ES-LPD-83-001
February 1983

CRBRP

HEAT TRANSPORT SYSTEM INCONTAINMENT PIPING

RESERVE SEISMIC MARGINS

PREPARED BY:

R. M. Mello

U. Chandra

APPROVED BY:

R. H. Mallett, Manager
Piping Design & Mechanical Equipment

SUMMARY

This report provides an evaluation of the inherent reserve seismic capacity of the CRBRP heat transport system large-diameter incontainment piping. The evaluations have been conducted to assess the capacity of the piping system to accommodate seismic excitation beyond the 0.25g SSE. The evaluations were made using ratios and extrapolations from linear elastic analysis.

Sources of reserve seismic capacity can be divided into the following three broad categories:

(a) Conservative predictions of building and equipment response,

(b) Conservative definitions of structural and functional performance limits,

(c) Reserve seismic capacity incorporated by means of designer conservatism.

Reserve seismic capacities from Items (a) and (b) were considered in arriving at seismic margins for the piping system. Reserve seismic capacities from Item (c) are listed and discussed, but not quantified.

The approach used to calculate the reserve seismic margin for the HTS piping system is that presented in NUREG/CR-2137, "Realistic Seismic Design Margins of Pumps, Valves and Piping". The reserve seismic margin is determined by combining the design margin and nominal margin and accounting for the percentage of seismic stress to the total stress. The design margin is defined as follows:

$$\text{Design Margin (DM)} = \frac{\text{Allowable Stress}}{\text{Calculated Stress}} = \frac{S_A}{\sigma_C}$$

The allowable stress is based on an applicable industry standard or code that always has a built-in margin of safety on ultimate strength. The margin between the Code allowable and the ultimate strength or failure is called the nominal margin on ultimate strength and is devined as follows:

$$\text{Nominal Margin (NM)} = \frac{\text{Ult. Stress}}{\text{Allowable Stress}}$$

The actual or combined margin is given by the product of the above two margins, or

$$\text{Actual Margin (AM)} = \text{DM X NM} = \frac{S_u}{\sigma_c}$$

If k is defined as the ratio of seismic-only stress to total calculated stress (σ_c), the seismic-only margin (SOM) can be defined as follows (see Section 3.1):

$$\text{SOM} = \frac{(\text{NM x DM} - 1)}{k} + 1.0$$

This seismic-only margin was used directly to determine the reserve seismic capacity of the HTS piping system.

The minimum reserve strength capacities obtained for the HTS piping system were calculated for the various piping and support systems components and are as follows:

(a) Piping components (elbows, tees, etc.) = 2.71

(b) Clamps = 3.37

(c) Snubbers = 1.89

(d) Embedments = 4.0

Combining these results with the conservatisms in the predicted seismic piping response (which is 1.45) gives an overall reserve capacity of 2.74 (1.45 x 1.89), which translates into a reserve margin earthquake of 0.685 g's.

TABLE OF CONTENTS

1.0 OBJECTIVE

The purpose of this report is to identify the inherent reserve seismic capacity of the CRBRP heat transport system large-diameter incontainment piping. Piping designed to withstand the SSE will, by virtue of the design methods, material data and criteria employed, have reserve seismic capacity to accommodate seismic excitations in excess of the SSE. It is the intent to assess the capacity of the CRBRP HTS piping system to accommodate seismic excitation beyond the 0.25g SSE used in the design of the plant.

2.0 INTRODUCTION AND BACKGROUND

2.1 Introduction and Scope

CRBRP components and piping systems designed to withstand the SSE will have reserve seismic capacity to accommodate seismic excitations in excess of the SSE. Factors which contribute to this reserve seismic capacity include (a) the conservative predictions of building and equipment seismic response, (b) the conservative definition of structural and functional performance limits, and (c) reserve seismic capacity incorporated by means of designer conservatisms. The evaluation procedure used to determine the seismic reserve for the HTS incontainment piping is illustrated in Figure 2-1 which is the approach derived and discussed in References 1 and 2. The lefthand side of the figure addresses the piping system or equipment seismic response conservatism. This consists of five items listed below:

(1) System damping assumptions.

(2) Development of ground accelerogram.

(3) Reduction of floor response spectra due to inelastic action of building.

(4) Development of design response spectra.

(5) Development of design time-histories.

These items have been discussed in detail for the CRBRP plant buildings and systems in Reference 2 and they will not be repeated here.

The righthand branch of Figure 2-1 addresses the reserve seismic capacity of the piping system which is limited by structural reserve capacity of the piping components or the piping support system. The reserve capacity of piping support system must account for the strength of clamps, seismic restraints (or snubbers) and support structures (or embedments).

The total piping system reserve seismic capacity is obtained from the product of the structural strength reserve capacity and the piping system seismic response conservatism.

