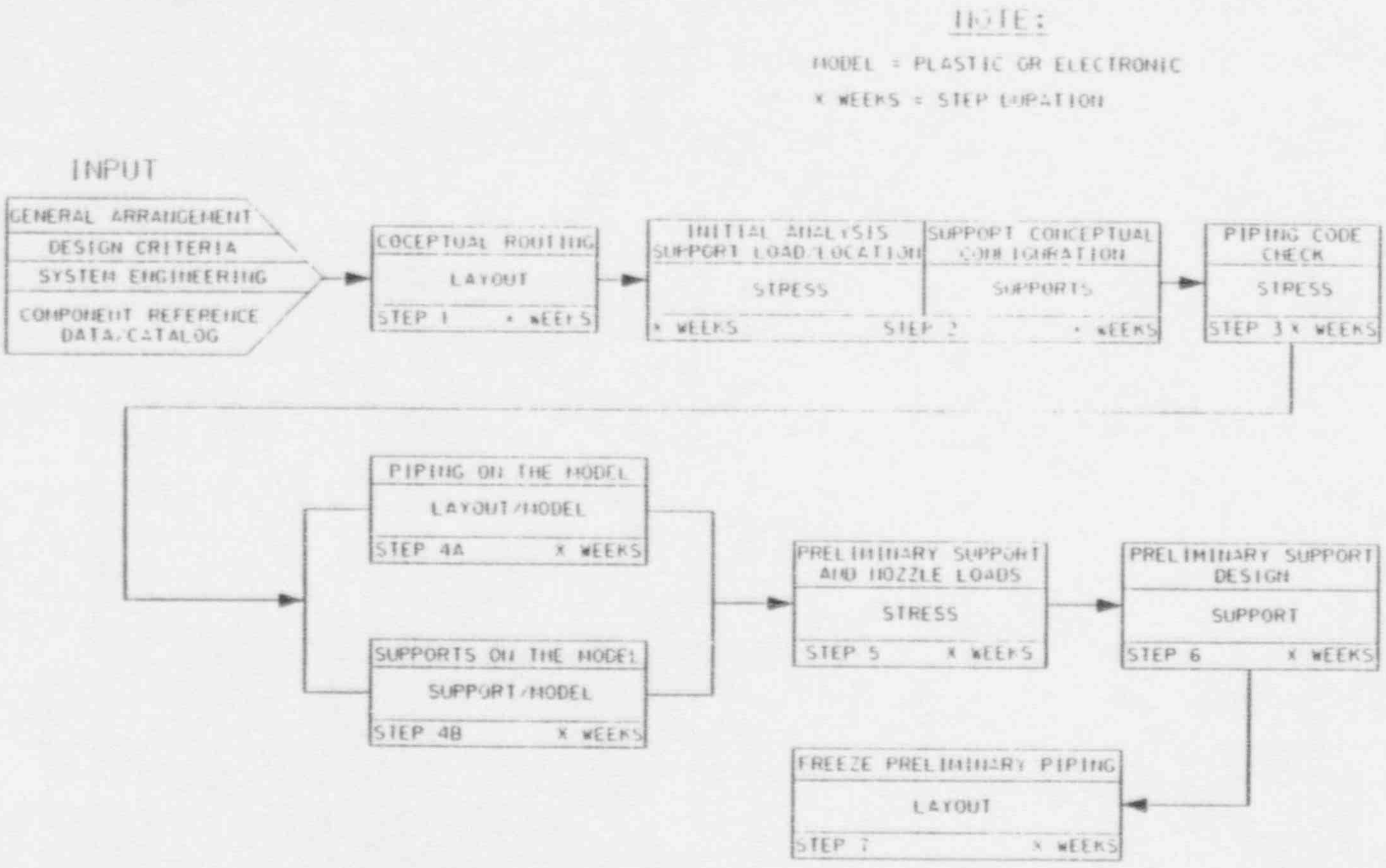


FIGURE 1: PRELIMINARY ANALYSIS DESIGN PROCESS FLOW CHART

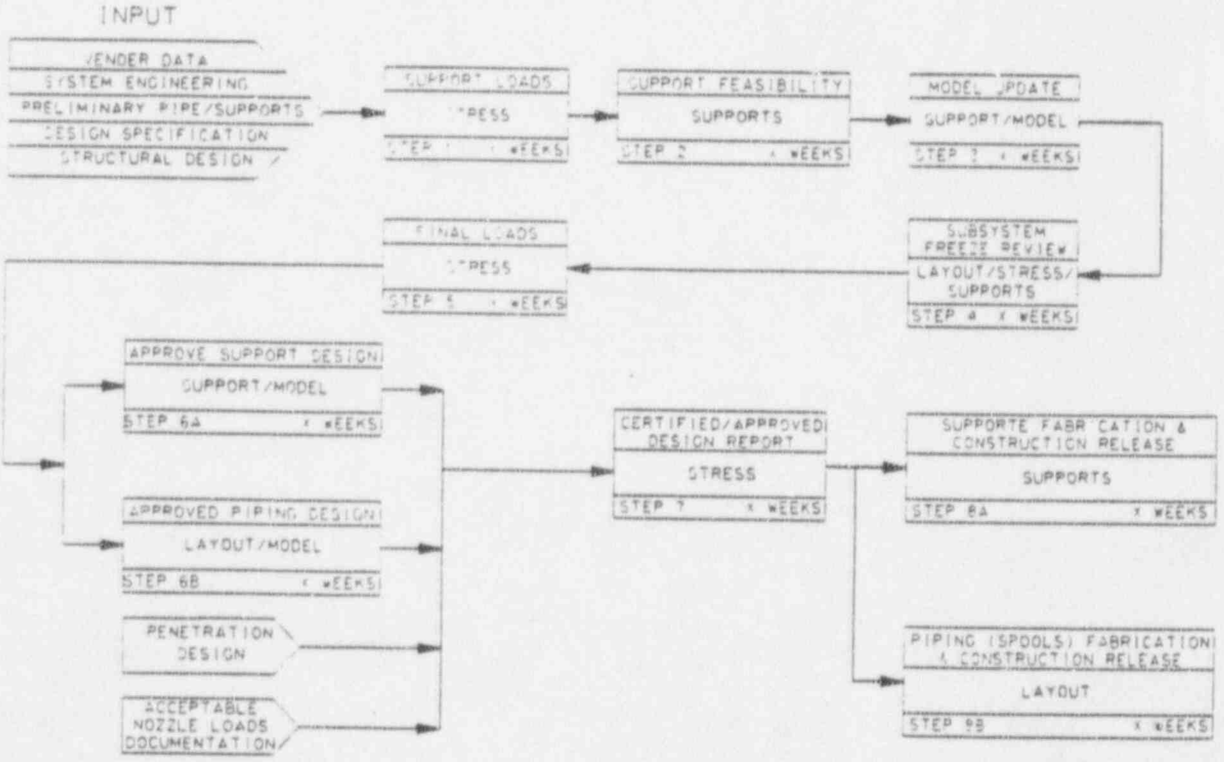


FIGURE 2: CERTIFIED ANALYSIS DESIGN PROCESS FLOW CHART

SECTION G.2

2.0 DESIGN CONTROL

This section provides the attributes for developing a Design Control System to manage the various aspects associated with the piping design and analysis work. Several of the controls that are designed in this section will require databases. A master database indexed by the common subsystem number shall be linked all the sub-databases to service this scope.

2.1 Process Control

Appropriate engineering procedures shall be in place to support this work.

2.1.1 Preliminary Analysis Procedure

See Section 1.1.2 and Figure 1 of this document for a detailed description of this procedure.

2.1.2 Certified Analysis Procedure

See Section 1.2.3 and Figure 2 of this document for a detailed description of this procedure.

2.2 Scope Control

2.2.1 Subsystem Boundaries

At the conclusion of the preliminary analysis cycle. The subsystem boundaries of each analysis problem are shown as an overlay over the system P&IDs. This controls the boundaries of the analysis problems and coordinates the interface with system engineering.

2.2.2 Subsystem Component Database

A subsystem component database listing each equipment, component and valve within each subsystem is generated using the subsystem boundaries mentioned above. This database should identify the vendor and the schedule and the actual dates of receiving certified/approved vendor data necessary to complete the Certified Analysis cycle for this subsystem.

2.2.3 Supports

A database listing all supports in each subsystem, class, type, drawing number, and pipe loads and movements at the support shall be developed and maintained throughout this process. Anchors between subsystems should identify the other subsystem number to ensure control over the total load imposed on the anchor from both sides.

2.2.4 Penetrations

Interface with piping penetrations shall be controlled to ensure that piping loads on the penetration or movements within the penetration sleeve are addressed and that the design of the penetration seals, if any, is consistent with the analysis basis. This requires a database listing of penetration sleeve and pipe sizes, schedules, temperature, insulation, loads, movements, gaps between pipe and sleeve, seal type, building locations, room and partition numbers, and subsystem numbers.

2.2.5 Branch Subsystems

The relationship between the header and branch piping is sensitive to changes in either subsystems. Therefore, it is important to control this relationship in a database throughout the process. The scheduling of subsystems has to take this relationship into consideration and schedule the branch subsystems such that the header /branch interface conditions are well developed by the header analysis before the start of the branch analysis. In some cases the branch location along the header pipe may be moved closer to anchors or guides on the header pipe to reduce the header movements imposed on the branch subsystem.

2.3 Schedule Control

The main purpose of any control system is to provide management with a means of assessing progress of the activity being undertaken and to identify problem areas early enough so that they can still be corrected before the schedule is delayed beyond recovery. The development of a control system that is able to fulfill the above stated goal requires the generation of four separate components that have to interface with each other. These four components are 1) a work process, 2) a detailed schedule, 3) a method for updating the schedule, and 4) a method for monitoring the progress of the work effort.

The schedule for the Preliminary Analysis cycle is straight forward and follows the engineering development in each building from the lowest elevation and upwards. The development of the Certified Analysis schedule is a much more complex issue and significantly impacts the construction schedule and therefore, is discussed below in detail.

2.3.1 Design Process Duration

A 7- step procedure guides the flow of the Preliminary and an 8-step procedure the Certified Piping Analysis/Design work, respectively. An explanation of these step processes, is given in Section 1. For easy reference, see the flow charts of this design processes given in Figures 1 and 2 of Section 7. The span of time of these processes is a key ingredient to the generation of a detailed subsystem schedule.

For pipe spools the total nominal span time of the design process from Step 1 through Step 8 shall be determined. For pipe supports the total span time shall also be calculated. For subsystems that have no pipe supports the total span time for pipe spools drops by the number of weeks in the support design steps. The start date for any particular subsystem is the completion of the prerequisite activities and the system engineering freeze notification (Section 2.4.2).

2.3.2 Schedule Development

The approach used to develop the Certified Analysis schedule consists of three main activities. These are 1) the development of an early schedule based on the availability of vendor input, 2) the development of a late schedule based on the needs of erection, and then by combining the early and late schedules, 3) the development of a schedule that could reasonably be supported by the available manpower. These activities are discussed below.

a. Early Schedule:

In developing the early schedule, it is first necessary to define what equipment and valves are contained in each subsystem. This is done by the development of a special database which contains this information and which could interface with the project's Vendor Input Schedule (Section 2.2.2). The Vendor Input Schedule (VIS) is another database which contains all equipment for which vendor input is required to support either structural design work or piping analysis. In this database is contained the actual or forecast dates for the receipt of vendor data. Relating the subsystem equipment database with the VIS provide early start dates for each subsystem. Using these start dates and the span times for the steps in the Certified Analysis Process an early schedule is developed.

b. Late Schedule:

The late engineering schedule is developed by working backward from the early erection start date given in the Construction Schedule, which is a detailed schedule that gives erection start dates by both system and elevation. Using the lead times for both spools and supports shown in Figures 3 and 4 (page 2-9 and 2-10) and the span times for the steps in the Certified Analysis process creates a late schedule for the Certified Analysis.

c. Reconciling Early and Late Schedules:

The lead times shown in Figures 3 and 4 constrain the design process at three different points. The pipe spool lead time constrains the design process at Step 8 by requiring it to be complete by a certain number of months prior to the start of spool erection. The pipe support lead time constrains the design process at both Steps 6 and 8. Step 6 needs to be completed by a certain numbers of months prior to the start of support erection with support erection starting after the start of spool erection. Step 8 needs to be completed prior to the start of support erection. At Step 6 supports are released for material purchase or takeout and credit is taken by supports for the completion of the certified support design work. At Step 8 supports are released for fabrication. Delaying support material takeout till Step 6 of the Certified Analysis (as opposed to the Preliminary Analysis) ensures that there would not be any greater than 5% changes in support design between those issued at Step 6 and those issued at Step 8. However, this delay greatly constrains the process, and the project team has to negotiate with the plant owner a more flexible arrangement to deal with surplus materials of supports and provide less constraints on the schedule.

The difference between the start dates for the early schedule and the late schedule gives the engineering float. Where this float is negative a special effort is required to resolve it. It is first necessary to review the constraints to starting the analysis earlier. After this is done, it is checked to see if the erection start date could be delayed. In some cases it is also possible to shorten the durations in some of the process steps. After these activities are carried out a final schedule for the subsystem is developed.

d. Levelizing Manpower:

The last step in producing a final subsystem schedule is to levelize the manpower requirements for this work. This is accomplished by moving the early schedule, for those subsystems with a positive float, out in time by a certain percent of the float and calculating the manpower requirement. Various manpower curves are developed for various percent values of float used and then compared to determine the best schedule. To calculate the manpower the manhours for each step in the process are required. These values shall be provided by the groups involved. Manpower curves are generated separately for Stress, Layout and Support steps. Manpower shall be calculated for the early schedule, the late schedule, and for increments of 25%, 50%, and 75% of the float between the early and late schedules. The results of this effort are reviewed and the ideal schedule for the best manpower picture is selected for the Certified Analysis effort.

2.3.3 Progress Monitoring

The monitoring of the progress of the Certified Analysis effort may take three separate forms. These are 1) weekly exception reports, 2) monthly status reports, and 3) monthly delayed subsystem report.

a. Weekly Exception Report:

The weekly exception reports list those subsystems that are late in each step of the process and are used as the basis for weekly expediting meetings which result in weekly meeting notes with action items assigned and monitored till resolutions are reached.

b. Monthly Status Report:

The monthly status report shows the percent progress of the Certified Analysis effort, provides production curves for the quantities that have passed through important steps, a list of completed subsystems, etc.

c. Delayed Subsystem Report

The delayed subsystem report keeps track of how various subsystems are being delayed and why and what the impact of these delays are relative to the shift of the work load. The delayed subsystem list is used for review against the construction progress and results in reassigning priorities to support construction as required.

2.4 Input Control

The piping and pipe support design work is a highly input-dependant scope. The releases of the pipe and support design for fabrication and construction have significant effect on the performance of the project's construction schedule. Therefore, an aggressive control mechanism over the input is critical to the overall success of this scope.

2.4.1 Vendor Data

As discussed in Section 2.3, the Certified/Analysis schedule for a given subsystem is developed based on the scheduled receipt of certified/approved vendor input for equipment and components within that subsystem.

The certified/analysis process may span over 20 weeks of calendar time for a given subsystem. To facilitate progress of this scope of work, certain rules have to be established about the relative importance of the component data in relationship with the process. Step 1 for a given subsystem cannot start if vendor data on a major equipment such as a pump, a heat exchanger or a tank, is not available. Vendor data on motor operated valves may be incorporated into the process if received prior to Step 4, the Subsystem Freeze. Vendor data on manual valves, orifices and such components may be incorporated into the process if received prior to Step 7, Certified Design Report.

A mechanism should be in place to use the subsystem database (Section 2.2.2) to track the schedule performance of the various vendors and communicate the defaults to the management, the responsible vendor and most importantly, to the owner. Late vendor input problems take long time to correct and an aggressive problem identification and feedback mechanism is an absolute must.

2.4.2 System Engineering Freeze

Prior to the start of the certified analysis of a given subsystem, system engineering shall provide assurance of engineering finalization of all issues impacting the piping within the subsystem boundary. Any open items should be identified and monitored till closure, or if significant, the Certified Analysis should not start until a resolution is reached. To control this interface with system engineering, the system P&IDs with subsystem boundary overlay and a list of the subsystem components from the database are used. The subsystem list of components from the database could be used by system engineering to respond to the analysis groups confirming the freeze and concurring with the start of the analysis , or listing the open issues that are considered grounds for holding the analysis.

Changes of System Engineering design basis while the Certified Analysis of the impacted subsystem is in progress can prove to be very costly to the project's progress. Therefore, controlling the system freeze interface (Section 1.2.2.c) is very important. Late vendor input impacts the completion of both system engineering and the subsystem analysis. The control of the system freeze process should recognize this inter-relationship and be able to control it relative to the progress of the analysis.

2.4.3 Construction Progress

There is an overlap between the final stages of the certified analysis scope of work and the early stages of construction progress. A mechanism should be in place for adjusting the subsystem progress priorities to respond to construction needs.

2.5 Documentation Control

The flow of design input, both within the process and with interfacing engineering groups shall be controlled. The nature of the control mechanism depends on the computer capabilities available to the team and to the team and the organizational structure of the project. Controlling data transmittal within the process itself can be greatly reduced if one integrated team under one leadership is assigned the responsibility for the entire scope; i.e. piping layout, piping analysis and support design. The same concept applies if the same organization that is responsible for large piping, is also assigned the responsibility of the small piping as well as the instrument lines.