The structural strength reserve capacity for each structural component of the piping system is determined in accord with the procedure illustrated in Figure 2-2. A structural component reserve capacity is given by the product of the material minimum strength assumptions and the conservatisms provided in the ASME Code allowables. The ASME Code usually dictates that minimum strength values be used to derive allowable stresses. However to determine reserve seismic capacity, it is appropriate in general to use average strengths because stress analyses are used to predict local failure which does not necessarily mean that a gross failure of the system will result. To be conservative, this evaluation of reserve seismic margin will use minimum material properties of the piping components which are loaded by internal pressure.

2.2 System and Piping Description

The CRBRP Heat Transport System consists of three almost identical cooling circuits, each of which includes a Primary Heat Transport System (PHTS) sodium loop, and an Intermediate Heat Transport System (IHTS) sodium loop, thermally coupled by an Intermediate Heat Exchanger (IHX). Each PHTS loop contains a 36" hot leg, a 24" hot leg (crossover) and a 24" cold leg. Each IHTS loop contains a 24" hot leg and a 24" cold leg within containment.

The primary sodium loops transport the hot radioactive sodium coolant from the reactor vessel to the intermediate heat exchangers, which thermally link the primary and intermediate loops, and transport cooled primary sodium back to the reactor vessel. The three primary loops have common flow paths through the reactor vessel but are otherwise independent in operation.

The intermediate sodium loops circulate hot non-radioactive sodium from the tube side of the intermediate heat exchangers (located in the reactor containment building) to the steam generators (located in the steam generator building), and transport cooled intermediate sodium back to the IHX units. The intermediate sodium piping within the containment building runs under the operating floor from the intermediate heat exchangers to the containment building boundary. A rigid seal is provided at each piping penetration through the containment building wall to enable containment integrity relative to leak tightness.

The CRBRP HTS large piping systems within containment are made up of the ASME Code Class 1 liquid metal piping configurations, as listed below (see Table 2-1):

1. PRP(A) - PHTS 36-inch hot-leg pipe from the reactor vessel to the pump suction (3 loops).

2. PRP(B) - PHTS 24-inch hot-leg pipe (crossover) from the pump discharge to the IHX primary inlet (3 loops).

3. PRP(C) - PHTS 24-inch cold-leg pipe from the IHX primary outlet to the reactor vessel inlet (3 loops).

4. INP(A) - IHTS 24-inch hot-leg pipe from the IHX intermediate outlet to the reactor containment building boundary (3 loops).

5. INP(E) - IHTS 24-inch cold-leg pipe from the reactor containment building boundary to the IHX intermediate inlet (3 loops).

The piping structural system includes the piping components such as straights, elbows and tees that make up the loops and its support system (clamps, spring hangers, snubbers, rigid rods, support steel and embedments).

2.3 Structural Design Criteria

The CRBRP Heat Transport System large-diameter piping within containment is designed and analyzed as an ASME Class 1, Seismic Category I nuclear component in accordance with the following rules:

a. ASME Boiler and Pressure Vessel Code, 1974, Section III, Nuclear Power Plant Components, with Addenda through Summer 1975 and with modifications to Sections NB-2000 and NB-3000 as presented in ASME Code Case Interpretation 1592-7 for design of Elevated Temperature Class 1 components in Section III.

b. RDT Standard E15-2NB-T, Class 1 Nuclear Components (Supplement to ASME Boiler and Pressure Vessel Code, Section III, Subsections NA and NB), November 1974.

c. RDT Standard F9-4T, Requirements for Construction of Nuclear System Components at Elevated Temperature (Supplement to ASME Code Cases 1592, 1593, 1594, 1595 and 1596), September 1974.

d. PSAR, Section 3.7A, Seismic Design Criteria for the Clinch River Breeder Reactor Plant, January 1977.

The consideration of thermal creep effects sets the elevated temperature rules (Code Case 1592) apart from the Section III, Subsection NB rules. Unlike Subsection NB design rules, which basically guard against time-independent failure modes, the elevated temperature rules are applicable for service conditions where creep and relaxation effects are significant. Therefore, the elevated temperature rules require that the design/analysis of a nuclear component consider time-dependent, as well as time-independent, material properties. In addition, Code Case 1592 extends specific rules of Subsection NB to elevated temperature service provided it can be demonstrated that the combined effects of temperature, stress level, and duration of loading do not introduce significant creep effects. This option proves to be applicable to the cold leg piping.

The HTS piping is designed to assure that stresses, strains and deformations are within the applicable ASME Code criteria and system functional limits. As required, the analyses performed to satisfy these limits reflect both time-independent and time-dependent materials properties and structural behavior (elastic and inelastic) by considering the following relevant modes of failure:

a. Ductile rupture from short-term loadings.

b. Creep rupture from long-term loadings.

c. Creep-fatigue failure.

d. Gross distortion due to incremental collapse and ratchetting.

e. Loss of function due to excessive deformation.