Documentation and/or controls for the following items needs to be in place.

a. Design Information Transmittals between interfacing groups

b. Penetration Design Basis (including seal design and analysis input)

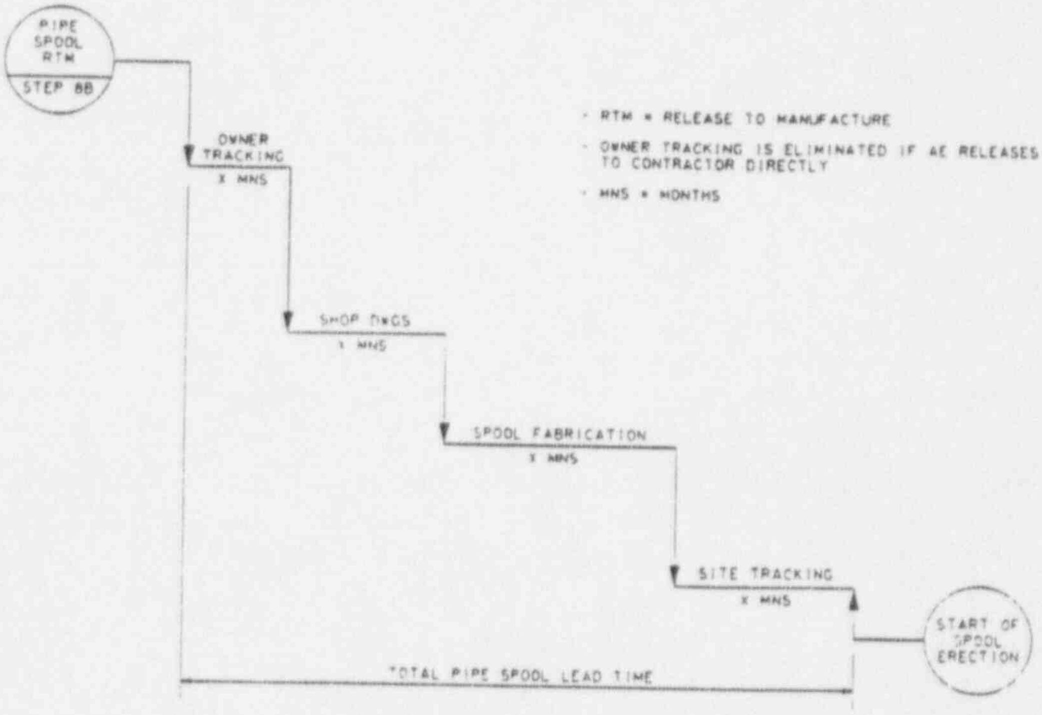
c. Calculations and Design Reports

d. Equipment Nozzles

e. Equipment Foundation

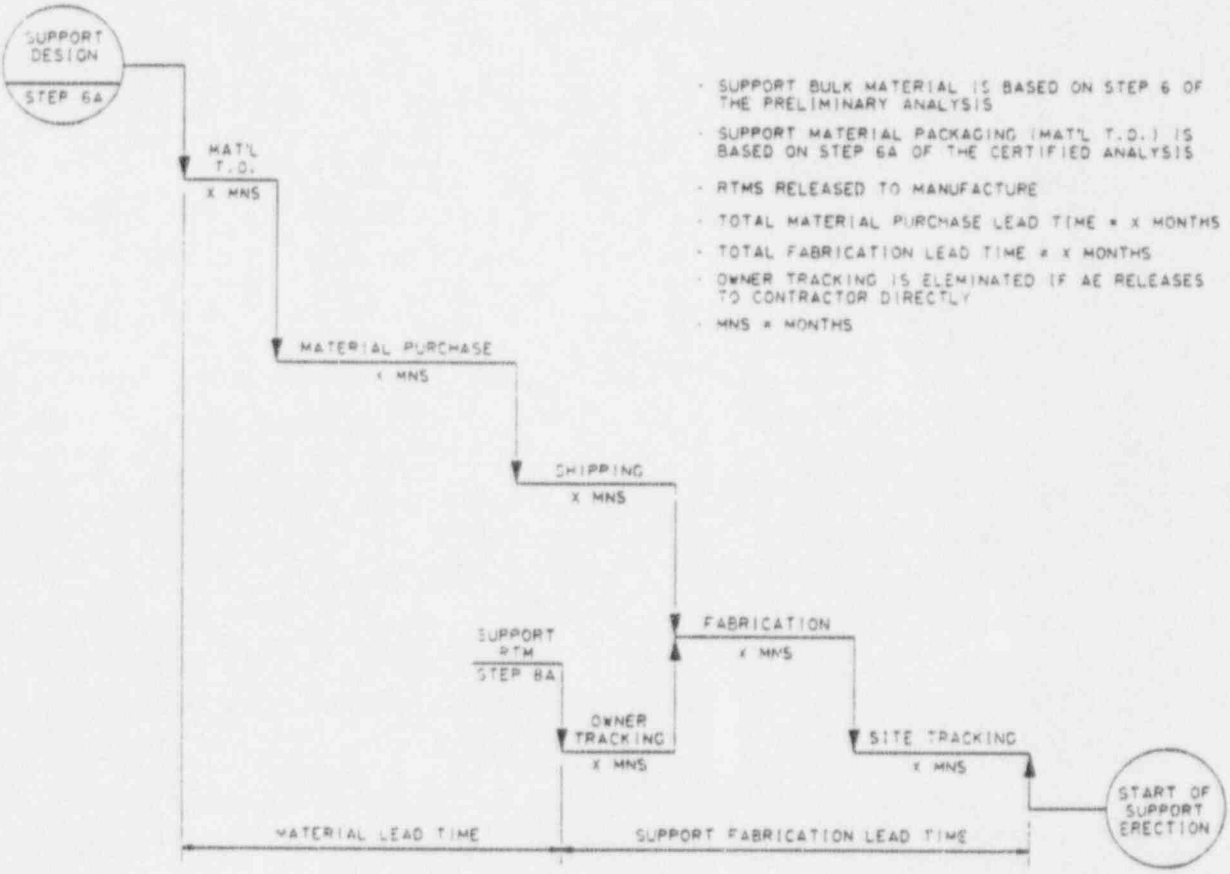
f. Vendor Data

g. System Engineering Data (line list, valve list and thermal modes)



- RTM = RELEASE TO MANUFACTURE
- OWNER TRACKING IS ELIMINATED IF AE RELEASES TO CONTRACTOR DIRECTLY
- MNS = MONTHS

FIGURE 3: PIPE SPOOL LEAD TIME



- SUPPORT BULK MATERIAL IS BASED ON STEP 6 OF THE PRELIMINARY ANALYSIS
- SUPPORT MATERIAL PACKAGING (MAT'L T.D.) IS BASED ON STEP 6A OF THE CERTIFIED ANALYSIS
- RTMS RELEASED TO MANUFACTURE
- TOTAL MATERIAL PURCHASE LEAD TIME = X MONTHS
- TOTAL FABRICATION LEAD TIME = X MONTHS
- OWNER TRACKING IS ELEMINATED IF AE RELEASES TO CONTRACTOR DIRECTLY
- MNS = MONTHS

FIGURE 4: PIPE SUPPORT LEAD TIME

SECTION G.3

3.0 PIPING LAYOUT GUIDELINES

3.1 Layout Aspects

A piping designer must consider all of the following items during the layout of piping systems. Many of the requirements are spelled out in more detail in industry standards and guidelines.

3.1.1 Clearances

Clearances for piping include, inservice inspection requirements, weld locations, space from the building structure, electrical equipment, cable trays and ducts. There are also pipe to pipe spacing requirements for ISI, seismic interaction and construction requirements.

a. Inservice Inspection

Piping clearances are necessary to provide:

- Access for inspection personnel and/or examination personnel and equipment necessary to conduct examinations
- Sufficient space for removal and storage of structural members, shielding, and insulation.
- Installation and support of handling machinery (e.g., hoists) where required to facilitate removal, disassembly, and storage of equipment, components, and other material.
- Performance of examinations other than those specified if structural defects or indications are revealed that require such alternate examinations.
- Performance of necessary operations associated with repairs or installation of replacements.
- As a general rule, the designer shall base the design on the direct examination method. Remote inspection should be considered only when adequate space or accessibility for the direct method cannot be provided, when it would be prohibitively expensive, or when the required inspection is to be performed in a high radiation area.
- No hanger straps, lug welds, radiograph ports, branch connections, etc., shall be located within 2t + 2 in. of shop and field welds, where t = pipe wall thickness. Review shall be made to provide adequate accessibility.

- Circumferential piping welds shall not be located inside wall and floor penetration sleeves. Weld locations shall allow adequate access for ISI.

- Piping shall be designed to avoid branch connection saddles and pads being installed over welds subject to ISI.

- Where piping is run in a pipe chase, or groups of piping are run in banks, the pipe to be examined by ISI, shall be located in the outside layers to ensure access without removing other piping.

- Where direct manual operations are required, clearance should be provided for the head and shoulders of a man within a working arms's length (20 inches) of the surface to be examined.

a1. General

- Piping systems must comply with OSHA requirements with regard to headroom, walkspace, etc.

- Piping that runs parallel and adjacent to cable trays must allow sufficient clearance for access to cable in trays and sufficient clearance so that there is no interference with the cable tray supports.

- Motor Control Center (MCC) location drawings must be reviewed to verify their location relative to the piping.

- Piping and hangers should clear bus ducts by a distance as determined by the project.

- For piping required for safe shutdown, it is recommended that a 6 in. clearance be maintained between the insulation (or piping if uninsulated) and adjacent components and structures where practical. This recommendation will reduce future seismic interaction calculations.

b. Relief Valve Vents

There are specific standards that depict the methods of layout and design of vents and vents stacks. Generally, the piping designer must locate vent valves so that the discharge piping is kept as short as possible.

c. Thermal

Any piping system over 150 degrees F should be reviewed using simplified standards for preliminary flexibility check. This will minimize having to reroute piping systems after the final analysis is run on the computer. Expansion joints can also be used in limited cases, to avoid overstressing piping and equipment.

c1. The following are some points which the piping designer should consider when routing a system to ensure adequate thermal flexibility of the piping.

- The most undesirable routing is a straight pipe run between the two anchor points. Therefore, locate as much pipe as possible away from an imaginary line drawn between two anchors.
- Minimize the number (not the length) of flexible pipe legs occurring between the anchors for each expansion direction.
- Narrow elbow-to-elbow U-bends are not recommended, since the bending stresses are highly localized at the bend.
- Symmetrical routings are preferred, because they will more evenly distribute the stresses.
- Out-of-plane pipe bends are preferred in order to take advantage of the greater flexibility of a pipe under torsion (as compared to a pipe subjected to bending).
- An increase in the length of pipe used to improve flexibility is acceptable, however, it should be remembered that large increases will only result in a higher material cost and greater pressure drop, while not significantly improving the thermal stresses.

c2. Expansion joints may be used in water piping at pump suctions, where the design pressure of the line is less than 50 psi. Otherwise, waterline expansion will also be accommodated by expansion loops. The expansion loop does not have to be a true loop configuration; it can be a combination of a number of bends between one anchor point and another.

d. Insulation

Pipe routing must consider the added diameter that insulation adds for proper clearances. There should also be provisions to temporarily store insulation removed during inspection or maintenance, in the vicinity of the piping system.

d1. The insulation thickness is particularly important to the piping designer. It is a surface covering that affects the weight and the overall diameter of the pipe being routed. As an example, a 4-inch insulation thickness will increase the working diameter by 8 inches; this, coupled with pipe movement as a result of thermal expansion, greatly affects the clearance requirements surrounding the pipe. Therefore, special care should be taken when routing hot pipelines through floors or walls, and adjacent to steel members, as well as to other plant piping and components to allow for these design conditions.

d2. The insulation covering all components and piping welds in adjacent base material shall be designed for easy removal and replacement in areas where external in-service inspection will be required.

e. Instruments

There are three primary types of instruments that affect pipe layout.

e1. Flow Measuring Devices

All flow elements shall be installed in straight pipe with proper length upstream and downstream of the device. Straight lengths taken from the appropriate curves are recommended minimums. Within limits, lesser lengths may be acceptable at the discretion of the user provided a ±0.5% additional deviation added to the uncertainty (limits of accuracy) of the flow measurement. Straight lengths have been standardized only for venturies, nozzles, and orifices. For proprietary devices the user should follow the manufacturer's recommendations. Whenever possible, it is preferable to locate the primary element in a horizontal line. It is recommended that no instrument protrusions (chemical injection nozzles, isokinetic samplers, etc.) nor pockets (thermowsells for test or for temperature elements) be located for a minimum straight distance on the upstream and downstream side of the element as determined by the project. Control valves must be located downstream of the flow element.

e2. Thermowells

Often, thermowells may have a minimum insertion length greater than the pipe ID. Provisions must be made to accommodate the inserted length. Consideration must also be given to access for the insertion and removal of the thermal element itself with regard to surrounding components.

e3. Orifices

Flow instruments encompass flow meters, rotameters, sight glasses, and orifice meters, among others. Orifice flanges may cause piping designers problems, especially in the larger sizes.

Many orifice flanges, or meter runs as they are commonly called, are critical to a plant's operation. For size 16 inches and larger, one solution is to replace orifice flanges with a venturi tube, which needs only a few feet of straight-run pipe upstream. Another solution is straightening vanes installed in the line upstream of the orifice plate. Orifice flanges may be installed in a vertical pipe run for liquid flowing up or down and for vapor flowing down. Horizontal meter runs are preferred and should be provided where feasible. It is preferable to locate orifice flange taps as follows:

Service	Location
Steam	Horizontal
Water	Horizontal
Compressed Air & Fuel Gas	Vertical (Preferred) or Horizontal

The piping designer must leave about 15 inches clear from orifice taps for valves and piping. The minimum orifice flange rating should be 300 pounds because a wide flange thickness is needed to allow taps to be drilled. Flanges are erected, bolted, and hydrotested prior to insertion of the orifice plate. When the plate is inserted, a gasket is placed on both sides and the flanges are then rebolted. This results in a gap, caused by the plate and two gaskets. When thick flanges are used for the taps, then the gap will require longer bolts, a fact often overlooked.

f. Support Locations

One of the most important consideration of pipe layout is to anticipate the requirements for supports. The location of heavy pipe loads with respect to the supporting building structure, (such that the support configurations are simple to enable the use of standard hardware to the maximum extent possible) should be identified very early in the design.

f1. The system design may require supports at mandatory locations, such as near the equipment or expansion joints or heavy pipe line-supported equipment (e.g., strainers).

- The supporting philosophy and routing configuration should be agreed upon before detailed design begins.

- The piping system being designed may have unique operating modes that sometimes affects the analysis and supporting requirements, such as removable spools.

- Also, the piping system being designed may require supports with heavy structural attachments, or embedments that could alter the pipe route in order to properly satisfy such attachments.

- During the layout of the plant piping, the piping should be arranged to minimize the number of piping supports required, and eliminate the use of snubbers.

- To minimize the number and size of supports required, piping shall be routed close to walls, ceilings, and floors or other large structural components, not including partitions or block walls, to allow the installation of restraints. Piping shall be grouped together as much as possible to allow the use of common supports.

g. Valves

The most desirable arrangement for valves is in a horizontal run of pipe with the operator in a vertical position and easily accessible to plant personnel. If this is not possible, care must be taken to avoid difficult analysis problems. For motor operated valves the location of the operator must be carefully reviewed.

h. Tap Lines

Tap lines are small branch piping generally less than 2 inches in diameter. They typically branch off of header piping having a much larger diameter. An example of a common tap line is a 3/4 inch size high point vent. Most tap lines have at least one valve near their header tap connections to provide isolation, and two valves are often required for double isolation. Different categories of tap lines include high point vents, low point drains, pressure tap connections, flow venturi pressure tap lines, process sampling lines, gland steam seal leakoff lines, and miscellaneous instrumentation lints. Many tap lines are short dead-ended runs of pipe, such as high point vents. Tap lines may also have downstream piping, such as pressure instrumentation pipe lines.

h1. Tap line locations are determined by their function, for example, a high point vent is located at the high point of the system. However, as much as practical, the tap line orientation and location should allow easy access to the valve. These lines should be located in a manner that will facilitate personnel access to the lines for operability and that will avoid interferences with nearby structures and insulation on the header piping. For example, expected thermal expansion of the header piping needs to be considered in locating the tap lines to avoid potential interferences. If a tieback design is to be used, the tap line should be in a location that will allow room for support. A tieback design refers to supporting the tap line by a structural member that is anchored to or "tied back" to the header piping. This is the preferred configuration to protect against failure of the tap to a header weld by either expansion or vibration induced stresses. If the tap line is to be connected to downstream piping, then consideration should be given to the routing and location of the downstream piping when locating the tap line. If possible, tap lines should not be located near areas of potential cavitation, such as control valves or flow orifices, or near areas of flow turbulence, such as elbows and branch connections.

h2. Valves specified for tap line applications should be as small and light as practical. A small valve will allow the routing to be kept short, which increases its stiffness.

h3. The length of a tap line is kept as short as possible to provide for a rigid design. The length of the routing is based on providing sufficient flexibility for thermal expansion, ease of access for operation, the distance required to avoid interference, and the minimum distance required between welds.

h4. Downstream piping refers to piping downstream of the tap line valve(s) that runs to a location remote from the branch location. Examples include a drain line that is routed to a common drain header and pressure tap lines that run to a remote instrumentational panel. The effects of downsteams piping must be considered in the tap line design.

h5. Sufficient flexibility must be designed into the downstream piping (or tubing) to allow for the expected thermal expansion movements of the header along with the dynamic movements resulting from postulated seismic or accident events. If necessary, this can be accomplished through the use of expansion loops. In some cases the temperature of dead end tap lines can be reduced to alleviate flexibility problems. This should be verified with the system engineer.

h6. Cantilever designs are desirable in that they take a minimum of space, require no support, and facilitate installation. Cantilever designs are possible with tap lines requiring only one valve, especially when light valves are used. The routing is kept short, which results in a high vibrational frequency, and allows the header piping and tap line to vibrate together as a rigid body. Cantilever designs have no downstream piping or are connected to downstream piping by flexible metal hose.

h7. Tieback designs, which involve supporting the tap line from the header piping, are used for longer routings, routings with downstream piping, and routings using two valves or one large valve. The objective of the tieback design is to keep the routing short, and the tieback into the header avoids relative motion between the header and tap line which allows the header and tap line to vibrate together as a rigid body. A primary objective of the tieback support is to restrain the valves on the tap line. Valves act as large lumped masses on the tap line piping. Lumped masses lower the vibrational frequency and increase their vibrational response. Restraining these valves through a tieback support significantly reduce the vibration response. Routing a tap line parallel to the process piping facilitates its support from the header. The pipe span between the nozzle and support is kept short and the parallel routing allows the line to be readily supported from the header. In circumstances where the tap line cannot be routed parallel to the header, for example to allow for easier personnel access to open and close the valves, the tap line can still be supported from the header piping. Tap lines not routed parallel to the header will require somewhat more elaborate tieback support configurations. Standard support configurations shall be developed for project use.

h8. Tap lines having large motor operated valves, such as in the case of valve bypass lines, may require the tap line valve to be supported independent of the header. In these cases, the tap line would be hard piped to the motor operated valve, which would be supported from the building structure or auxiliary steel. The hard pipe routings must contain sufficient flexibility to accommodate header movements.

i. Pipe Sleeves

The location of pipe penetrations through walls in high radiation areas must be carefully reviewed before finalizing the design.

- Wherever it is practicable to do so, the penetration should be located near where two or three shield walls join (for example, near the upper corners of a room where the penetration is far away from radiation sources), and near beams and columns which may serve as extra shielding to at least one side of the penetration (e.g., when a beam or a column is between the source and penetrations).

- The penetration should be located as high above the floor as is practicable and not less than 8 feet if possible.
- The penetration should not be aligned with a radiation source, nor (where practicable) should it be aligned with areas of frequent occupancy.
- Generally, a penetration should penetrate through the thinnest of shield walls when a choice exists.
- Normally each process pipe should have its own sleeve.
- For adjacent pipes, sufficient space must be allowed for sleeves a minimum of 2" larger than the process pipe. Space must also be allowed for head fittings welded to the sleeve and used as anchors.
- Project requirements must be established to determine if piping inside sleeves will be insulated or if other types of seals will be required.

j. Substructure Piping

It usually is desirable to embed large coldwater piping systems (Circ. water, service water etc.) in the substructure foundations. This avoids taking large amounts of space in the plant or having to support very large loads from the building structure.

- The substructure piping philosophy must be reviewed and agreed upon with the project team
- Preliminary foundation sizes shall be determined by the Structural Designer
- The depth of the finished floor must be determined
- The mechanical piping drawings must be reviewed for possible interference with plumbing, electrical conduits, and column pockets.
- Corrosion conditions of the piping should be investigated by system engineering against the piping material.

k. Equipment Drains

When equipment is located in the plant equipment drains must be anticipated and provisions made for these drains in concrete floors.

- Equipment baseplate drains must be incorporated into the substructure.

- If equipment drain locations have not been finalized, agreements must be made to allow for future routing within the finish thickness.
- Spare piping stubs may be located in the substructure in anticipation of additional users.
- Piping with operating temperature of 150°F or over must be reviewed by the Structural Designer.
- Generally, 2-inch or smaller piping should not be routed in the substructure unless stipulated by the project scope of work as provided by the client.

I. Pump Suction

Pump suction piping has certain requirements that should be followed to ensure proper and most efficient pump operation. Some of these requirements are as follows:

I1. The following approach will be used in the layout of suction piping for pumps with double suction first stage impellers. For other designs of horizontal pumps, there is some leeway in the requirements of this approach. The suction piping shall be laid out so that each eye of the double suction impeller sees the same piping approach configuration. The elbow in the approach piping should be in a vertical position, perpendicular to the pump's centerline. There should be at least four diameters of straight pipe between the elbow and the reducer. If the elbow at the pump suction must be in a horizontal position, there must be at least 8 diameters of straight pipe between the elbow and the reducer. Reducers in the pump suction piping close to the pump connection should be of the straight sided type (not contoured). If the reducer is in a horizontal position, eccentric reducers should be used with the top of the reducer horizontal to avoid an air pocket in the suction line. The reducer should use a minimum side angle when it is located at the suction connection of the pump. The suction piping should be at least the same diameter of the pump connection, or preferably one size larger.

I2. For general service centrifugal pumps with a suction lift, the pump manufacturer's recommended minimum submergence of the suction line should be observed. The suction piping should slope continuously upwards towards the pump and an eccentric reducer with the top surface horizontal shall be used to prevent air pockets in the pump's suction. Suction isolation valves should be either butterfly or gate type, with the stem in a horizontal position to vent air that could be trapped in the valve bonnet. The suction valve should be located at least 3 pipe diameters upstream of the pump connection. When expansion joints are used in the pump suction, anchors or restraints should be installed to prevent forces that result from pressure (or vacuum) in the pipe from being transmitted to the pump.

m. Design Holds

When piping design and layout begins on a project the designer must prepare a design that will cause minimum changes as input becomes verified.

m1. The ideal situation would be to have 100% of the input available before the piping design process begins. The piping design process cannot wait for all of the input to be assembled before design work begins, it would only delay the schedule. Therefore, the key is to use the available input and assess the possible effect that incomplete or missing data may have on the overall design. The design decisions are then made based on an allowance for these contingencies. In this way, the effort required to bring all of the station design to completion is kept to minimum. The design input will be finalized as the missing components and information are applied to the original design.

m2. All areas of the system piping drawings where design input is not verified, is not intended for release for fabrication, or is not based on certified vendor equipment drawings, shall be circled and marked "Hold." A "Hold" list shall be generated and each hold shall be numbered with a description of the reason for the "Hold".

n. Radiation/Shielding

All radioactive or potentially radioactive pipelines require special routing considerations to decrease the amount of exposure to plant operating personnel.

n1. Piping shall be routed to optimize radiation protection, and enhance ALARA and lead shielding considerations.

n2. Radioactive process piping shall be routed in shielded pipe tunnels, trenches or chases, or in areas where the radiation field due to the pipe is consistent with the radiation zone for that area.

n3. To aid in preventing crud buildup in radioactive and potentially radioactive process piping, sharp bends, dead ends and other obvious crud traps shall be avoided. In general, socket welds and welds employing backing rings should be avoided to the extent practicable in these systems. These welds contribute to radioactive crud accumulation which results in increased radiation fields near the weld.

n4. Shielding of radwaste drain piping (including floor and sink drain piping) shall be provided as necessary. Radwaste drain piping not specifically shielded shall be routed so that it is not exposed to normally occupied areas and general access routes. Vertical runs of radwaste drain piping not specifically shielded shall be run against walls and sufficiently isolated so as to facilitate compensatory shielding, if required.

n5. Penetrations in shield walls for pipes, shall be located and designed to minimize radiation levels to personnel. Location and orientation of penetrations shall be selected to avoid streaming to areas most likely to be occupied by operating and maintenance personnel. Compensatory shielding shall be used where necessary to reduce radiation streaming due to penetrations and localized shield deficiencies (expected hot spots).

n6. Routing of radioactive lines in low radiation zones shall be avoided to the extent practicable. Lines that require shielding shall be routed in shielded pipe tunnels or in radiation areas to the extent practicable. Where necessary, radioactive and nonradioactive lines may be routed in common pipe tunnels. This however, is not preferred.

n7. Penetrations through shielded pipe tunnels should not be made by lines which do not themselves run through the pipe tunnels.

n8. Lines that carry radwaste demineralizer resins, filter backwash, filter/demineralizer sledges, or other particulate should have 5 diameter radius bends and should be continuously sloped. The use of loop seals on these lines shall be avoided to the extent practicable.

n9. Radioactive piping shall not be routed near the designated location of an area radiation monitor thereby causing abnormally high radiation readings which are non-representative of the area in which the monitor is located. The monitor shall be relocated when the above criteria can not be satisfied. Slightly radioactive lines shall be routed in a manner which minimizes radiation exposure to plant operating and maintenance personnel. Slightly radioactive lines in low radiation zones shall, to the extent practicable, be routed at a minimum elevation above the finished floor of 10'-0", but it is desirable that these lines be routed as high above the floor as is practicable. To the extent practicable, slightly radioactive lines shall not be routed near normally travelled passageways, or near galleries and other elevated work areas.

n10. Shielded valve aisles shall be provided to permit greater accessibility to valves requiring frequent maintenance. The valves should be shielded to the extent practicable from the equipment it services.

o. Pipe Connections

The majority of pipe connections in a power plant are welded or flanged. It is important for the pipe designer to review the connections on all vendor furnished equipment to ensure it is compatible with the piping design requirements. If not a note must be added to the piping drawing to provide a matching connection.

o1. Flanged joints are generally required where pipe line, piping components, or equipment must be disassembled for maintenance work. Connections to cast iron valves and fittings and to steel flanged-end valves, where such construction is considered more desirable, must be flanged.

p. High-Energy/Separation

High energy piping should be located so that it could not impact any safety related components in the plant.

p1. Piping systems which are part of the engineered safety features shall be separated from each other and from cable associated with the other safety divisions.

p2. The pipe routing for systems essential to safe shutdown shall provide physical separation between redundant systems. To protect safe shutdown components from the adverse effects of postulated high energy line breaks, high energy lines shall be eliminated from safety-related areas wherever possible. To protect electrical components essential to safe shutdown from the adverse effects of postulated moderate energy line cracks, moderate energy lines shall be eliminated from areas containing safety-related electrical components.

p3. To minimize engineering and construction costs, redundant systems shall be routed symmetrically. By providing a symmetrical design the analysis and construction of piping systems is greatly simplified.

q. Maintenance

It is important for the piping design layout to avoid spaces reserved for equipment removal and maintenance.

q1. Equipment removal spaces or aisles as well as large truck or rail aisles must be reviewed for specifics and their relationship to the system or systems being designed. Equipment removal drawings are often more current and show in greater detail, the removal schemes for major plant equipment. These drawings should be reviewed for the compatibility with the piping layout.

r. Main Steam & Feedwater

Main steam and feedwater should be designed, routed and analyzed during the development of the general arrangements.

r1. The routing inside the containment of the MS and FW lines shall be such as to minimize subcompartment pressurization and environmental effects. Also the potential for damage to safety-related equipment due to pipe whip and jet impingement shall be minimized.

s. Other Pipe Considerations

There are other items that a piping layout designer should be familiar with.

s1. Long radius (lr) elbows (ells) are normally used in the design of piping systems. If suitable for the design, bends may be substituted when acceptable to the project. Short radius elbows should be used only if their use has been reviewed and if their use complies with the applicable requirements of ANSI Standards. ANSI B16.28 limits the pressure rating of short radius elbows to 80% of a pipe of comparable size, wall thickness and material. If short radius fittings are used, they must be certified to the full pressure rating of the system to which they are connected. If bends are used, the radius for the size and wall thickness must be determined.

s2. Pipe lines that require slope for drainage must be routed with continuous sloping in mind. Usually, the minimum acceptable slope is 1/8 inch per foot.

s3. Provisions shall be made to effectively eliminate condensation in steamlines, and adequate venting of air shall be ensured for all waterlines.

s4. All steam lines should be designed with a minimum number of low points, as the low points must be drained. Low points should preferably be located on the inlet side of isolation valves, as water will tend to follow the steam flow, regardless of the slope of the pipe. Steam piping at the location of the low point shall have at least 3 feet of clearance between the bottom of the pipe and the structure to allow for the low point drain pot, controls, and valving. All steam piping shall have adequate provisions for expansion. Expansion joints will only be used in extraction steam lines for feedwater heaters, unless otherwise justified.

3.1.2 Input Required

The following is a list of items required by a piping designer to complete the design of all piping systems in a nuclear power plant.

- General Arrangement Drawings
- Piping and Instrument Diagrams (P&IDs)
- Design base drawings (DBDs)
- Piping Design Tables (PDTs)
- Vendor Equipment drawings
- Piping Line list
- Valve list
- Instrument index
- Other design drawings (electrical, structural, etc.)

SECTION G.4

4.0 PIPING ANALYSIS GUIDELINES

The ASME code provides rules and requirements for maintaining pipe stresses below specified limits. To satisfy code rules, one must perform a stress analysis for all loadings to which the piping system is subjected. Before the advent of computers, the piping analyst designed piping systems by using handbooks and/or simplified design rules to achieve a conservative design. With advances in computer technology, designers are relying more and more on computers to achieve optimized piping system designs. Many commercially available computer programs have been developed for piping stress analysis. All these programs are linear, three-dimensional space frame, finite element programs.

Not all piping in a nuclear plant is designed by analysis. Small-bore piping, 2-inch diameter and under, is usually designed using small-bore piping design by rule procedures. These procedures are used to route the piping using simplified rules, and to obtain loads for support design. Compliance with the rules ensures that pipe stresses meet code allowables. These simplified rules can be applied manually, or applied by a computer program.

The piping engineer's overall responsibilities are

- to establish a piping, suspension, and restraint system arrangement that satisfies all design requirements for the system, and that is consistent with good piping design practice;
- to ensure that the suspension and restraint system arrangement is physically designed to function in a fashion that is consistent with the calculations used to qualify the piping system design; and
- to properly document all design calculations that were required to demonstrate that the design arrangement meets all pertinent requirements.

The basic design steps followed in performing a complete system evaluation are shown below:

- identification of design parameters,
- piping structural evaluation,
- code evaluation, and
- documentation and review.

4.1 Overview of Design Parameters

4.1.1 **Physical System Characteristics.** Before any evaluation can begin, an adequate representation of components to be evaluated must be prepared, including routing of the piping system, the various components that make up the piping systems, their weights, preliminary supporting system, etc.

4.1.2 **Identification of Design Basis Loading.** The loadings that must be acknowledged in the design of a given piping system are given in the design specification for the piping system and may depend on the service that it provides and its location in the plant. These loadings fall into two categories: normal service loads (dead weight and thermal expansion) and occasionally acting dynamic loads. Typical examples of the dynamic loads are building vibration loads (earthquake, etc), and fluid transient loads that result from the operation of fast acting system controls (water hammer loads).

4.1.3 Structural Evaluation

Once the loading required for design is identified, a structural analysis is performed to determine the effect of loading on the system. For routine piping system design, four types of structural analyses are usually performed. Three are static analyses and one is a dynamic analysis. The four types are listed below:

- static analysis for dead weight loading,
- static analysis for thermal expansion loading,
- static analysis for relative support displacement, and
- response spectrum analysis for building vibration loads.

For water hammer loads, time history using direct integration methods is required. However, these analyses are only performed on few systems, where water hammer loading is significant.

4.1.4 Code Evaluation and Load Combination Calculations

After a structural analysis for each individual load has been completed, the results are used for two purposes, those being:

- performance of all design calculations required by the piping code that governs the design of the piping, and
- computation of suspension and restraint system hardware design loads and pipe-imposed loads on equipment nozzles.

Should these computations indicate that the design does not comply with code requirements, or that equipment is overloaded, corrective action is necessary. Repetition of the individual structural analyses and the design calculations is then required to confirm that corrective action was adequate.

4.1.5 Review and Documentation (Quality Assurance)

Once the adequacy of the design has been confirmed and a complete design report package is assembled the work must be reviewed by an independent party to ensure that it is technically adequate. One of the piping engineer's responsibilities will be to act as a reviewer of design calculations that were performed by another person. After the review has been completed, documentation of all computations and/or calculations that were performed is required.

4.1.6 Applicable Design Documents

Before proceeding with a more detailed discussion of the design steps and their implementation, a piping engineer should be aware of the numerous documents that directly or indirectly affect the course of his work. Regardless of whether his analysis pertains to a nuclear or fossil power plant the design will be controlled by information contained in some or all of these documents. A summary of the types of documents the piping engineer should be aware of is contained in Exhibit 4.1-1. The list is not necessarily all inclusive but it indicates the magnitude of information available.

A major portion of the work for piping is designed per the requirements of ASME Section III of the B&PV Code (hereafter referred to as the Code). Most of the piping engineer's exposure will be related to Code-related documents. In a very general sense the Piping Engineer will be working with three types of Code documents: the Design Specification, Design Documents, and the Design Report. Without going into details the following definitions apply:

- **Design Specification**. A document that contains sufficient detail to provide a complete design basis for components covered by the Code.
- **Design Documents**. A set of reports, calculations, drawings, and sketches that show that the applicable sections of the Code have been met. (This includes the Design Report.)
- **Design Report**. A design document that includes the stress analysis complying to the Code requirements and those requirements set out in the Design Specification.

4.2 Preparation of Piping Model

4.2.1 Introduction

A piping system model is a mathematical representation of the piping system being analyzed that is used as input to the computer programs. The piping analysis programs are large structural analysis programs that are designed specifically for the analysis of piping systems. These programs are linear, three dimensional space frame, finite element programs. The programs perform four basic functions:

- The programs read in the analytical data for the model that the piping engineer prepares.
- The programs perform the structural analyses that are specified by the engineer.
- The programs collect the results of all the structural analyses that they perform and use them to check the piping design against the requirements imposed on them by the piping codes that govern them.
- The programs summarize all the design information that they generate in a report that can be transmitted to the parties responsible for the designs of associated equipment and structures.

The models that are prepared contain two basic sets of information. The first set of information consists of the structural model, which is a detailed description of the piping being analyzed. The second set of information consist of type of analyses to be performed and how to combine these analyses to perform code evaluation.

4.2.2 Building Blocks of the Model

Structural models for piping are constructed from two basic building blocks called Nodes and Elements. The two building blocks are described below.

a. Nodes. A node is a reference point in space that is used to define a physical location on the piping system.

b. Elements. An element is a length of pipe that spans between two nodes. Straight elements are used to represent straight pipe and curved elements are used to represent elbows and pipe bends.

4.2.3 Information for Modeling a Piping System

a. Node Information. Nodes are reference points that are used to define physical locations on the piping system. Nodes are used as reference points to specify the following information in a piping model:

- location of a hanger or restraint,
- location of a fitting,
- location of an elbow,
- location of valve ends,
- location of equipment,
- location of a weld that joins two different types or sizes of piping,
- center of gravity of valves,
- location of anchors, and
- location of an intermediate data point in the model.

There are two basic pieces of information about each node that are required to be provided by the preparer of the model. These are its location, and then what it represents.

b. Element Information. Elements are used to represent the pipe segments that run between two nodes. To describe the pipe, the following information is required:

- outside diameter of the pipe,
- wall thickness of the pipe,
- weight of pipe, its contents and its insulation,
- what material the pipe is made of,
- which two nodes the element runs between, and
- for curved elements, information about how the element is curved and oriented.

Some computer codes combine the node and element cards into one set of cards.

4.2.4 Component Representation

Piping systems contain a broad range of fittings, such as elbows, branch connections, or valves. In addition to fittings, piping systems may also contain miscellaneous types of welded attachments that are used to connect restraint hardware to the pipe. The piping codes that govern the design and erection of power piping (ASME Boiler & Pressure Vessel Code and ANSI B31.1) require that stress analysis be done on those components. This detailed analysis is done by the computer program. In order to do this analysis, the computer program has to know what types of fittings are in the piping system and where they are.

There are two basic types of components, the first type being small components that are represented by a single node, and the second type being large pieces of in-line equipment, such as valves and large bends, that are typically represented by several elements. Both types will be discussed.

a. Single Node Representation of Components. In modeling piping systems, most of the components will be represented by a single node. Information about the details of these fittings may be input into the computer program on the node card. Typically the following type of components are represented by a single node representation:

- straight seamless pipe,
- girth butt welds.
- girt fillet welds to socket fitting,
- longitudinal butt weld in straight pipe,
- tapered transitions
- branch and tee connections,
- reducers

b. Modeling of Components Using Elements

Several types of components commonly installed in piping systems are modeled using one, or several, elements. Listed below are the components falling into this category.

- all types of valves,
- elbows or bends,

The modeling of each of these types of components is be discussed below.

c. Modeling of Valves. For the purposes of piping analysis, valves fall into two main categories.

c1. Valves with Center of Gravity Approximately on the Centerline of the Pipe. Valves that fall into this category include most hand-operated valves, control valves, and some air-operated valves. To determine if a valve falls into this category, the distance from the CG to the pipe centerline should be less than or equal to one-half of the pipe outside diameter. Valves that fall into this category should be modeled in the following manner.

- The valve is represented by a single element.
- A node should be located at each end of the valve, where the valve is connected to the pipe. These node types will depend on how the connections are made.
- The material of this single element should be the material of the valve body, given on the valve drawing.
- The geometry of this element will have these properties:
  - -- Unit weight is equal to the total weight of the valve plus normal operating contents plus insulation, if any, divided by the length of the valve.
  - -- The wall thickness of the valve element can be either the maximum wall thickness of the valve body (shown on the drawing) or five times the wall thickness of the attached pipe. Either of these values will give a reasonably accurate model; however, the latter approach is recommended for consistency in normal modeling situations.
  - -- The outside diameter of the valve can be either the maximum outside diameter of the valve body, or the outside diameter of the pipe.

c2. Valves with Center of Gravity off the Centerline of the Pipe. Some valves that fit into this category are motor-operated valves, solenoid-operated valves, and some air-operated valves. Any valve whose CG is greater than one-half of the pipe diameter from the pipe centerline should be coded in the following way:

- The valve is represented by three elements as shown in Exhibits 4.2-1.
- The nodes are located as shown in Exhibit 4.2-1. When specifying the coordinates of the CG node, the piping engineer makes sure how the valve is

oriented. The CG might not be directly above the pipe; it may be at an angle. It is important that the valve CG is located correctly with respect to the pipe. The valve orientation will be shown on the single line drawing.

- The material used in all three elements should be the material of the valve body.
- The geometry of all three elements should be as follows:
  - All three elements are weightless.
  - Wall thickness and outside diameters of all three elements as discussed before.
  - Lump valve weight at C. G. node

d. Modeling of Elbows or Bends. The elbows or bends are modelled using curved elements. The radius of the elbow or bend should be input correctly as the properties of the bend or elbow depend on the radius. The elbow end connections should be modelled properly as the elbow flexibility factors depend on the end conditions.

4.3 GENERAL STRUCTURAL MODELING

4.3.1 Node Spacing and Element Lengths

After locating nodes at all welds, fittings, special components, subsystem boundaries, etc., the piping engineer must locate nodes on the remaining portions of plain, straight piping. These nodes should be located in a way such that the following three criteria are satisfied:

- The length of any element divided by the outside diameter of the piping being modeled by that element L/D should be between 0.5 and 15.

  These values are extreme values. The piping engineer should, in general, try to keep the L/D ratio somewhere in the middle of that range.

- To simulate proper dynamic behavior of continuous piping system, the minimum distance between node points (mass points) can be determined based on frequency formula for simple-simple supported beam for the frequency of interest. For various pipe sizes the tables of minimum distance can be developed.

- Adjacent elements should be approximately the same length. In cases where adjacent elements are different diameters, the L/D ratios should be approximately equal.

One situation that should always be avoided is having a very long element next to a very short element. If one is forced to have a very short element (L/D approximately 0.5) due to weld locations or some type of fitting one is modeling, make the adjacent element slightly longer and the element after that slightly longer yet, and so on, until the L/D ratio is in the more acceptable range. The piping engineer should avoid having a large jump in the L/D ratios of adjacent elements.

4.3.2 Location of Nodes Between Restraints

At least one node should always be located between any nodes that are restrained in any direction.

4.3.3 Additional Structural Modeling Detail for Class 1 Piping

The Class 1 pipe design rules require a fatigue evaluation of the piping system. To support the fatigue analysis, internal bending moments are required at all locations being analyzed. The computer program will not store the internal bending moments required unless there is a node located at those points in the model.

To ensure that one will be able to calculate all information required for the fatigue analysis, the piping engineer must take the following precautions:

- **Step** 1. Inspect the system carefully and identify all locations at which fatigue analysis is required (for instance, at all weld locations on the pipe).
- **Step** 2. Ensure that there is a node in the model at all locations that he identified in Step 1.