For the HTS piping that normally operates at temperatures over 800°F, the elevated temperature criteria given in Code Case 1592 and RDT Standard F9-4T are invoked for the piping evaluation to supplement the ASME Code, Section III criteria. In accordance with Code Case 1592 criteria, the in-containment HTS hot-leg piping is evaluated against the following limits:

a. Load-controlled limits (limits on primary stress intensities).

b. Limit on primary-plus-secondary stress intensities or ratchetting (or strain limits).

c. Limit on creep-fatigue damage.

The primary HTS cold-leg piping normally operates in a temperature range between 400° and 750°F while the intermediate HTS cold-leg piping operates between 400° and 673°F. However, as some thermal transient conditions exceed the 800°F limit for austenitic stainless steels, the elevated temperature criteria, given in ASME Code Case 1592 and RDT Standard F9-4T, are invoked for the evaluation of the HTS cold-leg piping. Code Case 1592 does, however, extend specific rules of Section III, Subsection NB, (as previously discussed) to elevated temperature service if it can be demonstrated that creep effects are insignificant. For the HTS cold-leg piping which operates at temperatures over 800°F for less than 20 hours, creep effects are negligible and a Section III type analysis is sufficient; i.e., ratchetting limits will be satisfied by limiting elastically calculated primary-plus-secondary stress intensities and only elastic fatigue analyses will be required.

2.4 Design Conditions and Loadings

The various types of design loading conditions in the Piping Design Specification have been categorized into design, normal, upset, emergency, and faulted conditions; and organized into a load histogram. The stress analysis is performed on the basis of these loading categories.

For the HTS piping, the steady state and transient events and their frequency of occurrences are identified in the Piping Design Specification. Each transient event is characterized by coolant temperature, flow and pressure variation plots which are given in the piping design specification. Based upon the transient events and steady state conditions, load cycles are constructed such that they begin and end at the same steady state condition. In general for constructing a load cycle, several transient events are used in sequence. Further, the construction is such that the full set of load cycles uses the specified number of occurrences of each type of transient.

From the definition of the loading cycles, the combination of loads acting on the piping system during the plant lifetime was established and used in the stress analysis. The loading combinations in the analyses include the load effects resulting from internal pressure, deadweight, support movements, thermal expansion, seismic, sodium water reaction (IHTS piping), and through wall temperature gradients. The fact that the time phasing of the loads was ignored in the analyses is significant.

For the flexibility analyses, a given piping leg between equipment nozzles was modeled using a series of straight and elbow components connected at a finite number of points. A computer analysis was than used to determine elastic displacements, forces and movements in the piping leg. The five basic loading conditions that are considered in the HTS piping flexibility analyses are:

A. Thermal expansion from 70°F to maximum normal operating temperature.

B. Dead weight with the system full of sodium.

C. Seismic motion from the Operating Basis Earthquake.

D. Seismic motion from the Safe Shutdown Earthquake.

E. Motion caused by the Sodium-Water Reaction pressure pulses (IHTS piping).

For elastic thermal flexibility analysis, the thermal motions of the nozzles acting as anchors were imrosed on the interfacing piping points. The seismic analysis of the piping was completed using the Response Spectrum Method with response spectra that enveloped the piping attachment points to the building structure, or in some cases, time-history seismic analysis was used. Damping values were selected as per NRC Regulatory Guide 1.61 where two percent and three percent of critical damping are used for OBE and SSE, respectively, for piping of nominal diameter greater than 12 inches.

The dynamic effects of the sodium-water reaction are comprised of time varying loads (force or pressure) applied at either a change in direction or a change in cross-sectional area of the piping. A computer code was used to develop force time histories at the elbows, tees, etc. for input into the dynamic structural analysis code flexibility analysis of the piping loops. This analysis determined peak load responses at features of concern (i.e., pipe fittings, welds, equipment nozzles, penetration anchors, supports/restraints and branch connections).

2.5 Analysis Procedures

To perform the structural evaluation of the HTS piping, the loadings on the piping loop that result from the usual load effects including internal pressure, deadweight, support movements, thermal expansion, seismic, sodium water reaction, and thermal temperature gradients were obtained at particular locations in the piping system (usually at piping components such as elbows, tees, reducers, transition joints, girth welds, etc.).

Computer-aided flexibility analyses (as discussed in the previous section) were used to determine the forces and moments in the piping components. All computer programs used have been verified or are in the process of being verified.