4.3.4 Piping System Analysis Boundaries and Support Modelling

Usually piping systems are modelled between anchors. The anchors define piping system analysis boundaries. The following criteria define acceptable methods for breaking up large continuous piping systems into analytically manageable system for qualifications.

- Anchors. Analysis boundaries can be located at in-line anchors or equipment anchors. In-line anchors provide complete isolation between adjacent piping segments on either sides. The piping results from one side will not effect the results of other sides. However, for in-line anchors, qualification must be based on loads from both sides of the system. For weight and thermal loads, algebraic sum should be used. For dynamic loads, the loads from both sides can be combined based on SRSS method. Anchors used to isolate seismic and nonseismic piping always present a problem that often loads are not available from the nonseismic portion of piping. One approach is to design the anchor for plastic moment capacity of the nonseismic pipe. This may result in extremely conservative design. EPRI Report

RP-2967-2, Vol. 5 provides additional guidelines for evaluating these type of anchors.

- Branch Line Decoupling. Small branches are generally decoupled from large headers. It is recommended that if the ratio of run to branch pipe moment of inertia is 25 to 1, or more, the branch pipe may be decoupled from the run pipe. The use of lower ratios may be used if adequate technical justification is provided. The mass effect of the decoupled branch line should be included, if significant, in the run pipe analysis.

  The appropriate stress indices and intensification factors should be calculated and applied to run and branch analysis. Also the effect of stresses from the branch and run pipe need to be added (see Section 4.10.9).

- Overlap Boundary Piping. When piping system boundaries are located at translational supports rather than at an anchor, additional overlap boundary pipe beyond the qualification limit is required to account for the effect of adjacent pipe. The overlap boundary should extend beyond two active supports in each of the three orthogonal directions. Enveloped results of the overlap boundary must be used for qualification. Other guidelines provided in EPRI RP-2967-2, Vol. 5 can also be used.

- Modelling Supports. The supports in the piping analysis are usually modelled as rigid boundary conditions. The pipe designer must assure himself that the support design will approximate rigid behavior. This is usually attained by imposing a deflection limit on the support. The recommended limit on support deflection is 1/8." Larger values may be used if demonstrated for a plant specific application. EPRI report RP-2967-2, Vol. 6 provide additional guidelines for justifying larger values.

  Supports, when installed on pipe, may have gaps associated with them. Current industry practice (WRC-353) is to limit the total gap in the range of 1/8" for loaded directions. For regions near sensitive equipment, this gap is further limited to 1/16". Gaps of this size limit redistribution of load and do not require any consideration in the piping analysis.

4.4 Weight Analysis

4.4.1 Dead Weight Analysis of Piping

a. A dead weight analysis is performed on all piping systems that are designed by computer analysis methods. Proper design of piping systems for dead weight loading consists of three steps.

   - A suspension system arrangement must be established by careful visual inspection of the physical structure of the piping system. This process is the most critical step in the design process. This step must be completed carefully to result in a properly supported system. It consists of an inspection of the piping system to identify and correct undesirable internal loading mechanisms.

- Suspension system loads must be calculated.
- The stress obtained from the computer program must be checked for code compliance.

b. A piping system that is properly supported will have the following characteristics.

- The bending stresses in the piping created by the dead weight loading will be below the allowable levels that are specified by the piping code that governs the design of the piping. Usually the support spacing is such that weight stresses are less 3000 psi.
- The weight loading will be evenly distributed on all elements of the suspension system.
- All vertical piping will be supported in a stable fashion.
- All vertical deflections of the piping will be downward and reasonably small (<0.2").
- All horizontal deflections of the piping will be less than 0.25 inch.
- The reactions on equipment to which the piping is connected will be minimized. The vertical nozzle reaction forces on all pieces of equipment will be downward.

4.4.2 **Loading Definition Data.** To perform a dead weight analysis, a considerable amount of information is required to define the loading. The information consists of two sets of data. These are:

- a description of the weight of all the components that exist in the piping system, and
- a listing of the hanger setting data that were used to preload the variable hangers in the system. This data is required only if the piping system that is analyzed, and its suspension system, have been purchased and installed.

These two sets of information will be discussed below.

a. Weight Data. The data required to perform a dead weight analysis are essentially detailed descriptions of the weight of everything that makes up the piping system. They consist of the items listed below.

a1. weight of every piece of pipe that makes up the system,

a2. weight of every valve in the system and the location of its center of gravity,

a3. weight of every strainer in the system and the location of its center of gravity.

a4. weight of every piece of inline equipment in the system and its center of gravity,

a5. weight of the normal operating fluid inside the piping, valves, strainers, and inline equipment,

a6. weight of the insulation installed on every piece of pipe, every valve, strainers, and inline equipment,

a7. weight of significant pipe restraint hardware that is supported by the piping, and

a8. weight of all socket welding fittings and all flanges regardless of what type they are.

The accuracy of weight data is very important when analyzing systems that are supported with variable hangers. Conservative overestimation of the weight of the piping, its contents, insulation, and valves actually does more harm than good in these cases. The reason for this is that variable hangers are preloaded devices. The preload specified for the hangers is called their setting. These settings are determined by the results of analysis. When the analysis is done with overestimated weights, hanger settings that are higher than those actually required to support the pipe will result. The hangers are then designed and purchased with excessive settings. This will result in a suspension system that pulls the pipe upwards rather than supporting it in a uniform manner.

b. Hanger Setting Data. Two types of dead weight analysis are usually performed, one being the initial design analysis, which determines the settings in the system, the other being an analysis of a system that has already been designed and fabricated. For this hanger settings are specified as input.

4.4.3 **Proper Piping and Suspension System Arrangement.** If a piping system is improperly supported, the support reactions will be unevenly distributed or will indicate that the hangers are holding the pipe down. This is an indication that the hangers in the system are not properly placed or that there is a heavy weight in the system that is not adequately supported. Both conditions cause unnecessary bending of the pipe and indicate an unstable condition.

The vertical reaction forces on equipment nozzles due to dead weight loading should load the equipment nozzle downward. Equipment nozzle loads from weight analysis should be reviewed to determine what proportion of the allowable load they represent. If they represent a significant proportion of the manufacturer's allowable loads for a nozzle, action should be taken to reduce them before any subsequent analyses are performed.

The following items summarize undesirable weight loading mechanisms that result from improper piping and/or suspension arrangements.

a. Uneven Support Spacing. The supports on the piping should be spaced at intervals that are as uniform as possible. If this feature does not exist, pivoting of the piping occurs about the supports as indicated in Exhibit 4.4-1. The result is uneven distribution of the weight of the piping on its suspension system. These conditions should be corrected by relocation of supports or addition of supports.

   Immediate Support of Large Valves and Fittings. Large valves and flanges should have supports located immediately adjacent to them. If they do not, pivoting about the nearest restraints will occur. If the potential for pivoting exists, a support should be added immediately adjacent to the valve on the line.

b. Unstable Risers. Piping systems can be unstable near risers (vertical legs of pipe). For this reason, there should always be a support near the top of every vertical leg of pipe in the system. If this is not feasible, the riser should be supported or guided near the top to prevent it from falling over if laterally loaded near the top, as illustrated in Exhibit 4.4-2.

   Note that piping analysis computer programs will not indicate if unstable configurations exist. Instability problems must be located and corrected by visual inspection of the system by the designer.

c. Drooping Flat Bends. Supports should be located near the elbows of horizontal flat bends. Not doing so may result in large lateral and vertical deflections of the piping. When this condition exists, supports should be added at or near any unsupported elbows. Failing to do so may result in excessive vertical deflections, which will present future drainage problems. See Exhibit 4.4-3.

d. Weight Shifting. During thermal expansion of the piping, weight shifts can occur between rigid hangers. This happens in low temperature and high temperature systems and must be prevented in the design. To prevent this, do not use rigid supports near the ends of the vertical piping legs. See Exhibit 4.4-4.

When the piping shown in Exhibit 4.4-4 is cold, the weight of the piping will be carried by both hangers shown. Upon warmup of the line, the piping will expand upward from hanger at the bottom. When this occurs, the pipe will lift off the support at the top of the riser and all the weight will impose on the bottom hanger. This must be avoided by replacing one of the rigid supports with a variable hanger.

e. Large Valves Near Equipment Nozzles. Heavy valves should not be located in piping systems immediately adjacent to equipment nozzles. Enough piping must exist between the nozzle and the valve to allow installation of supports to prevent the equipment nozzle from supporting the weight of the valve.

Particular attention should be paid to the arrangement of piping near pump nozzles. Skid-mounted pumps are very sensitive to nozzle loads. Skid-mounted pumps consist of two separate pieces of machinery, a motor and a pump. The motor and the pump are mounted adjacent to one another on a skid. Their shafts are connected by a coupling. See Exhibit 4.4-5.

Excessive piping loads on the pump nozzles will distort the pump mounting structure and cause misalignment (shaft bending) problems. Alignment problems can be experienced even when the nozzle loads are below manufacturer's allowable. Accordingly, nozzle loads on skid-mounted pumps must be as low as practically possible.

To allow the lowest reactions possible, any motor-operated valves or heavy strainers must be located far enough away from the nozzles to permit the installation of several supports between the valve or strainer and the pump nozzle.

f. Overstress and Equipment Problems. Overstress and equipment load problems caused by dead weight loading may be caused by overspanning, or the presence of one of the mechanisms discussed above. To solve the problem, identify the problem by inspection of the computer output and the physical arrangement of the system. Then add supports to the system or relocate existing supports to alleviate the overstresses.

4.5 Thermal Expansion Analysis

The function of piping in a plant is to carry fluid from one piece of equipment to another. In most systems, the fluid is at a higher temperature than the surrounding atmosphere and the major building structures that support and restrain the pipe. When this condition exists, the individual legs of a piping system will expand, and move relative to the building structure. Generally, there will be anchors, rigid restraints and supports on the system for the purposes of seismic and weight control. These restraints prevent the motion of the pipe, and in doing so, cause bending of the pipe. This bending gives rise to pipe stresses, restraint loads, and equipment loads that must be acknowledged in the design of the piping and its support and restraint system. These loads can be very high in a system that is improperly designed, and if the piping is large, they can be large enough to cause damage to major building structures and equipment.

Thermal expansion loads are accounted for in the design of piping systems by performing a thermal expansion analysis. A thermal expansion analysis is a static analysis that accounts for loading caused by the following mechanisms:

- expansion of legs of piping that make up the system,
- displacement of equipment nozzle connections caused by thermal expansion of the equipment,
- displacements of piping connections to large headers caused by thermal expansion of the header piping, and
- cold springing of the piping when cold springing is used.

The product of the analysis is a set of loads that are used for design of the piping system's restraint and suspension system, and a set of internal bending moments that are used to check compliance with piping code rules.

To evaluate thermal expansion loading for a piping system, a set of input information is required. That information consists of the following items for a given operating condition:

- A detailed description of the temperature of all segments of the piping during that operating condition. This collection of information is called a thermal mode.
- A detailed description of the displacement of each equipment connection, and connection to large headers which form boundaries of the system. These displacements are referred to as anchor movements of the corresponding thermal mode.

These two sets of information are discussed below.

4.5.1 **Thermal Modes**. A thermal mode is a detailed description of the temperature of the system during a specific plant operating condition. Thermal modes are described by using a schematic flow diagram of the subsystem, which shows all areas of the subsystem. The temperatures of the various areas of the piping are marked on the schematic diagram.

A thorough understanding of the thermal modes, which are required for each unique piping subsystem analysis, is critical. Misinterpretation of the thermal mode generally results in the incorrect design of all rigid restraints and hangers in the subsystem and could conceal several equipment load problems.

4.5.2 **Anchor Movements**. Each thermal mode will have associated with it a set of anchor movements. These movements will be the thermal expansion movement of an equipment nozzle or the thermal expansion movement of a large header that the system is a branch of. These displacements must be imposed at their specified locations in the analysis of every thermal mode. When the subsystem being analyzed is a branch line off a large header, the anchor movements of the header (translations and rotations) should be obtained from the latest analysis of the subsystem containing the header. In situations where the anchor movements are small, e.g., less than or equal to 1/16 inch in each of the three global directions, then an anchor displacement analysis generally need not be performed.

4.5.3 **Resolution of Design Problems**. Thermal expansion design problems with piping systems fall into four basic categories. These categories are described below:

- pipe overstress caused by excessive bending moments,
- equipment nozzle loading above manufacturer's specified limits,
- unreasonably high rigid support and restraint loads, and
- excessive piping displacement.

All of the problems listed above are caused by the same basic mechanism. That mechanism is shown in Exhibit 4.5-1.

The basic mechanism consists of four parts, the first being the base that the expanding leg pushes off from. The base could be an anchor, a rigid restraint, or a portion of the piping system that is not flexible. The second part is an expanding leg. The expanding leg expands when its temperature is increased. The expanding leg could be a single pipe or a portion of the system consisting of several lines. The third part is the bending leg. The bending leg can also be a single leg or a portion of the system. The fourth part is the restraint. The restraint prevents the bending leg from moving freely with the end of the expanding leg and causes it to bend. The restraint could be an anchor, a rigid restraint, or a portion of the system that is stiffer than it should be.

To correct a problem, the piping engineer must take one of the actions listed below.

- Do away with the base that the expanding leg is pushing off from or add more flexibility so that the net effect of the base and expanding leg is less than it was.
- Shorten the expanding leg.
- Lengthen the bending leg.
- Do away with the restraint that is preventing the bending leg from moving.

To accomplish one of the corrective actions listed above, one must first identify the basic parts of the mechanism that is causing the problem, and then determine physically how one will adjust it to alleviate the problem.

4.6 Dynamic Analysis of Piping Systems

Safety-related piping systems, and their associated suspension and restraint systems, are designed to withstand seismic and any hydraulic transient loads that may be imposed on them. There are several types of dynamic analysis options that are available in various computer programs. These options are:

- Response spectrum method:
  - uniform response spectrum method, and
  - multiple support response spectrum method.
- Forced vibration time history:
  - mode displacement method,
  - mode acceleration method,
  - direct integration method with proportional damping, and
  - direct integration method with variable damping.
- Support excitation time-history analysis:
  - modal time-history analysis when all collinear supports are excited by the same acceleration time history using the mode displacement formulation,
  - direct integration time-history analysis for systems with variable damping and subjected to uniform support acceleration excitation,
  - direct integration time-history analysis for piping systems with proportional damping and subjected to multiple support displacement time-history excitation,
  - modal time-history analysis for piping systems subjected to multiple support displacement time-history excitation using the mode acceleration formulation,
  - modal time-history analysis of systems subjected to multiple support acceleration or displacement time histories using the mode displacement formulation, and
  - direct integration time-history analysis for systems with proportional damping and subjected to uniform support acceleration excitation.

Most dynamic piping analyses for seismic loading are performed using the uniform response spectrum method. For hydraulic transient-type loadings, mode displacement method or direct integration methods with proportional damping are generally used. Only uniform response spectra method will be discussed here.

4.7 Uniform Response Spectra Analysis

4.7.1 Description of Basic Procedure Used

Most dynamic piping analyses for the vibration sources are performed using the uniform response spectrum method of analysis. This method consists of three separate analyses (one for each one of three perpendicular excitation directions) and the combination of their results. A representation of the physical situation that is analyzed is shown in Exhibit 4.7-1.

4.7.2 Procedure Used

- **Step 1.** The response of the piping inside the box is calculated for a vibration of the rigid box that is specified in the X direction.
- **Step 2.** The response of the piping inside the box is calculated for a vibration of the rigid box that is specified in the Y direction.
- **Step 3.** The response of the piping inside the box is calculated for a variation of the rigid box that is specified in the Z direction.
- **Step 4.** The three responses are combined per the rule in Regulatory Guide 1.9-2 to obtain restraint loads and internal bending moments that are used for design.

It should be noted that the box used to represent the building is assumed to be completely rigid. Since it is assumed to be rigid, the piping system is excited with the same vibration at every attachment point to the box. This is the reason for the word "uniform" in the name "Uniform Base Excitation Response Spectrum Analysis."

In reality, different parts of the structure will be vibrating in different fashions during a given event. This means that different parts of the building will be moving relative to one another and bending the pipe. Loads induced by such relative movements cannot be calculated by this method of analysis. Design loads calculated using the response spectrum technique are referred to as "inertia loads." They are, theoretically, only a portion of the total design loads generated by a given vibration condition. Generally, the relative movements between major structures in nuclear power stations are very small, since the building is designed to sustain earthquakes. There will usually be enough conservatism inherent in the response spectrum method to account for relative displacement-induced loads. Relative displacement loads are discussed later in this section and should be considered, unless it is demonstrated that these loads will be small and can be ignored.

4.7.3 Specification of the Forcing Functions and Its Use in the Calculations

a. Response Spectra. To calculate the response of a piping system for a given direction of excitation, the computer programs break the structural model of the piping system down into a large number of single-mass spring systems (single-degree-of-freedom oscillators). The operation used to break the model up into single-degree-of-freedom oscillators is called "equation of motion decoupling." The end result of the decoupling operation is a set of single-degree-of-freedom oscillators. Each single-degree-of-freedom oscillator corresponds to one mode of vibration of the system. The piping engineer specifies the number of modes to be used in the calculation. Determination of an adequate number of modes for the analysis will be discussed later in this section.

After the equations of motion are decoupled, the computer programs calculate the maximum response of each single-degree-of-freedom oscillator (i.e., each mode) using the forcing function that is provided.

The forcing function that is required is a graph of the maximum response (acceleration) of a spectrum of single-harmonic oscillators to the building vibration. These graphs are called response spectra.

To determine the maximum response of each single-degree-of-freedom oscillator (i.e., each mode), the computer programs simply read the graph that is input. This is the reason that this technique is called response spectra analysis.

After the maximum response of each single-degree-of-freedom oscillator is calculated, these maximum modal responses are combined according to the rules specified in Regulatory Guide 1.92 to get the total response.

b. Selection of Response Spectra. The response spectra that are used for piping analysis are calculated for all points of interest in the building (based on a building model). For a given load, at a given location in the building, there will exist spectra for each of the three directions of excitation used in the analysis. Also, for each location and direction there will be an assortment of spectra, each of which corresponds to a different amount of damping. To set up the analysis, the correct ones must be selected. This selection process consists of three steps, for a given loading, these being:

- identifying all locations on the building structure to which the piping system is attached,
- selecting all response spectra that are required to describe the building vibration at all the locations identified in the first step, and
- selecting the correct damping.

These steps will be discussed below.

b1. Identification of Attachment Points. The first step in the selection process is to identify all locations on the building structure to which the piping system is attached. To do this correctly, the support and restraint details for all supports and restraints in the model must be reviewed. This is particularly important when the model is located near the interface between two portions of a structure, or two structures that have radically different responses. Examples of these cases are reactor building-auxiliary building interfaces, and containment wall-reactor building slab interfaces. If care is not taken in these areas, the design loads for the restraints and supports in the model may be underestimated; or, all restraint and support loads may be overestimated and cause unnecessary hardware replacement. The engineer must be familiar with every attachment point of the model to the structure. A tabulation of all attachment locations should be made.

b2. Selecting the Actual Spectra. After tabulating all the structural attachment locations in the model, the next step is to review all the spectra that are available for the loading with which the engineer is concerned, and select the spectra that will be used for the analysis. This listing consists of a drawing of the building model and a table of contents for the computer file containing the spectra. The building model drawing will show all the locations for which spectra are available.

The frequency and magnitude of the building vibration will be different at every attachment point in the model. The goal, therefore, is to select a set of spectra that will be a conservative representation of the vibration at all locations in the building to which the piping model is attached. One spectrum must be constructed from this set. The reason for this is that the analysis being run is a uniform response spectrum analysis, which means that only one response spectrum (for each direction of excitation) is used in the analysis. This final spectrum is constructed by a process called "enveloping."

Enveloping simply consists of physically comparing all response spectra specified for enveloping, at every point in the defined frequency range, and then constructing a new spectrum from the maximum accelerations found at each frequency. The resulting spectrum is the actual spectrum that is used to calculate the response of the piping model. It is called the "enveloped response spectrum" and is model unique.

The responsibility of a piping engineer is to identify and specify the response spectra that are to be enveloped. To do this, follow the instructions listed below:

- **Step 1**. Locate all the attachment points in the model on the building model drawing.
- **Step 2**. Identify all the structural model data points that surround the attachment points that were located in Step 1.
- **Step 3**. Identify the response spectra that correspond to all the data points that were identified in Step 2. These are the spectra that will be specified for enveloping to analyze the system.

b3. Selection of the Amount of Damping. The design loads and pipe stresses that the engineer will be calculating are due to steady-state resonant vibration of the piping. The amplitude of steady-state vibrations is very sensitive to the amount of damping that exists in the piping and its support and restraint system. In response spectra analysis, by virtue of how it is done, damping is accounted for when generating the response spectra. Response spectra are always calculated for an assortment of damping values. This requires that the engineer select the spectra corresponding to the correct amount of damping in the piping system he is analyzing.

Damping, a measure of the energy-loss mechanisms of the system, is defined as a percentage of the critical damping of the single-degree-of-freedom oscillator. The correct amount of damping to be used in the calculations is dependent on the size of pipe and the loading conditions being analyzed. NRC Regulatory Guide 1.61 and Code Case N-411 (see Regulatory

Guide 1-84 for acceptable conditions for its use) specify permissible amounts of damping for use in response spectra analysis and other types of dynamic analyses.

4.7.4 **Selection of Number of Modes to be Used in Analysis.** Previously this section discussed the basic procedure used to calculate the response of the piping. That procedure was to:

- decouple the equations of motion of the piping into single-degree-of-freedom oscillators, each of which represented a mode of vibration of the system,
- calculate the maximum response of each single-degree-of-freedom oscillator using the enveloped response spectra, and
- combine the individual modal responses to obtain the total response.

To correctly estimate the maximum response of the piping, an adequate number of modes (single-degree-of-freedom oscillators) must be used to do the analysis. If the number of modes used to do the analysis is too small, the response will be underestimated. Typically cutoff frequency is specified. The effect of the remaining modes is calculated as missing mass effect and added to the calculated response till the cutoff frequency. The effect of the missing mass is usually added by SRSS.

4.7.5 Natural Frequency and Mode Shape Data

Computer output generally contains the results of the equation of motion decoupling calculations. It consists of three sets of results, these being:

- The natural periods of all the modes of vibration of the piping system that were used in the response calculation (eigenvalues).
- The mode shape vectors of each mode of vibration (eigenvectors).
- The participation factors for each mode of vibration for each direction of excitation.

These data are useful for reasoning through design problems, and conceiving modifications to correct them. Each set of data will be discussed below.

a. Natural Periods of Vibration and Orthogonality Checks. The total response of a piping system to the base excitation that the engineer specifies is really a sum of the responses of the piping system in a number of individual modes of vibration.

A mode of vibration is a characteristic deflected shape of the piping. Each mode of vibration has its own natural frequency of vibration, and the response of the piping while vibrating in it is identical to the response of a single harmonic oscillator with the same natural frequency.

The orthogonality check for the modes of vibration is a check for numerical accuracy in the decoupling operation. Theoretically, all the modes should be numbers in the orthogonal to each other. If the deviations in orthogonality check are too large, an error message is usually printed out. The error message indicates that the decoupling process was not done accurately enough. These problems are caused by poor modeling. When such an error message occurs the engineer must search through the model for elements that are much stiffer or shorter than others, or areas of the model where the lumped masses are much smaller than lumped masses in other regions of the model. These will always be easy to find when such deviations occur. The must be locally adjusted to make the lumped masses and element stiffness more uniform in magnitude.

b. <u>Mode Shape Vectors</u>. The mode shape vectors or "mode shapes" are lists of numbers that describe the deflected shapes of the piping system that correspond to each mode of vibration of the system. These vectors are proportional, at every instant in time, to the displacement of the piping in their corresponding modes of vibration.

c. <u>Participation Factors</u>. Participation factors are measures of how sensitive a given mode is to a given direction of excitation. Each mode of vibration will have an X-direction, a Y-direction, and a Z-direction participation factor. If a given mode has an X-direction participation factor of 2, and Y and Z participation factors of 1, it would mean that the mode is twice as sensitive to X-direction excitation as it is to Y or Z excitations.

4.7.6 **The Role of Natural Periods, Mode Shapes, and Participation Factors in the Response Calculations.** Every mode of vibration has a response to each one of the three directions of excitation. That response is proportional to the participation factor for the direction of interest, the response spectrum acceleration at the natural period of the mode, and the mode shape vector. The relationship between the parameters follows.

$$\begin{bmatrix}\text{Response of}\\ \text{mode to}\\ \text{X-excitation}\end{bmatrix} \alpha \begin{bmatrix}\text{X}\\ \text{participation}\\ \text{factor}\end{bmatrix} \text{x} \begin{bmatrix}\text{X-response spectra}\\ \text{acceleration at}\\ \text{natural period}\end{bmatrix} \text{x} \begin{bmatrix}\text{Mode}\\ \text{shape}\\ \text{vector}\end{bmatrix}$$

$$\begin{bmatrix}\text{Response of}\\ \text{mode to}\\ \text{Y-excitation}\end{bmatrix} \alpha \begin{bmatrix}\text{Y}\\ \text{participation}\\ \text{factor}\end{bmatrix} \text{x} \begin{bmatrix}\text{Y-response spectra}\\ \text{acceleration at}\\ \text{natural period}\end{bmatrix} \text{x} \begin{bmatrix}\text{Mode}\\ \text{shape}\\ \text{vector}\end{bmatrix}$$

$$\begin{bmatrix}\text{Response of}\\ \text{mode to}\\ \text{Z-excitation}\end{bmatrix} \alpha \begin{bmatrix}\text{Z}\\ \text{participation}\\ \text{factor}\end{bmatrix} \text{x} \begin{bmatrix}\text{Z-response spectra}\\ \text{acceleration at}\\ \text{natural period}\end{bmatrix} \text{x} \begin{bmatrix}\text{Mode}\\ \text{shape}\\ \text{vector}\end{bmatrix}$$

(Proportional to)

It can be seen that the combination of a large participation factor for a given direction, combined with a large response spectrum acceleration for that direction, will give a large response. This means large restraint loads and high stresses.

To optimally design a piping restraint system for a given load the engineer must locate restraints on the system that create the following situations:

- All modes of vibration that have natural frequencies near peaks in the response spectra must have a low participation factor for the direction of excitation to which the spectrum corresponds.
- All modes of vibration have natural frequencies higher than the frequency of the response spectrum peaks (practical for small systems).

Locating restraints on piping systems to create these situations is called tuning. It is generally only possible on a large scale during the preliminary stages of plant design. The second situation is generally impossible to create for higher frequency loads.

If the engineer is analyzing a system for which all the restraint hardware has been designed and purchased, and he finds out that a large number of restraints in the system will be overloaded by the loads he just calculated, he will have to tune the system to reduce the loads.

This data could be used for tracing back through the response to determine the locations of restraints that may be needed to add or rearrange to correct overstresses, equipment nozzle overloads, or large-scale restraint overloading. The accelerations printed out in the combined response contain the maximum accelerations of valve centers of gravity. These accelerations must be checked against allowable valve acceleration criteria to determine if they are acceptable. If they are too large, the situation will have to be corrected by adding, removing, or shifting restraints.

4.7.7 Resolution of Design Problems for Response Spectrum Analysis

Most dynamic load design problems fall into three categories. These categories are listed below:

- pipe overstress caused by excessive internal bending moments,
- excessive equipment loading, and
- excessive valve accelerations.

The basic mechanism that is responsible for these problems is excessive local displacement of the piping. In the response spectrum method, maximum displacements for each mode are found as the product of the eigenvector (mode-shape) and displacements calculated from the modal participation factors, the modal frequency, and the response spectrum acceleration corresponding to that frequency. Based on these maximum modal displacements, internal moments and forces and external reactions are calculated. These individual modal responses are then combined.

To alleviate problems, the engineer must identify the areas of the system that are deflecting excessively, and then determine how to modify the restraint and suspension system to reduce these deflections. This may be accomplished by doing one of two things. These are:

- Prevent the excessive local deflection from occurring by placing a restraint in the system at the deflected location in the direction of that displacement.
- Adjust the natural frequencies and participation factors of the modes of vibration of the system to reduce their sensitivity to the building's vibration. Reducing acceleration in this manner is called tuning. Tuning is done by rearrangement of the piping restraint system.

4.8 Dynamic Load Forced Displacement Analysis

During dynamic loading events, the various points of attachment of the piping system to the building structure, and to the other piping systems, will move relative to one another. This relative movement causes bending of the piping system. The bending results in restraint loads, equipment loads, and piping stress. Accordingly, the effect of the relative movements must be acknowledged in the design. The loadings that are a result of this bending are referred to as "displacement loads" or "anchor movement loads." These loads fall into two categories:

- Loads induced by the relative movement of piping system restraint attachment points to the building structure. These loads are referred to as "building displacement loads."

- Loads induced by the dynamic displacement of headers at branch piping system connections. These loads are referred to as "header displacement loads."

4.8.1 Building Displacements

Building displacement loads are generally very small and, in most cases, the conservatism inherent in the traditional uniform response spectrum analysis used to determine inertial loads is adequate to account for them. The reason for this is that the building is also designed to withstand these loads. The fact that the building is designed to withstand the dynamic loads generally requires that the relative displacement between adjacent points in the structure be small to avoid overstressing of the building. Building displacement analysis need not be performed for piping located in zones of the building where the maximum building displacement is known to be less than or equal to 1/8 inch.

4.8.2 Dynamic Header Displacements

The displacement of header piping during dynamic loading events can be very significant to the design of branch piping. Overload and overstress problems can occur near the branch pipe-header pipe connection if sufficient flexibility does not exist in the branch pipe routing near the intersection.

It is poor design practice to restrain branch piping near its intersection with the larger header because it causes the small branch pipe to constrain free movement of the header. The placing of restraints on branch lines close to header connections must always be carefully reviewed for this reason. Earthquake experience database shows failures in situations like this.

Header displacement analysis may be significant in many cases. However, in situations where the header displacements are small, i.e., less than or equal to 1/16 inch in each of the three global directions, then a header displacement analysis need not be performed. Header displacement analysis is also not required in situations where the header displacements are less than or equal to 1/8 inch in each of the three global directions provided that no support/restraint is located within a distance "L" from the header/branch interconnection anchor, where "L" is as defined as follows:

Nominal Pipe Size	L (feet)
2	7
4	10
6	13
8	14
10	16
12	17
20	21
24	23

When a displacement analysis is determined to be required, it should be performed in accordance with the guidelines discussed in the following sections.

a. Loading Definition Data. To perform a header displacement analysis, the global direction displacements of all header pipes that the system ties into are required. A set of displacements at each branch location is required for each dynamic loading for which the piping is to be designed. Each set of displacements consists of the six numbers listed below for each dynamic load:

- the maximum amplitude of the Global X direction displacement of the header pipe,
- the maximum amplitude of the Global Y direction displacement of the header pipe,
- the maximum amplitude of the Global Z direction displacement of the header pipe,
- the maximum amplitude of the rotation about the Global X axis,

- the maximum amplitude of the rotation about the Global Y axis, and
- the maximum amplitude of the rotation about the Global Z axis.

These displacements are obtained from the response spectra analyses of the run pipe system.

b. Basic Procedure Used. To perform a header displacement analysis, an individual static analysis is performed for each displacement amplitude component that is specified. The static analysis is identical to the static analysis used for thermal expansion loads, except that all snubbers (active for dynamic loads) are assumed to be rigid. Each one of these individual analyses is referred to as a "displacement group."

After all required individual analyses are performed, the results of the analysis for each group are combined by the square root of the sum of the squares method. The process is very similar to that used for response spectra analysis. The reason for this is that the displacements that are being analyzed are uncorrelated and time variant. No specific knowledge about the time phasing (synchronization) of any two components exists. Because this knowledge does not exist, their individual effects must be determined separately and combined based on a probabilistic technique.

For a given load, 6 groups are required for each header connection in a system. A system that branches from two headers will require 12 groups. A system that is connected to three headers will require 18 groups, etc.

4.8.3 Building Displacement Loads

When two adjacent structures in the plant move relative to one another during dynamic events, and those relative movements are large, the movements must be accounted for in the design of any piping systems attached to those structures. Problems occur near interfaces between independent structures.

These effects are plant and load unique. In most cases, these relative movement-induced loads may be adequately covered by the conservatism inherent in the response spectrum analysis used to calculate the inertia load. In cases where they are not, an additional analysis is required to account for them in the design of the piping system. Guidelines for performance of the analyses are discussed as follows.

a. Basic Procedure Used. Performance of a building displacement analysis on a general piping system consists of two steps. These steps are:

- Identify the source of the displacement field.
- Identify the deflected shape of the structure (displacement field) that will govern the design of the piping system.
- Perform a structural analysis using the governing displacement field.

Guidelines for performance of these two steps are discussed below.

b. Governing Displacement Field. During dynamic loading events, the structures to which the piping is attached will be in motion. At each instant in time the structure will have a deflected shape. This deflected shape is described by a list of the displacements of a representative number of locations on the structure. This list of displacements is called a displacement field. The displacement fields are calculated during the analysis of the building, and saved. There will be a displacement field on the file for every instant in time required to accurately describe the motion of the structure.

During the dynamic loading condition, the piping attached to the structure will deflect to accommodate the deflected shape of the structure. To account for this in the design, a static forced displacement analysis is required. The analysis consists of forcing the deflected shape of the structure on the piping. This is done by forcing the displacement of the structure at all the piping system attachment locations, on the piping. These displacements are contained in the displacement fields saved on the computer files.

To determine the maximum building displacement effects on the piping system (that are needed for design), a static analysis for each displacement field saved on the file is required. Generally, there will be from 1000 to 5000 displacement fields saved on the file. Performing an individual analysis for each displacement is not practical because of the large number of analyses that would have to be done. To reduce the number of analyses required two different methods are usually used, 1) a random sampling method is to select the displacement fields that will be used for the static analysis for various buildup locations. The random sampling process is usually designed to select the number of fields required to result in a 95% confidence that the calculated response has a 95% probability of nonexceedance. 2) A static analysis similar to header displacement analysis using maximum displacement for each location of attached piping.

4.8.4 Design Problems and Resolutions

Design problems resulting from relative header or building displacements during dynamic loading events are always caused by the same mechanism. That mechanism consists of two restraints that oppose each other and force excessive relative displacements on the portion of the piping system between them. Design problems fall into two categories. These being:

- piping overstressing, and
- excessive restraint and equipment loading.

Pipe overstress problems are generally associated with header displacement loadings. They seldom occur as a result of relative building displacement. Excessive building displacements will cause excessively high restraint loads and equipment reactions in isolated areas of a system.

Resolving these problems consists of first identifying the mechanism response for the condition, and then making restraint-support system modifications to remove the aggravating mechanism from the system.

4.9 Code Equation Applicability and Other Requirements

The individual analyses discussed above are performed to generate input for following operations:

- ASME code evaluation of piping system,
- flange joint evaluation,
- design loads for support and restraint system,
- equipment loading induced by piping,
- flued head evaluation,
- welded attachment evaluation,
- valve accelerations,
- piping displacements, and
- functional capability.

4.9.1 ASME Code Evaluation of Piping System

Piping stress analysis is performed for various loading conditions. In addition to pressure, these loading conditions include static loads, such as the weight of pipe and its contents, or dynamic loads, such as equipment vibration, earthquake, or fluid transients in the pipe. The resulting stresses from these loads must be limited to certain allowables based on applicable code. Class 1 piping requirements are very complex and Class 2 and 3 requirements are simple and straightforward. These requirements are as follows:

a. Class 1 Piping Analysis NB-3650. Class 1 piping analysis requirements are given in Article NB-3650. These requirements provide a relatively simplified "cookbook-type" methodology in comparison to general requirements (NB-3200) for analysis of Class 1 components. To meet NB-3650 requirements the stress results are checked against simplified equations: NB-3650 conceptually addresses the following modes of failure.

- **Failure Due to Primary Loads**. Limit loads such as pressure, dead weight, and non reversing dynamic loads such that gross plastic deformation is prevented.
- **Failure Due to Reversing Dynamic Loads**. Limit loads such as seismic inertia so that failure can be prevented.
- **Failure Due to Fatigue**. Limit the loads that are cyclic so that fatigue failure is prevented.
- **Thermal Racheting**. Checked only if secondary stresses exceeds 3 S_m limit.

Code Equations employ the concept of stress indices (NB-3681(a)-1) for evaluation against allowable stresses. There are three types of stress indices that are used in Class 1 analysis:

- **B indices**. B indices are used in primary stress equations and are intended to prevent gross plastic deformation due to sustained loads or failure due to reversing dynamic loads.
- **C indices**. C indices are used in Secondary stress equations. These indices represent primary plus secondary membrane and bending stresses. Secondary stresses are those that are generated by deflections rather than loads imposed on the system, or by discontinuity stresses.
- **K indices**. K indices are used in fatigue evaluation. These indices represent peak stresses due to concentrations and discontinuities.

The flow chart for evaluation of Class 1 piping systems is presented in Exhibit 4.9-1.

b. Class 2 and 3 Piping Analysis NC/ND-3650. Class 2 and 3 piping analysis requirements are given in Articles NC/ND-3650. The analysis requirements for Classes 2 and 3 are simpler and easier to use than Class 1 analysis rules. The code uses a concept of B-type stress indices for evaluation of primary loads, and stress intensification factors for evaluating secondary loads. The B-type stress indices have been discussed previously. The stress intensification factors (i-factors) are based on cyclic fatigue tests performed by Markl. The i-factors indicate fatigue strength of a piping component relative to the fatigue strength of a typical girth butt weld. The relationship between i-factors, stress, and number of cycle for various types of pipe fittings and components was established by the Markl test as follows:

$$iS = 245{,}000\ N^{-0.2}$$

where:

S = applied stress (amplitude)

N = number of cycles

i = stress intensification factor
(i = 1 for girth butt weld)

The analysis requirements for Class 2 and 3 piping systems are outlined in NC/ND-3650. The flow chart for evaluating Class 2 and 3 Piping is presented in Exhibit 4.9-2.

c. Flange Evaluation

The effect of moment loading on flanged connections must be checked per the requirements of NB/NC/ND-3658. This section of the code evaluates the flange for leakage under applied moments. For flanges conforming to the standard ANSI B16.5, the calculations are simple. For nonstandard flanges the calculations are complicated. Nonstandard flanges must be analyzed and the stresses evaluated using the methods given in Appendix XI of AMSE Section III Code. For Class I piping, the nonstandard flanges must be designed per the rules given in NB-3200, which may require a big effort. For this reason standard B16.5 flanges should be used.

d. Design Loads for Support and Restraint System

After an acceptable piping and suspension-restraint system has been determined, all hardware associated with the piping system must be designed. These designs will be based on the loading the support designer receives from the pipe designer. The following information from piping analysis is needed for the support design.