The results of the flexibility analyses were used to formulate the combined stresses for assessment against the ASME Code limits. Moment components for various loadings were combined to determine appropriate moment resultants at the piping components and weld locations between the components. Stress values for moment loadings were computed using the simplified stress indices approach provided in NB-3600. Stress indices at the piping components were computed based on the component nominal geometry using equations or values provided in Table NB-3682.2-1 for ANSI B16.9 butt-welding components. Stress indices for the girth welds were based on the piping dimensions, using the Table NB-3682.2-1 values for a flush girth butt weld.

The following additional assumptions were used to establish and modify the appropriate stress indices:

A. If out of roundness at the piping component does not exceed 0.08t, i.e., F_{1a} was assumed unity, otherwise F_{1a} as given by Code was used.

B. Weld shrinkage at the girth welds was 0.02R (the maximum permitted by RDT E15-2NB-T) and the C_1, C_2 indices modifications in RDT E15-2NB-T were employed.

The simplified analysis formulas given in the ASME Code, Section III are used to determine stresses resulting from internal and external pressure.

For simplified analysis, the heat transfer analysis for the individual transients was performed using finite element methods. For the thermal hydraulic data, the thermal response of the piping components was evaluated by calculating the radial temperature distribution at various time intervals during a transient and then calculating the quantities T, ΔT_1, and ΔT_2 as per NB-3653 of the ASME Code, Section III. These quantities are used to obtain the stresses in the piping component due to the temperature gradient through the component wall thickness using the appropriate simplified stress index approach in NB-3600.

TABLE 2-1

PHTS & IHTS PIPING WITHIN CONTAINMENT

PIPING DESCRIPTION	DESCRIPTION	O.D. (in)	WALL THICKNESS (NOMINAL) IN.	MATERIAL	ASME CLASS
PRP-A	PHTS - HOT LEG From Reactor Vessel Outlet Nozzle to Primary Pump Inlet Nozzle.	36.0	0.5	PIPE SA-358 GRADE 316 ELBOW SA-403 GRADE WP316	1
PRP-B	PHTS - HOT LEG (Crossover) From Primary Pump Outlet Nozzle to IHX Primary Inlet Nozzle.	24.0	0.5	PIPE SA-358 GRADE 316 ELBOW SA-403 GRADE WP316	1
PRP-C	PHTS - COLD LEG From IHX Primary Outlet Nozzle to Reactor Vessel Inlet Nozzle.	24.0	0.5	PIPE SA-358 GRADE 304 ELBOW SA-403 GRADE WP304	1
INP-A	IHTS - HOT LEG (Within Containment) From IHX Intermediate Outlet Nozzle to the Containment Seal.	24.0	0.5	PIPE SA-358 GRADE 316 ELBOW SA-403 GRADE WP316	1(1)
INP-E	IHTS - COLD LEG (Within Containment) From Containment Seal to IHX Intermediate Inlet.	24.0	0.5	PIPE SA-358 GRADE 304 ELBOW SA-403 GRADE WP304	1(1)

Notes

1. IHTS piping is classified as ASME Class 2 but has been analyzed to meet Class 1 criteria.

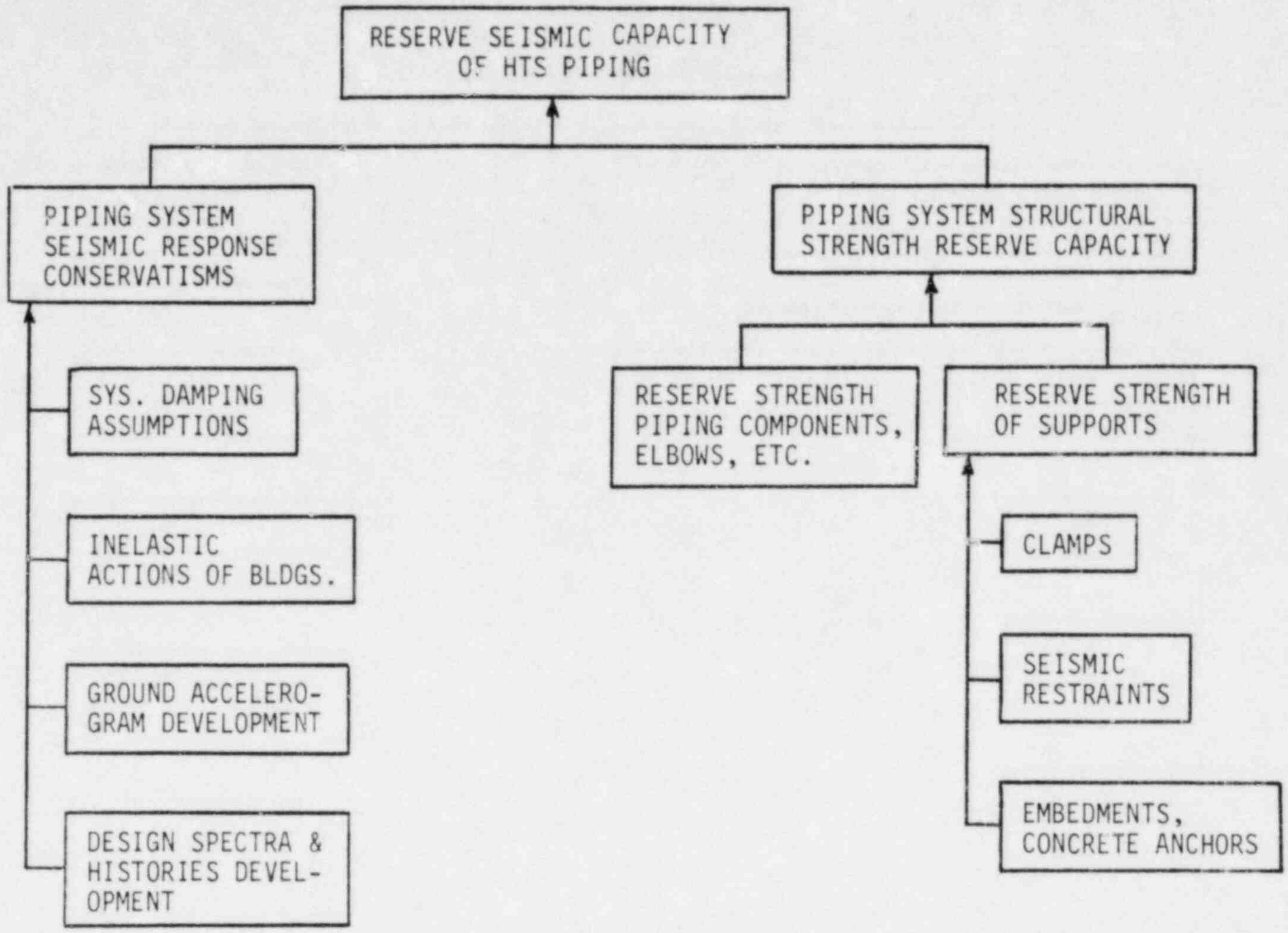
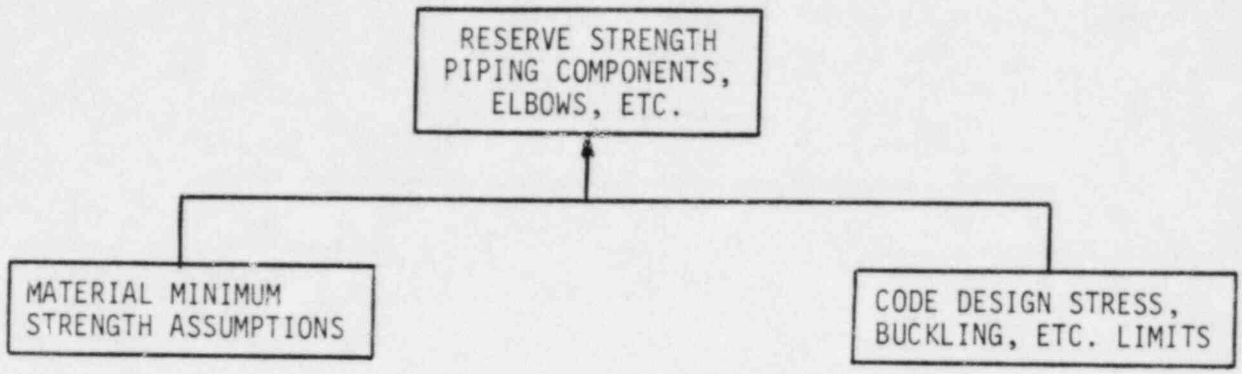


FIGURE 2-1

CRBRP HTS PIPING SYSTEM
RESERVE SEISMIC CAPACITY
EVALUATION PROCEDURE



Example:

$$\text{Fac.} = \frac{(S_{ult.})_{aver}}{(S_{ult.})_{min.}}$$

Example:

$$DM = \frac{3S_m}{(P_L + P_b)}$$

$$NM = \frac{(S_{ult.})_{aver.}}{3S_m}$$

FIGURE 2-2

RESERVE STRENGTH OF PIPING COMPONENTS

3.0 SEISMIC MARGIN EVALUATION

3.1 Approach

The approach used to calculate the reserve seismic margin for the HTS piping system is that presented in NUREG/CR-2137, "Realistic Seismic Design Margins of Pumps, Valves and Piping", (Reference 1).

In safety evaluation reports prepared in support of applications for nuclear power plant licenses, the adequacy of structural components, such as a piping system, to withstand a combination of loads (including seismic) from the SSE event is expressed in the form,

$$\text{Design Margin (DM)} = \frac{\text{Allowable Stress/Load}}{\text{Calculated Stress/Load}} = \frac{S_A}{\sigma_c} \qquad (1)$$

The allowable stress or load is based on an applicable industry standard or code, such as the ASME Boiler and Pressure Vessel Code, that always has a built in margin of safety on ultimate strength or failure. The calculated stress on the structural component is determined using the operating loads, deadweight loads and SSE loadings on the structure.