- **Type of restraint**--identifies the type of support the pipe designer used for analysis purposes (rigid, variable, snubber);
- **Location and pipe coordinates**--identifies the node number in piping model and pipe coordinates;
- **Direction of restraint.**
- **Location and global thermal movements**--from the movements, the envelope of pipe thermal movements can be calculated. This information is needed for hanger settings.
- **Combined loads and displacement for each service level**--these give information about maximum loads and displacements. The loads can be used to design the support various service levels and the displacements can be used to check the functionality and clearance around the support.

e. Equipment Loading Induced by Piping

For piping connected to equipment nozzle, the piping reactions imposed on the equipment nozzle must be evaluated. This must be done for all equipment in the system. The reason for doing this is to ensure that the piping system will not impose unacceptable loads on the equipment. If poorly designed, piping can place loads on equipment that are many times the acceptable limit. Excessive loading on equipment can cause structural failures of the equipment, or prevent if from operating properly during loading events when its service is required. Excessive loading can also significantly reduce its service life and cause costly unplanned outages. If equipment loading is exceeded, vendor approval is required. If loads are not acceptable to the vendor, the piping suspension-restraint system may need to be redesigned as discussed earlier.

f. Flued Head Evaluation

There are usually no allowable loads for flued head or structural anchor. These need to be evaluated on a case-by-case basis using finite element computer programs.

g. Welded Attachment Evaluations)

Piping codes do not give any techniques for analysis procedure except that Paragraph NB/NC/ND-3645 requires that effect of integral attachments on pressure retaining members be taken into account when checking against the allowable stress value. in the early years of piping design, the designers based the attachment design on experience or whatever material was available; everyone came up with their own unique design. In the 1950s Professor Bijlaard developed methods to evaluate localized stress produced by attachment loads. His work led to the publication of WRC-107. In 1974, WRC-198 was published that gave simplified procedures for evaluation of lugs. Based on the work in WRC-198 and data available in literature. ASME Code put together code cases for evaluation of welded attachments. These code cases are:

- N-122 Stress Indices for Integral Structural Attachment, Section III, Division 1, Class 1
- N-318-3 Procedure for Evaluation of the Design of Rectangular Cross Section Attachments on Class 2 or 3 Piping, Section III, Division 1.
- N-391 Procedure for Evaluation of the Design of Hollow Circular Section Welded Attachments on Class 1 Piping, Section III, Division 1
- N-392 Procedure for Evaluation of the Design of Hollow Circular Cross Section Welded Attachments on Class 2 and 3 Piping, Section III, Division 1

These code cases give simplified methodology for evaluation of welded attachments. These evaluation procedures can be further simplified by developing standard forms and stress indices for standard attachment sizes, thereby making the calculation easier.

h. Valve Accelerations

Valves impose additional requirements and restrictions on a piping analysis. Active valves on safety-related systems usually have accelerations and/or end reaction allowables.

i. Piping Displacements

Piping displacements due to design loading conditions should be evaluated so they are within reasonable limits. These displacements are needed

- to make sure piping is moving in the predicted direction during hot functional walkdown,
- to check interference with other components, and
- for proper design of supports

j. Functional Capability

Satisfaction of code requirements provides assurance of functional capability.

4.10 Support Placement and Recommended Design Practice

The goal of the piping analyst should be to optimize piping design for actual loading normally expected to occur in power piping systems. This must be accomplished with reasonable cost for design, fabrication and erection. Some of the practices outlined in the following section have been successfully implemented in the design of power piping.

4.10.1 Optimize Pipe Supports

The goal of piping engineer should be to minimize, to the extent possible, the number of supports on a given piping system. Vertical support locations, in general, will be controlled by limits on pipe weight deflections of no more than 0.2" rather than stress limits. In order to minimize support locations for seismic loads, guides should generally be located at vertical support points.

4.10.2 Maximum Use of Wall and Slab Penetration as Supports

The use of penetration anchors and grouted guides will minimize supports and potential interference problems in the design. However, at all penetrations the fill material must be identified and a determination should be made if the material should be considered for its effect on the piping analysis. Use of penetration will reduce space needed for supports and increase plant accessibility for maintenance and equipment removal. Reducing supports through the use of penetration, will also reduce construction time and cost by limiting the tonnage of aux. steel required by the field to cut and weld supports, and by limiting the cost of ordering standard component hardware.

4.10.3 Minimize Structural Anchors and Welded Attachments

The use of structural anchors requiring aux steel and welded attachment should be avoided. For places where welded attachments are necessary, standard welded attachments such as trunnions, stanchions or lugs should be used on straight pipes away from discontinuities. Welded attachments on elbows should be avoided. Project should set up standardized design to be used for various size of pipes and approximate load ratings. This will avoid design iterations.

4.10.4 Maintaining Design Margin in Initial Analysis

As far as practical, each allowable limit, including code stress allowable for each equation, equipment, valve, penetration, flange allowable, etc., should be met with a minimum of 30% margin. This margin will allow as built discrepancies to be resolved relatively easily.

4.10.5 Maximum Routing Symmetry and Duplication

Maximize the routing symmetry will cut the cost of analysis and installation.

4.10.6 Use Existing Embedments

Supports should be located near the existing embedment plates as much as possible. An extensive system of embedment plates should be layed out for the purpose of supporting piping and other components. It is important that final pipe support load and locations and embedded plate layout are determined based on the preliminary pipe layout. Effective control over pipe layout and support configuration will eliminate the use of drilled-in concrete anchors.

4.10.7 Do Not Locate Supports Close to Equipment

Except for spring hangers, supports should not be located close to equipment nozzles. If supports are located near the equipment, the loads predicted by the computer model may not be realistic. For example, if a support is located only a few feet from an equipment nozzle, and the support has a small gap or deflect under the load, it is possible that all of the load will be taken by the equipment nozzle, even though the computer model shows load sharing.

4.10.8 Use of Appropriate Slab Response Spectra and Header Enveloped Spectra

a. Slab Spectra

Where vertical supports are attached to slabs more than 2 structural slab thickness away from the face of a shear wall, the slab spectra should be used in the analysis.

b. Header Spectra

When piping is decoupled from header pipe, the response spectra of header tee connection should be input to correctly evaluate the decoupled system. However, the response spectra at this location is usually not available. An acceptable solution is to either use the envelope response spectra of the header system in analyzing decoupled system, or limit the header spectra to those applicable for two supports in each direction on both sides of the header connection.

4.10.9 Stress Margins at Decoupled Branch Locations

For qualifying the intersection point of decoupled systems, the stresses from decoupled systems must be added to stresses from large bore system. Sufficient margins must be maintained in the two analyses. Also at these locations, correct stress indices should be specified. In order to minimize total stresses at branch location, the use of full size tee with a reducer can be specified in place of a reducing tee.

Vent and drain lines should be located a straight pipes. Vent and drain lines on elbows should be avoided.

4.10.10 Local Stresses in Thin Wall Pipe at Support Locatio

Criteria should be developed for supporting large diameter thin wall pipes at box type supports. Welded pads or sleeves should be avoided. Preference should be given to struts with clamps or wider aux. steel with welded pads.

4.10.11 Thermal Analysis for Cold Piping (< 150°F)

Thermal analysis for piping where all the thermal modes are less than 150°F need not be performed. However, the piping designer should make sure that enough thermal piping flexibility exists in the piping system to avoid large loads or equipments.

4.10.12 Effect of Friction on Piping Model

In long runs of pipe, where many friction type supports are used consecutively, the effect of friction should be evaluated. The use of consecutive pipe stanchion friction supports or box guides should be avoided.

4.10.13 Pipe Support Stability

For piping systems where only vertical supports are required by analysis, horizontal stability should be considered, so that piping is not susceptible to external loads applied during maintenance and operation of the plant.

Vertical struts loaded under compression weight loads are not stable unless there are lateral supports that control the horizontal movements to reasonable vales at the strut location.

4.10.14 Pressure for Elbow Flexibility Calculations

ASME Code requires that when performing piping analysis for Class 1 systems, the effect of pressure stiffening of elbow should be considered. Use of normal operating pressure is recommended when performing piping structural evaluations.

4.10.15 Design Tolerance for Support Locations and Tolerances

The guidelines given in NCIG-05 should be used when evaluating as built and as analyzed conditions.

4.10.16 Support Hardware Weight

Pipe supports should generally be designed to avoid requiring pipe to carry excessive mass from the support especially in directions other than the loaded axis. For supports partially supported by the pipe, the estimated lumped mass of support should be modelled at pipe support location. Support mass less than one foot weight of the pipe need not be modelled in the analysis.

4.10.17 Design Consideration for Branch Connection and Tees

It is recommended that butt welding tees rather than UFT's (unreinforced fabricated tee) be used for branch connections where diameter ratio of branch to run exceed 0.5.

4.10.18 Area Replacement Calculation at Branch Connections

Area reinforcement calculations must be performed if UFT or reinforced branch connections are used. These calculations must be documented in the piping stress report.

4.10.19 Code Case N-319 for Class 1 Piping

For ASME Class 1 piping, Code Case N-319 may be used to lower pipe stresses. When using Code Case N-319, the flexibility factor given in the code case must be specified in the piping analysis.

4.10.20 Use of Rod Hangers

For rod hangers it is important to verify that the downward weight load is greater than the upward thermal load. If upward load (thermal) is more than 70% of the downward load (weight), rods should not be used.

4.10.21 Minimizing the Use of Snubbers

Since snubbers have been shown to be unreliable and require costly in-service inspections, the minimization or elimination of snubbers should be a priority when initially designing piping subsystems. The most effective method for minimizing snubbers is for the piping layout, the pipe support and the piping stress engineers to work closely together to route pipe with enough inherent flexibility to eliminate the need for snubbers. Piping layouts should not be finalized until the pipe stress engineer is able to analyze and adequately support the piping. The use of a scale model can dramatically improve communication and coordination between the groups. Enough lead time needs to be provided in the overall design schedule so that drawing issue dates for construction will not be delayed by the additional iterations required in eliminating snubbers.

Exhibit 4.1-1

ASME Documents

ASME Boiler and Pressure Vessel Code (ASME B&PV Code)

Section II	Material Specifications
Section III	Nuclear Power Components - Division 1 Subsections NCA, NB, NC, ND, NE, NF, Appendices
Section VIII	Pressure Vessels Division 1 and 2
Section XI	Rules for Inservice Inspection of Nuclear Power Plant Components

ASME B&PV Code, Code Cases

American National Standards, ANSI B31.1 (Power Piping)

Federal Regulatory Documents

Code of Federal Regulations-...such as 10 CFR 50.10 CFR 100

Nuclear Regulatory Commission Documents (NRC)

NRC Regulatory Guides

NRC Standard Review Plans

NRC Office of Inspection and Enforcement

IE Bulletins

IE Information Notices

Licensing Documents

PSR, SER, FSAR

Industrial Standards

American Society for Testing and Materials (ASTM) Specifications

Manufacturers Standardization Society (MSS) Standard Practices

Project-Unique Standards and Procedures

Mechanical Engineering Standards

Mechanical Standard Specifications

Mechanical Specification Worksheets

Mechanical Standard Drawings

Mechanical Administrative Standards

Quality Assurance Manual

Project-Unique Documents

Project Scope of Work

Design Criteria

Project Instructions

Purchase/Design Specifications

System Descriptions

Project-Unique Design Tables

Line Lists

Valve Lists

Equipment Lists

Drawing (including P&ID, C&ID, Composites, Analytical, Component Support, Single Line, Spool Piece, etc.)

Note:

The documents, standards and procedures are constantly in the process of revision. When referencing them, it is important that the analyst be aware of which version pertains to his project in their application.

Exhibit 4.2-1

Motor Operated Valves

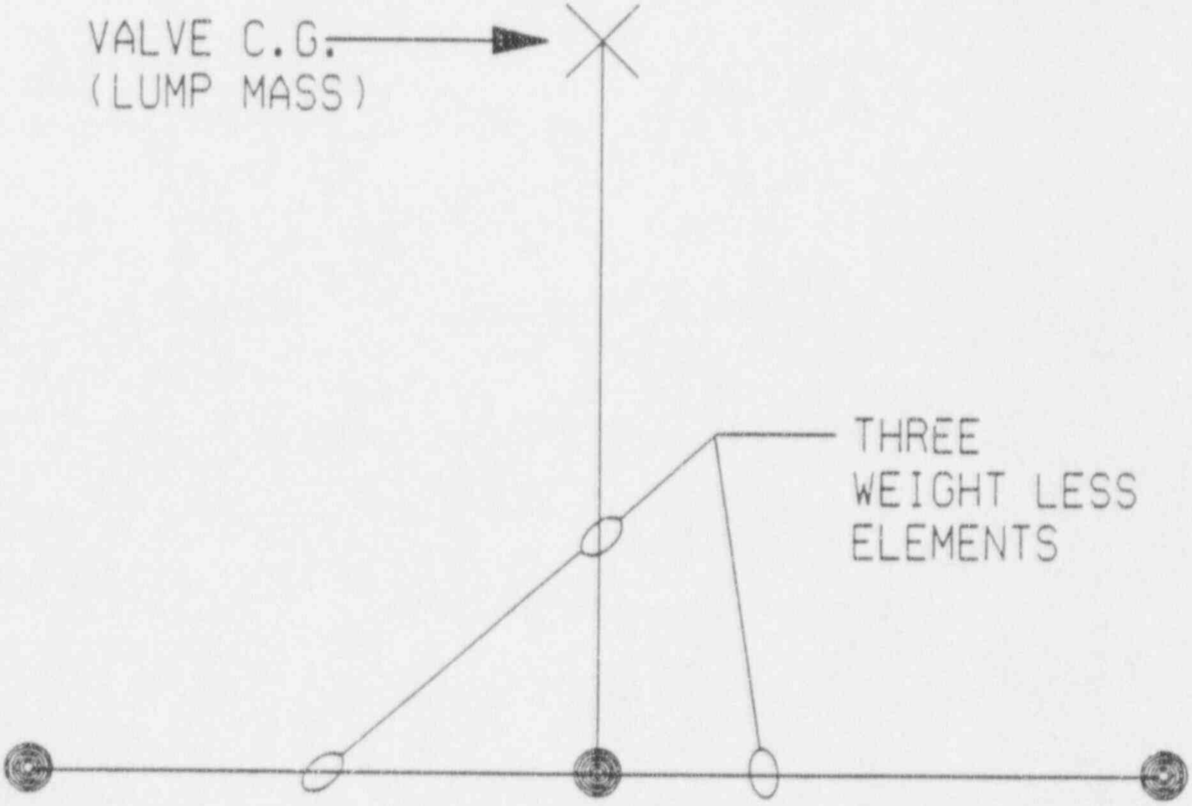


Exhibit 4.4-1

Uneven Weight Support Spacing

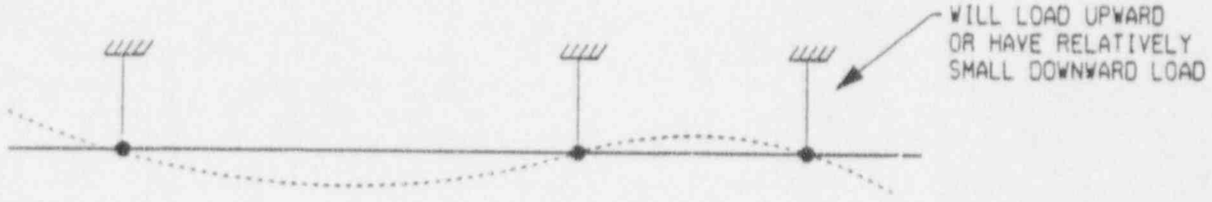
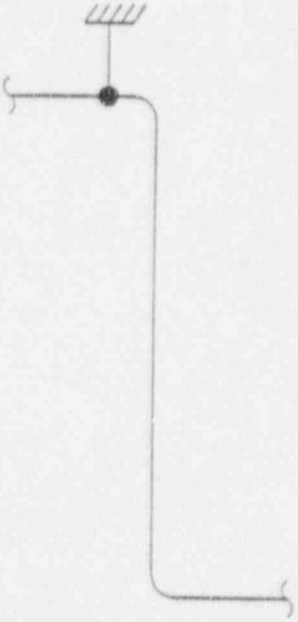
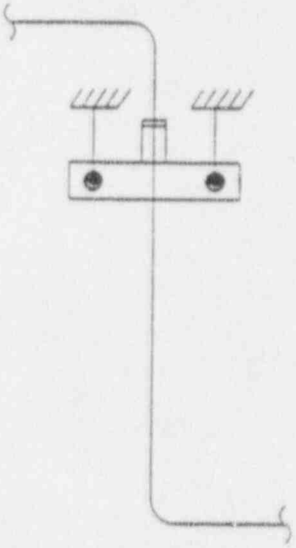