For a structural component to be acceptable, the seismic event design margin must be greater or equal to 1.0. If the loads on the component are underestimated such that σ_c is actually higher than calculated, the component may still not fail because of the reserve strength available because the Code allowable is defined to be less than the ultimate or failure stress. This built in margin of safety is called the nominal margin on ultimate strength or failure and is defined as follows:

$$\text{Nominal Margin (NM)} = \frac{\text{Ult. Stress/Load}}{\text{Allowable Stress/Load}} = \frac{S_u}{S_A} \qquad (2)$$

Nominal margins indicate the reserve strength that is available when the seismic event design margin is unity. Nominal margins depend upon the source of the allowable stress or load, S_A, which in turn depends upon material properties, temperature, failure mode, functional limits, etc. For example, a nominal margin based on ultimate strength or breaking must consider the basis used for establishing the ASME Code allowable tensile stresses. The allowable stress is a fraction of the tensile properties of the material used in the construction of the component. This nominal margin would be defined as follows:

$$\text{Nominal Margin} = \frac{S_u}{S_A} \text{ for ultimate strength} \qquad (3)$$

If yielding is a primary consideration in order to prevent excessive deformations, the nominal margin may be defined as follows:

$$\text{Nominal Margin} = \frac{S_y}{S_A} \text{ for yielding} \qquad (4)$$

In a similar manner, nominal margins may be defined for buckling loads, shear loads, bending loads, and combined loads.

In summary, the nominal margin corresponding to a design margin of 1.0 depends upon the following;

(1) Material

(2) Operating Temperature

(3) Type of Loading

(4) Failure Criteria

(5) Source of allowable stress, S_A, For example, ASME Code Section III, Subsection NB allowable stress for pressure boundary integrity or Subsection NF allowable for piping supports.

The seismic event design margin has been defined by Equation (1) as S_A/σ_c, where σ_c is the calculated stress due to all loads. Because seismic loadings are subject to larger uncertainties, it is pertinent to evaluate the margin that exists for seismic-only loads. If the total calculated stress, σ_c, for the seismic event is separated into the seismic, σ_{cs} and non-seismic stress, σ_{cn} or

$$\sigma_c = \sigma_{cs} + \sigma_{cn} \tag{5}$$

the seismic-only margin may be defined as follows:

$$SOM = \frac{S_u - \sigma_{cn}}{\sigma_{cs}} \tag{6}$$

If k is defined as the ratio of seismic-only stress to total calculates stress ($k = \sigma_{cs}/\sigma_c$), the seismic-only margin given by equation (6) can be written as follows (see Appendix A for derivation):

$$SOM = \frac{(NM \times DM - 1)}{k} + 1.0 \tag{7}$$

This margin can be used directly to determine the reserve seismic capacity of a structural component or piping system.

3.2 Margin Analysis

3.2.1 Piping System Seismic Response Conservatisms

The resulting system seismic response conservatism margin was determined in Reference 2 and is listed below:

(a) System damping assumptions = 1.2

(b) Development of ground accelerogram = 1.05

(c) Inelastic action of buildings = 1.05

(d) Development of floor spectra or time-histories = 1.1

(e) Combined margin = 1.45

3.2.2 Piping System Structural Strength Reserve Capacity

Piping Components (Elbows, Tees, etc.)

For faulted (or Level D) conditions the ASME Code (Reference 3) limits on the calculated primary stress for piping can be expressed as follows (see Section III, Appendix F and Code Case 1592-7):

$$P_L + P_b \leq 3\ S_m \qquad (8)$$

where P_L = primary membrane stress from pressure deadweight and SSE loadings

P_b = primary bending stress from pressure deadweight, and SSE loadings

S_m = time independent material allowable

The safe-shutdown earthquake (SSE) event is identified as a faulted loading in the HTS piping design specification.

In terms of Equation (1), the seismic event design margin for the CRBRP HTS piping components can be expressed as follows:

$$DM = \frac{S_A}{\sigma_c} = \frac{3\ S_m}{(P_L + P_b)} \qquad (9)$$

For austenitic stainless steels (Types 304 and 316) the S_m allowable is equal to 0.95 S_y. The ASME Code faulted stress limits do not necessarily preclude gross yielding, but they do provide margin against breaking or the ultimate material strength. Therefore, the normal margin for the piping can be expressed as follows:

$$NM = \frac{S_u}{S_A} = \frac{S_u}{3\ S_m} \qquad (10)$$

where S_u is the ultimate strength for the material. The ultimate strengths were obtained from the NSM Handbook (Reference 4) and are based on minimum strength values. From a study of ultimate strengths for austenitic stainless steels, the ratio of average-to-minimum ultimate strengths is 1.06.

However, for the piping seismic margin evaluation, this safety factor is conservatively not considered and the nominal margin will be based on the minimum ultimate strength. The nominal margins for the incontainment HTS piping components in each piping loop are listed in Table 3-1. The margins are based on the reserve strength between the 3 S_m allowable and the minimum ultimate strength of the material.

TABLE 3-1

NOMINAL MARGINS (NM) FOR INCONTAINMENT HTS PIPING

PIPING LOOP	MATERIAL	TEMP. °F	S_A ($3\ S_m$) (ksi)	S_u (ksi)	NM
36" PHTS HL	316SS	1015	45.93	57.554	1.2531
24" PHTS HL	316SS	1015	45.93	57.554	1.2534
24" PHTS CL	304SS	750	46.50	57.480	1.2361
24" IHTS HL	316SS	965	46.41	59.772	1.2868
24" IHTS CL	304SS	690	47.82	57.818	1.2091

The piping system flexibility analysis gives a set of forces and moments acting at various locations in the piping system for deadweight, thermal expansion and SSE loadings. These forces and moments along with operating loads such as pressure are converted into stresses using procedures given in Section III of the Code, Subsection NB-3600, for Class 1 piping systems. The Code uses stress intensification factors (B_1, C_1, B_2, C_2, etc.) to indicate the relative strength of a component (such as at an elbow) to the strength of the straight pipe. For Class 1 piping, the combined stresses due to an SSE and associated loads (pressure and deadweight) are limited to $3\ S_m$ or the faulted limit.

The other mode of failure considered in the margin evaluation was plastic collapse of the piping elbows. The piping restraints (or snubbers) as well as the blocks on the hangers constrain the piping system from excessive deformations or rotations under seismic loadings. In the actual piping configurations, the elbows will not be able to rotate sufficiently to cause collapse of the elbows or piping system. Thus, buckling or collapse of a piping elbow is not a practical mode of failure in the CRBRP HTS piping systems.

The stresses at the elbow locations for the five piping loops that comprise the CRBRP HTS incontainment piping system are given in Tables 3-2 through 3-6. Each table provides the following information:

(1) Elbow number; the location identified in Figure 3-1 through 3-5.

(2) σ_{cn}; non-seismic membrane-plus-bending stress at the location due to pressure and deadweight.

(3) σ_{cs}; the SSE seismic stress at the location.

(4) σ_c ; the total stress at the location.

(5) k ; the fraction of stresses due to the SSE loadings to the total of all stresses, i.e., σ_{cs}/σ_c

(6) NM ; the nominal margin presented in Table 3-1.

(7) DM ; the SSE event design margin at each location.

(8) AM; the actual margin (DM x NM) at each location.

(9) SOM; the seismic-only margin as calculated using equation (7) at each point.

Stresses due to restraint of thermal expansion are not included in the tables because thermal expansion loads are not considered primary loads. If stresses due to such loads are above the elastic capacity, the higher stresses portions of the piping yield slightly to accommodate the thermal expansion.

The tables illustrate a typical aspect of piping systems in that only a few points are highly stressed. Typically for thin-walled, high temperature, low pressure piping as used for the HTS piping system, the elbows are usually the highest stressed components in the piping loop. Therefore, the margins have been calculated for the beginning (BEG), middle (MID) and ending (END) for each elbow in the piping system.

A review of the tables show the following ranges of seismic-only margin for the five HTS piping loops:

(a) PHTS 36" HL; SOM = 4.25 - 11.37

(b) PHTS 24" HL; SOM = 4.76 - 58.9

(c) PHTS 24" CL; SOM = 2.71 - 14.58

(d) IHTS 24" HL; SOM = 7.72 - 25.2

(e) IHTS 24" CL; SOM = 5.31 - 13.58

The highest stress point is elbow 8 (MID) in the PHTS cold leg. The seismic-only margin at this point is equal to 2.71, and is associated with the following margins:

DM = 1.997

NM = 1.236

AM = 2.469

These results show that at SSE plus associated loads (with peaks of the various loadings assumed to occur at the same time), there is a significant available reserve strength margin in the piping elbows and components to accommodate additional seismic loadings.

Piping System - Clamps

A typical piping restraint assembly used on the CRBRP HTS piping is shown in Figure 3-6. The assembly included an insulated clamp, snubbers, rigid rods or hangers attached to the clamp, and the embedment or building support structure. The CRBRP pipe clamps and snubbers have been designed and tested to meet the requirements of Subsection NF of the ASME Code for Class 1 supports. Thus they have designed to satisfy the faulted limits (Level D) for the SSE event.