Exhibit 4.4-2

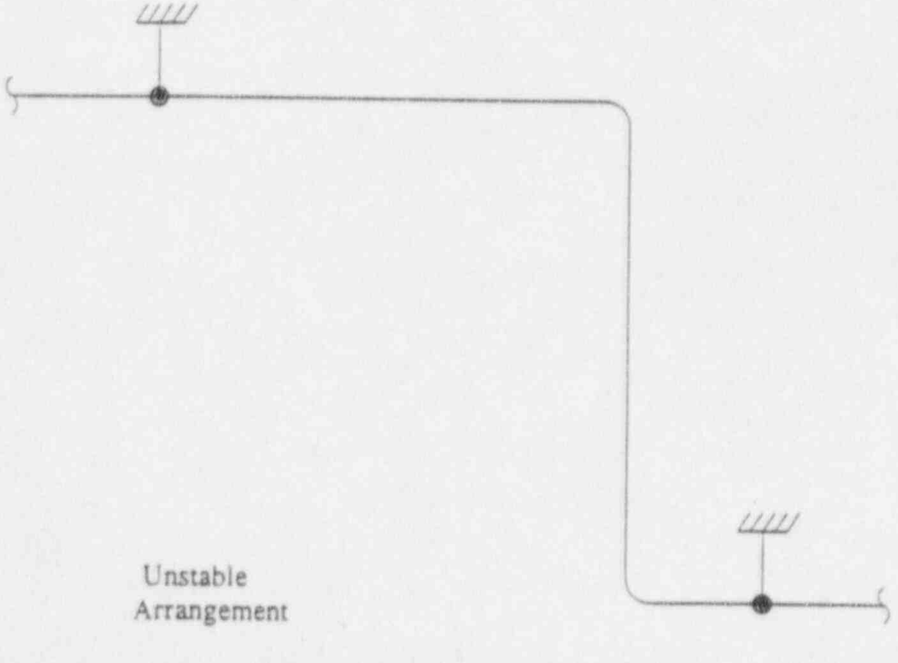
Riser Support Configurations



Desirable



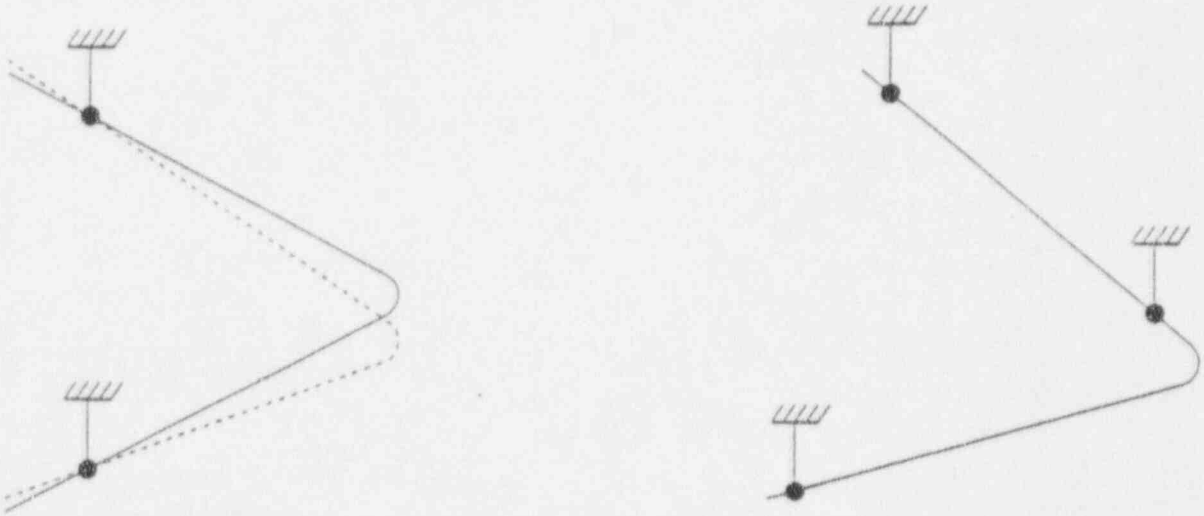
Desirable



Unstable Arrangement

Exhibit 4.4-3

Support of Bends

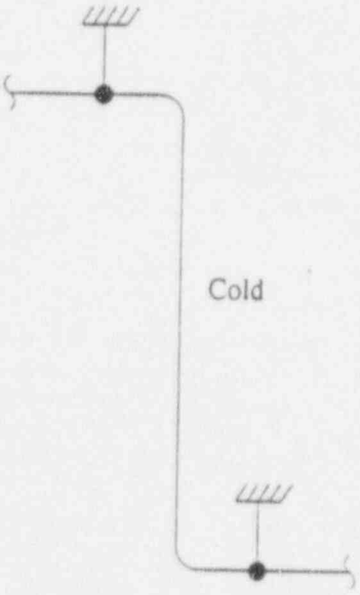


Undesirable

Desirable

Exhibit 4.4-4

Weight Shifting at Risers



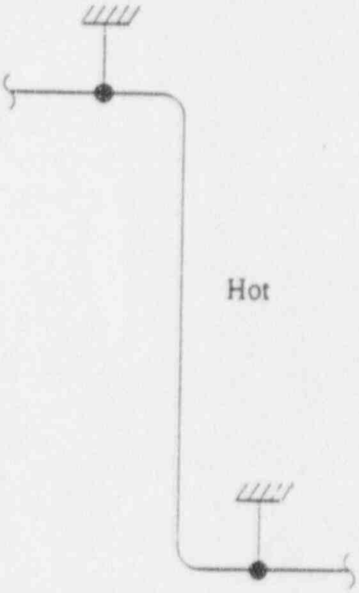


Exhibit 4.4-5

Typical Pump-Motor Configuration

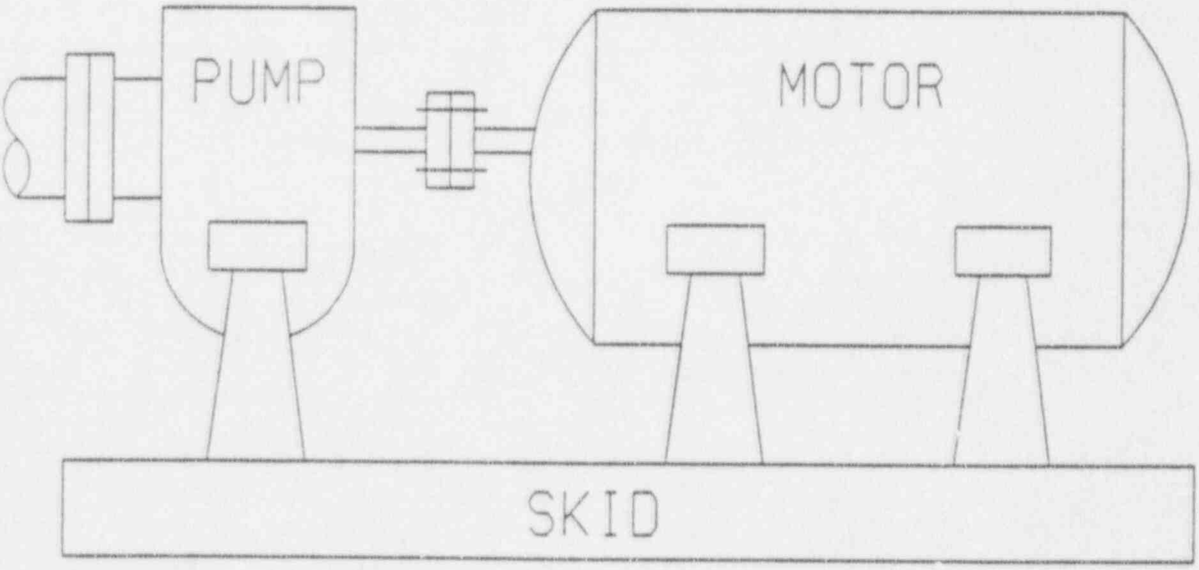


Exhibit 4.5-1

Basic Thermal Expansion Mechanism

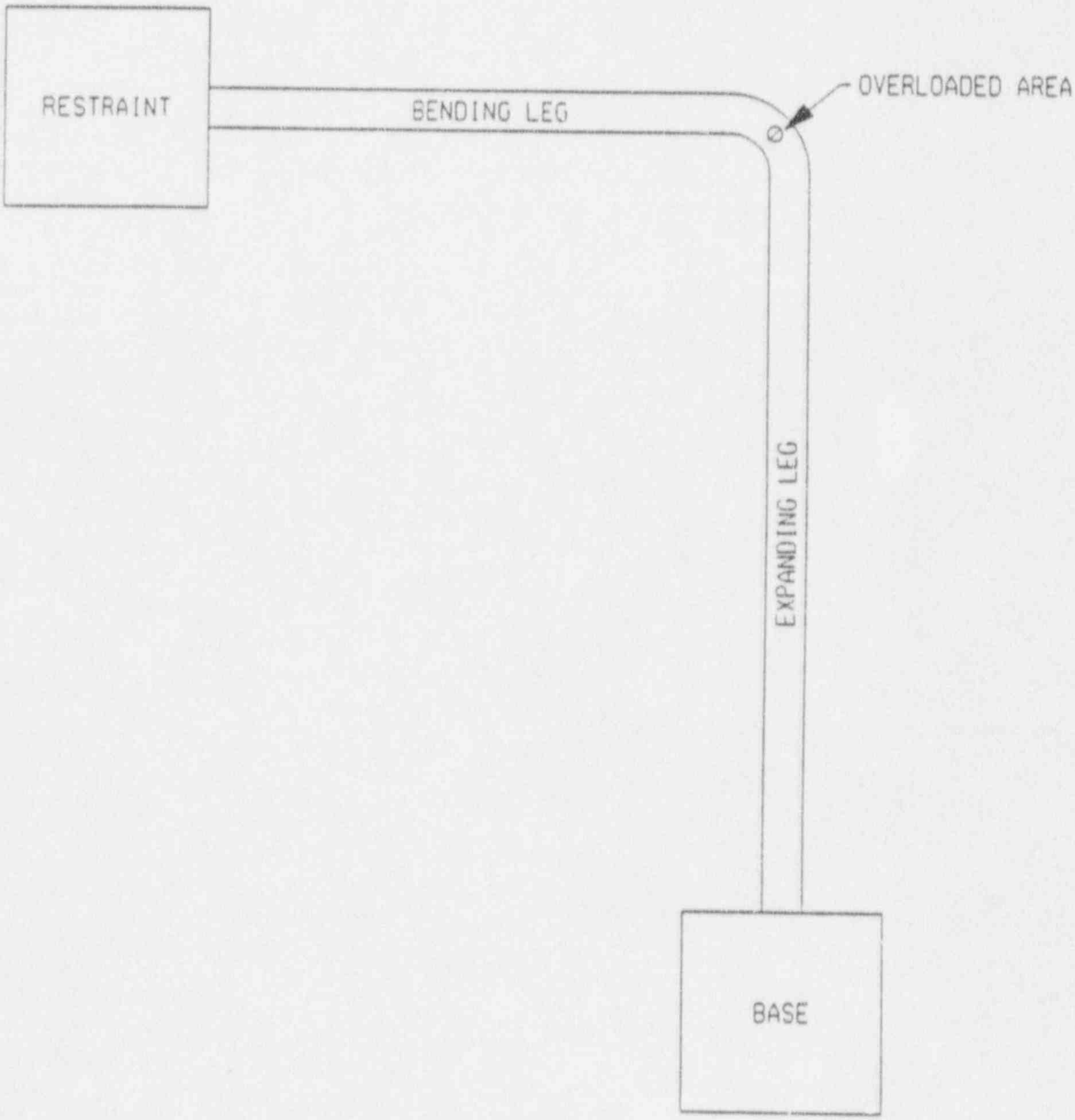


Exhibit 4.7-1

A Presentation of Physical Situation Being Analyzed

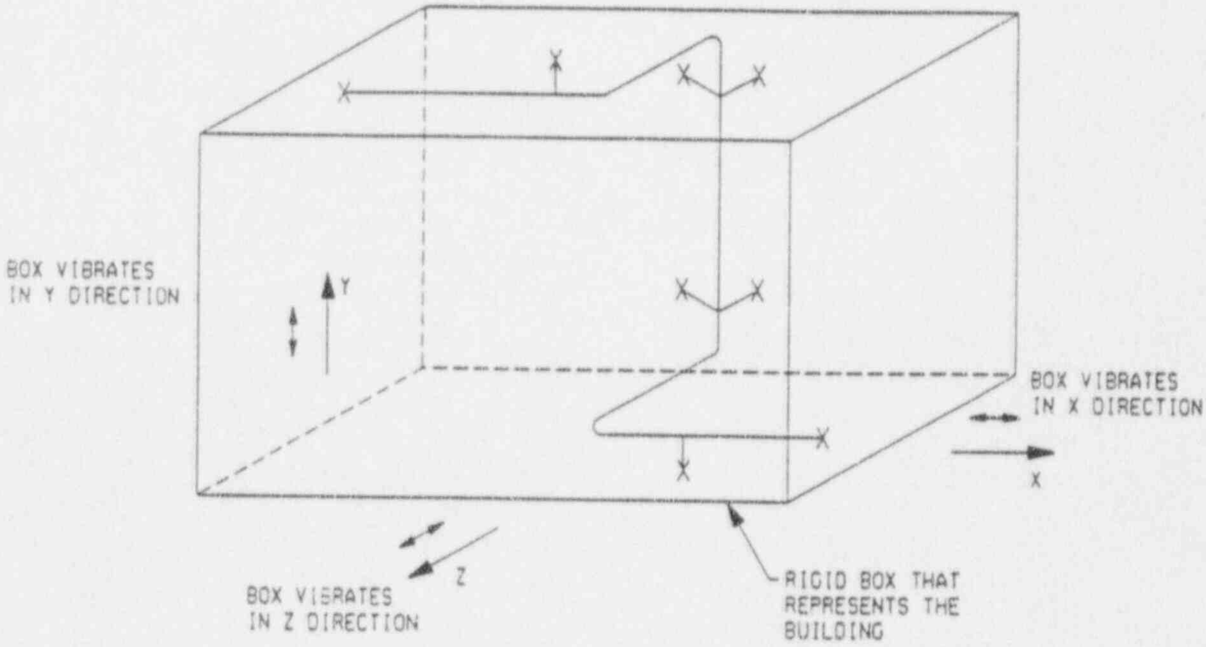
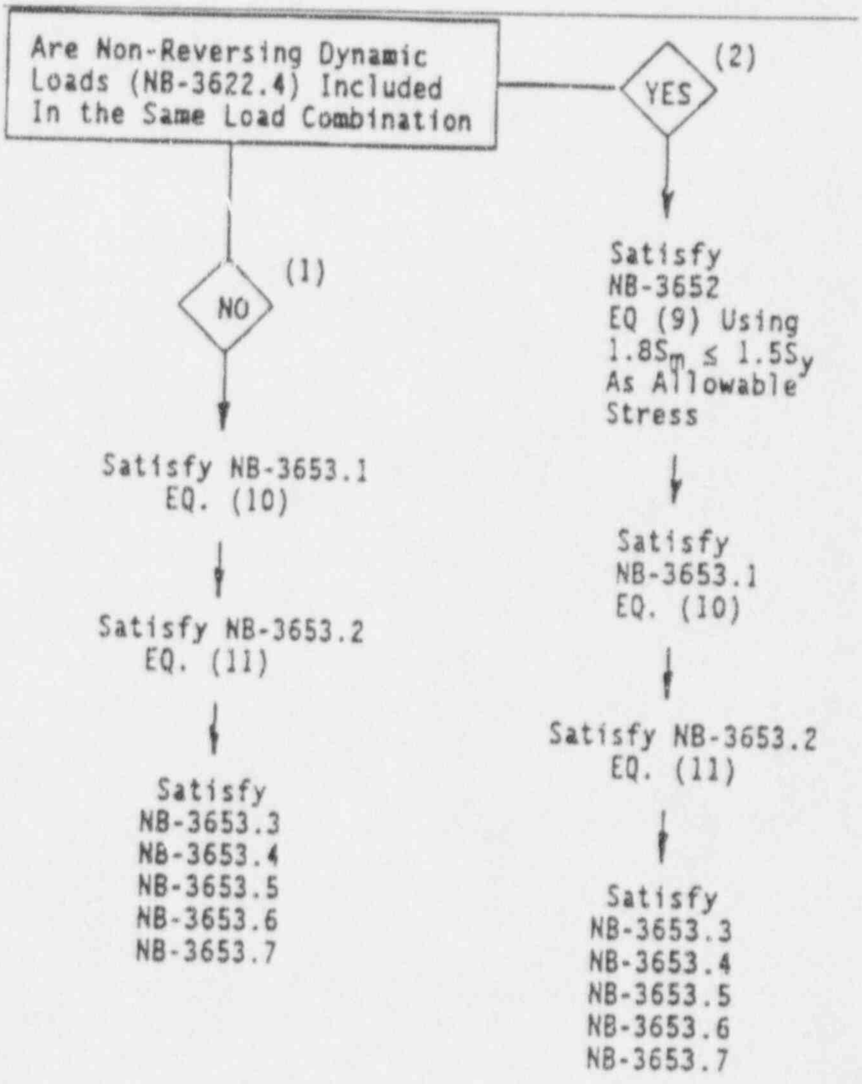


Exhibit 4.9-1

NB-3600

LEVEL B SERVICE LOADING WHICH INCLUDES REVERSING DYNAMIC LOADS

LOADS (NB-3622.2)



Notes:

(1) Rules are provided in NB-3654.2(b)
(2) Rules are provided in NB-3654.2(a)

Exhibit 4.9-1

LEVEL C OR D SERVICE LOADING WHICH INCLUDES REVERSING DYNAMIC LOADS (NB-3622.2)

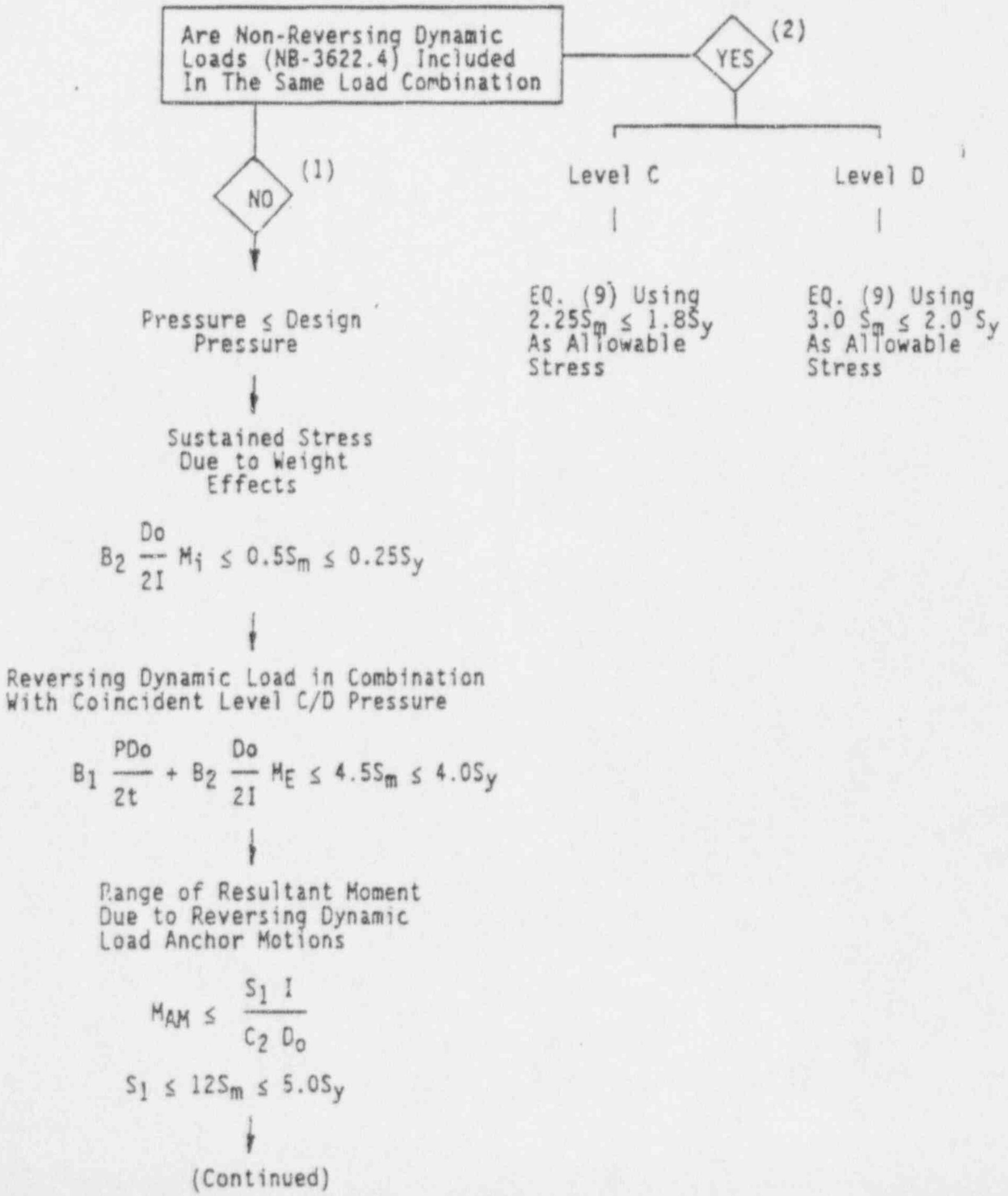


Exhibit 4.9-1

NB-3600 (Continued)

Amplitude of Longitudinal
Force Due to Reversing
Dynamic Load Anchor Motions

$F_{AM} \leq S_2 A_M$

$S_2 \leq 1.5S_M \leq S_y$

Notes:

(1): Rules are provided in NB-3655.2(b) and NB-3656.2(b)
(2): Rules are provided in NB-3655.2(2) and NB-3656.2(a)

Exhibit 4.9-2

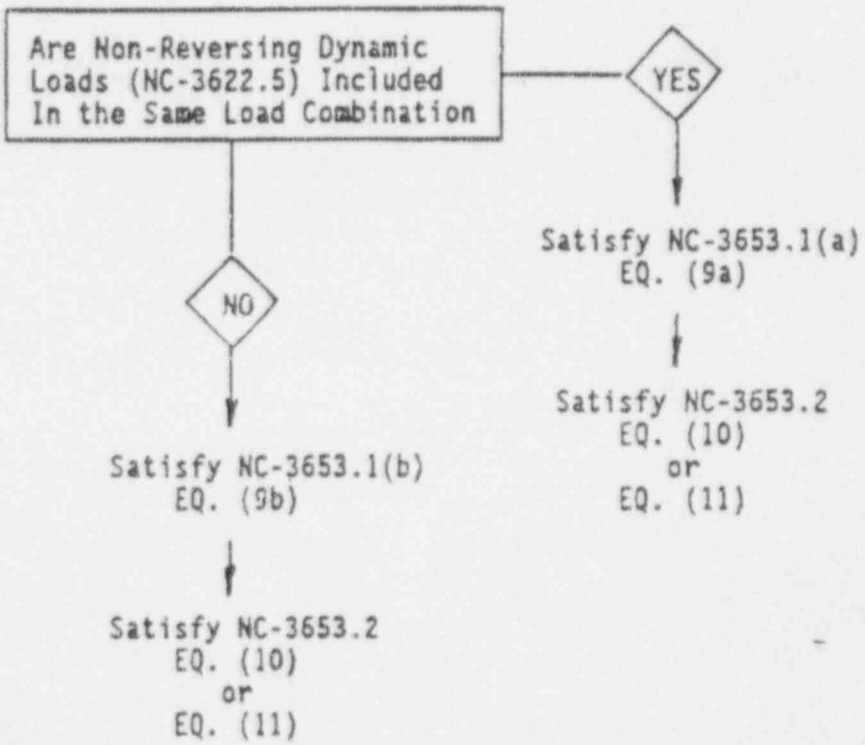

Are Non-Reversing Dynamic Loads (NC-3622.5) Included In the Same Load Combination
YES
NO
Satisfy NC-3653.1(a)
EQ. (9a)
Satisfy NC-3653.2
EQ. (10)
or
EQ. (11)
Satisfy NC-3653.1(b)
EQ. (9b)
Satisfy NC-3653.2
EQ. (10)
or
EQ. (11)

Exhibit 4.9-2

NC/ND-3600

LEVEL C OR D SERVICE LOADING WHICH INCLUDES REVERSING DYNAMIC

LOADS (NC-3622.2)

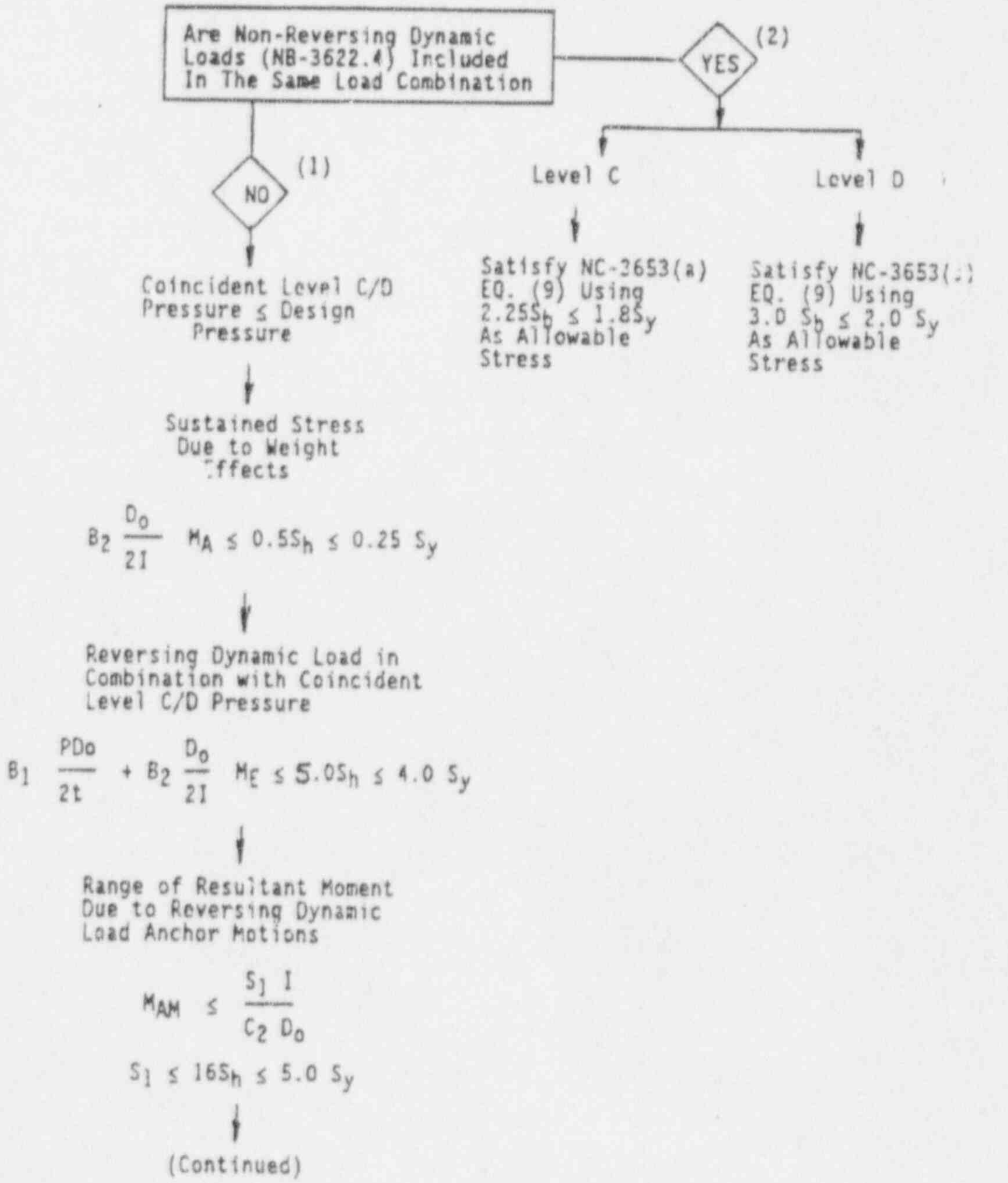
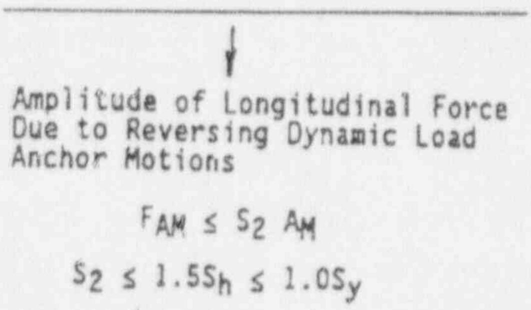


Exhibit 4.9-2

NC/ND-3600 (Continued)



Amplitude of Longitudinal Force
Due to Reversing Dynamic Load
Anchor Motions

$$F_{AM} \leq S_2 A_M$$

$$S_2 \leq 1.5S_h \leq 1.0S_y$$

Notes:

(1) Rules are provided in NC-3654.1 and NC-3655.1
(2) Rules are provided in NC-3654.2 and NC-3655.2

SECTION 5

5.0 PIPE SUPPORT DESIGN GUIDELINES

Acceptable quality pipe support design is only achievable if the pipe system has been effectively routed with due consideration given to conceptual design of the pipe supports. Adequate space must be provided between the pipe, adjacent components and the structure to permit installation of standard pipe support hardware. Use of welded frames and complicated auxiliary steel arrangements are costly and time consuming to install and therefore not desirable. These types of supports can be precluded by effective pipe routing.

Optimal support design can be achieved in congested areas, such as pipe tunnels, through the use of simple gang supports.

5.1 Embedded Plate Layout

A system of embedded plates should be laid out throughout the plant based on preliminary design of the piping, cable tray, HVAC, conduit and instrumentation system. The typical embedded plate used in this layout should be designed to have a capacity required for most of the component support reactions.

Large bore piping support reactions in excess of 10 kips will require special higher capacity embedded plates to be located based on the preliminary piping analysis cycle.

A disciplined approach to pipe routing and support configuration subsequent to the establishment of the embedded plate system will preclude the use of drilled-in concrete anchors. These types of anchorages have proven to be costly to install and a regulatory nuisance and therefore should be avoided.

5.2 Support Configuration

Effective routing of the pipe system will result in simple support designs using standard piping support hardware welded directly to the in-place structure. As a general rule support installation should require welding only at the support-structure interface point in order to be cost effective.

Recommendations regarding support configurations discussed in the following are shown in pages 5-5 through 5-8.

Standard pipe support hardware attached directly to the in-place structure should be used for all large diameter piping. Rod or strut hardware can be used in most applications. Costly welded frame guide type supports can be replaced with 2 struts installed at opposing angles (mostly 90°) thus behaving as a truss.

Use of standard hardware will achieve the following:

- reduce cost of design
- reduced cost of installation
- reduced schedule for installation
- improved pipe behavior and performance reliability (no friction type supports)
- improve space in plant

Simple cantilever members with U-bolts or straps can be used effectively for small diameter piping. In these cases, the member size can be standardized to simplify construction and design.

5.3 Gang Supports

Effective routing of piping systems in congested areas, such as pipe tunnels, can greatly reduce the number and complexity of pipe supports. Large structural beams can be located in these areas such that the pipes can rest directly on top of the beam. In these cases the gang support is a single wide flange section sized with significant margin to allow the development of the pipe design and the addition of pipes throughout the life of the plant.

The merit of using frame type gang supports should be evaluated on a plant by plant basis. The cost of installation and subsequent configuration control issues related to these auxiliary structures may preclude their use, except in special applications.

5.4 Penetration Sleeves

The initial locations for pipe supports should be established to optimize the use of the concrete structure directly at penetrations. The concrete elements have significant in-plane load carrying capacity and thus can always be used as guides with no design penalty. This is particularly true in places where concrete elements have been thickened due to shielding requirements. Using the concrete elements to directly support the pipe systems is an effective use of the plant.

Additional supports, utilizing standard hardware, should be located between the penetration locations only after the penetration locations have been fully utilized.

Cold pipes may be supported at the penetration by merely grouting the void between the penetration sleeve and the pipe. Hot piping can be guided at the penetration by simply welding angle support members to the sleeve. Pipes can be anchored at the penetration by use of welded pipe head plates.

Optimal use of the penetrations for pipe support will achieve the following:

- reduce the number of pipe hangers
- improve space in the plant
- reduce installation and design costs
- reduce schedule for installation

5.5 Design Criteria

Implementation of pipe support design based on the guidelines previously outlined will preclude many of the complicated technical issues that evolved during recently completed nuclear plants. In an effort to simplify the design and construction process of pipe supports, many in the industry have been investigating alternatives to some of the ASME Section III, Subsection NF requirements as presented in the EPRI ALWR Constructability Design Requirements and the Welding Research Council Bulletin (WRC) 353, Position Paper on Nuclear Plant Pipe Supports. Significant cost savings could be realized if exceptions to the ASME code requirements are taken in the following areas for-example:

- Material Procurement - procure material nuclear grade rather than per ASME III.
- Welder Qualification - qualify welders per AWS D1.1 in lieu of ASME IX.
- Weld Inspection - inspect welds per ANSI N45.2.5 or AWS D1.1 in lieu of ASME IX.
- Material Traceability - hardmark identification rather than heat numbers per ASME III.

- Documentation - construction checklists and FQC inspection reports in lieu of ASME Control Drawings and Weld Data Sheets.

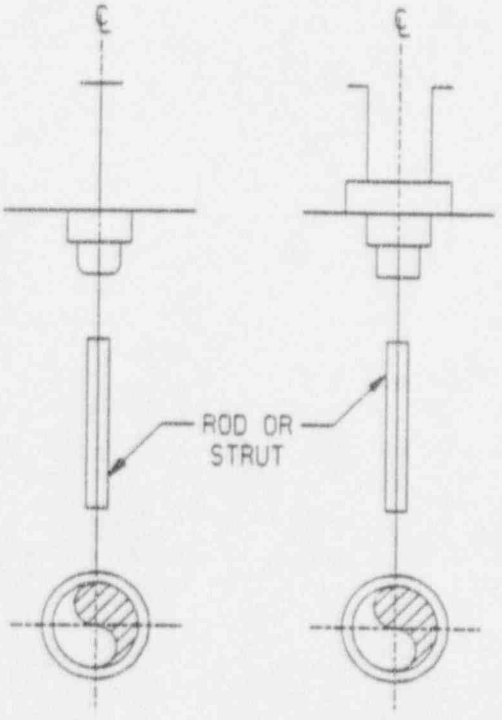
The above items will result in cost savings and are potentially defendable provided that the alternate programs are clearly defined at the beginning of the project.

The WRC Bulletin 353 provides current recommendations for consideration in pipe support design. This document may be referenced for guidelines relative to the following aspects of detailed technical design, fabrication and construction:

- Jurisdictional boundaries
- Loads and load combinations
- Functional requirements
- Support stability
- Thermal/seismic movements
- Fatigue and ratcheting
- U-bolts
- Gang supports
- Inspection requirements
- Tolerances
- Applicable design codes and standards
- Applicable fabrication and installation codes and standards

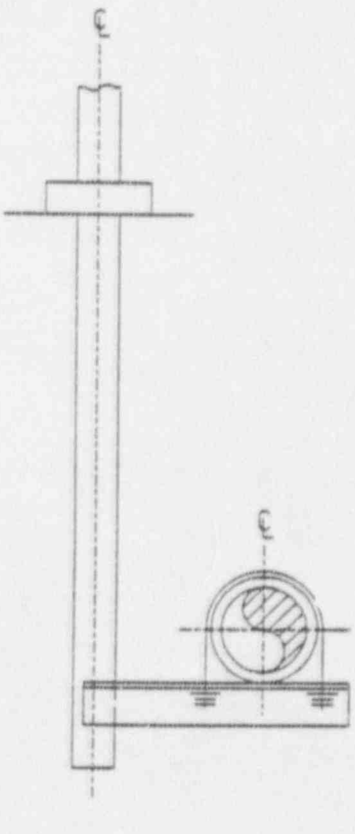
TYPICAL SUPPORT CONFIGURATIONS

PREFERRED CONFIGURATIONS



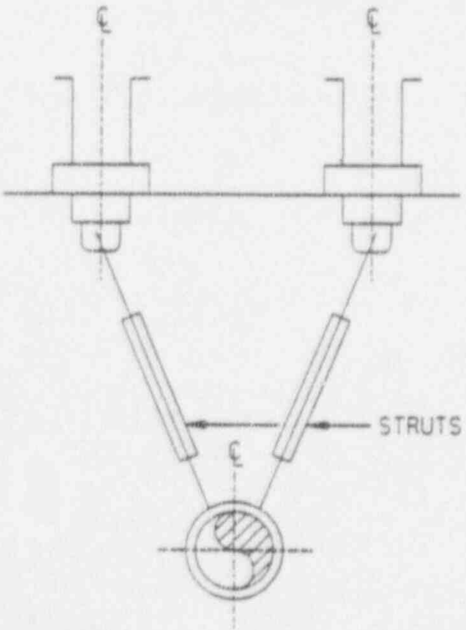
SINGLE DIRECTION

NOT RECOMMENDED



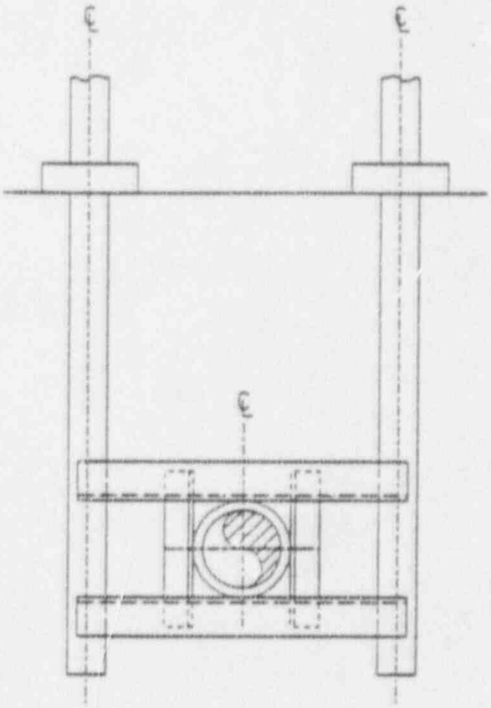
DOUBLE CANTILEVER

PREFERRED CONFIGURATION



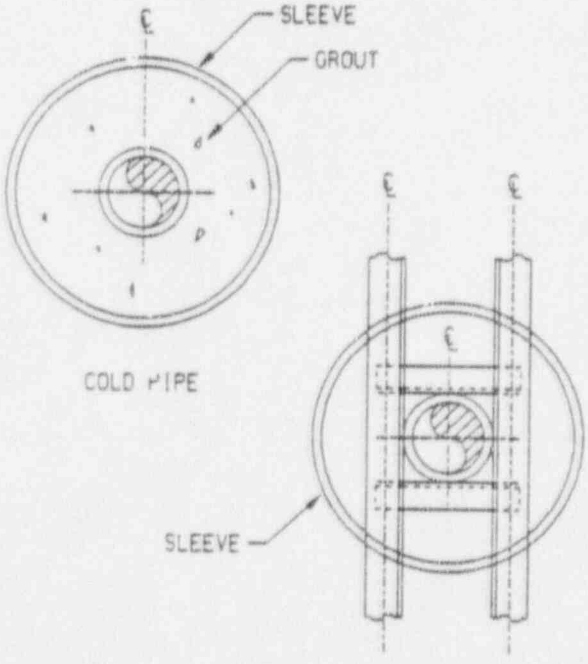
GUIDE

NOT RECOMMENDED



FRAME-GUIDE

RECOMMENDED CONFIGURATION

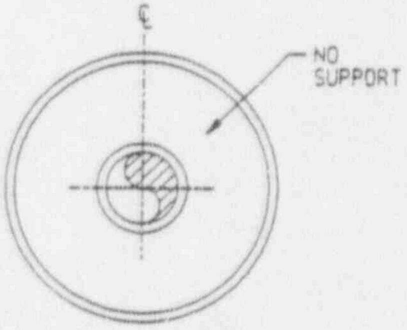


COLD PIPE

HOT PIPE

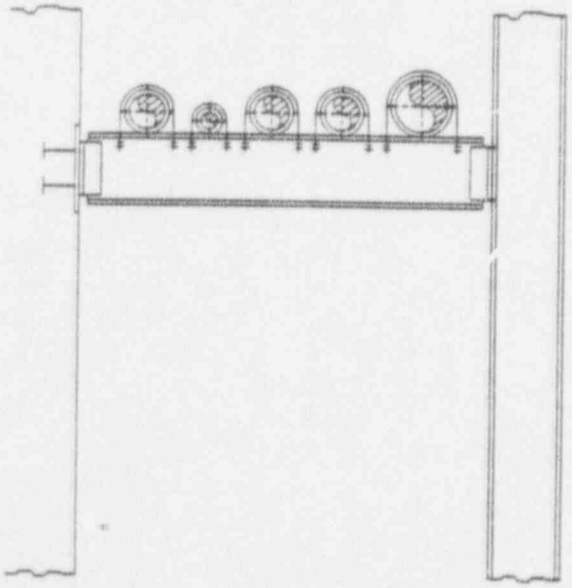
PENETRATION

NOT RECOMMENDED



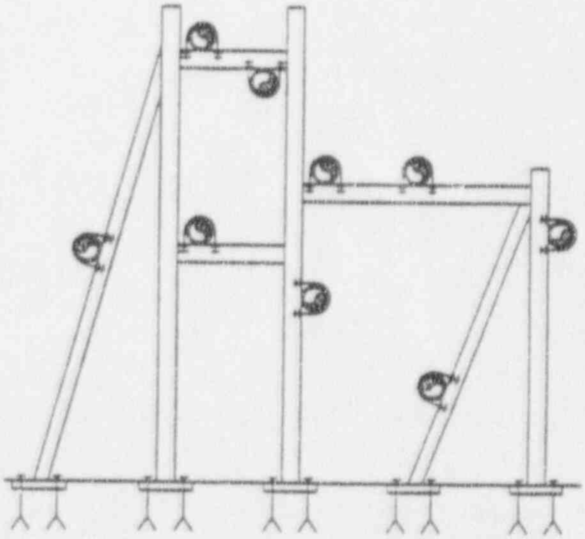
PENETRATION

RECOMMENDED CONFIGURATION



GANG

NOT RECOMMENDED



GANG FRAME

Note: Careful pipe layout arrangement simplifies support design.

SECTION 6

6.0 DEFINITIONS

6.1 Subsystem

The part of piping and pipe support arrangement of a system comprising one structural analysis problem.

6.2 Pipe Spool:

A shop fabricated spool of pipe bounded by field welds and has a unique identification number.

6.3 Layout:

The group responsible for piping layout.

6.4 Stress:

The group responsible for pipe stress analysis.

6.5 Support:

The group responsible for pipe supports.

6.6 System Engineering: The group responsible for specifying the system's equipment, components sizes, operating modes, control and instrumentation and configuration required to ensure that the system can meet its intended functions.