Detailed stress evaluations have been completed for the pre-loaded, insulated pipe clamp to be used on the HTS piping. The faulted stress limit used to assess the structural integrity of the clamp is as follows:

$$P_L + P_B \leq 2.25\ S_m \qquad (11)$$

where P_L, P_b and S_m have been defined previously. Using this equation, the various reserve strength margins can be defined as follows:

$$DM = \frac{S_A}{\sigma_c} = \frac{2.25\ S_m}{P_L + P_b}$$

$$NM = \frac{(S_u)_{aver}}{S_A} = \frac{(S_u)_{aver}}{2.25\ S_m}$$

The clamp is constructed using SA-387, Grade 2, Class 1 material. At 300°F, the 2.25 S_m allowable is equal to 52.9 ksi and the minimum ultimate strength is equal to 55.0 ksi. For carbon steels it has been shown in Reference 2 that average ultimate strength properties are at least 120% of the minimum ultimate strengths. Therefore, for this material the NM against ultimate failure is the following:

$$NM = \frac{(S_u)_{aver}}{2.25\ S_m} = 1.20\ \left(\frac{55.0}{52.9}\right) = 1.248$$

The most critically stressed clamp for SSE loadings is the 24" OD by 12" width clamp used on the 24" OD HTS piping. For the SSE event, only seismic loadings introduce primary stresses in the clamp band and the maximum combined membrane plus bending stress was 19.6 ksi. Thus the DM for this clamp was 52.9/19.6 = 2.699. The actual margin (and in this case the seismic-only margin also since only seismic loads are present) is:

$$SOM = (1.248)\ (2.699) = 3.37$$

Piping Support System - Snubbers

The snubbers used to restrain the HTS piping are of the mechanical type due to radiation considerations and have many moving parts. The vendors that supply snubbers have established faulted (Level D) loads for their designs and have completed static tests to insure operability at the rated faulted loads. The mechanical snubber available for use have had detailed stress analyses completed on their structural parts and their capability is certified to ASME Code, Subsection NF requirements for Class 1 supports. Modes of failure considered in the evaluations of the snubber structural parts included ball screw shaft buckling, Brinnelling of the ball screw, buckling of the enclosure cylinder, and failure of the pins, fittings and clevises. From a review of the snubber stress analyses, it was judged that buckling is the likely critical failure mode. Since the ASME Code applies a 1.5 factor to buckling for faulted (Level D) limits, the nominal margin (NM) to failure for the snubbers is at least 1.5.

In addition, there is in most cases for the HTS piping a substantial design margin (DM) between the actual calculated SSE snubber load and the faulted condition rated load because in most cases the size of the snubber selected is based on the SMBDB (structural margin beyond the design base or hypothetical loads) loads for the primary system and on the SWR (sodium water reaction event) loads for the IHTS piping. A review of maximum SSE loads for Loop 1 of the primary system gives the following margins (it is expected the Loops 2 and 3 will give similar results):

(a) PHTS 36" HL, SSE DM = 1.933

(b) PHTS 24" HL, SSE DM = 1.369

(c) PHTS 24" CL, SSE DM = 1.258

(d) IHTS 24" HL, SSE DM = 1.407

(e) IHTS 24" CL, SSE DM = 2.45

The minimum actual margin (AM), and in this case the seismic-only margin, for the snubbers in the HTS system is:

$$SOM = 1.5 \times 1.258 = 1.89$$

Piping Support System - Concrete Anchor Bolts

The final component of the support train that must be considered is the supporting structure or embedment. A major aspect of seismic capability of piping systems is to assure that they are adequately held to the building structure (see Reference 1). For piping, this means adequately attaching the snubbers to the building. The weak link in attaching supports to the building are usually the concrete anchor bolts.

Bolting connections to concrete can be made either by installing the bolts before pouring the concrete or by drilling a hole in the concrete and inserting an anchor bolt.

Bolts installed before the concrete is poured have not produced any known field-installation problems. The embedded ends of the bolts can be hooked or installed with large washers; thereby, the tensile and shear strength of bolting like SA-307 Grade B can be developed. However, anchor bolts installed after pouring the concrete have given field-installation problems. Considerable skill and care in the installation process are required to consistently obtain anchor bolts that, as intalled, develop the tensile and shear strength indicated by Manufacturers' catalogs.

From review of Reference [illegible] ta, it appears that the tensile and shear strength of anchor bolts given in Manufacturers' catalogs can, with appropriate skill and care, be achieved in field installations. Manufacturers commonly recommend (a) that design loads for anchor bolts should not exceed one-quarter of the manufacturer's tensile or shear strength, and (b) that a linear interpolation should be used for combinations of tension and shear. If the recommendation is used for both SSE and OBE and associated loadings, the average Nominal Margin would be 4.0.

For CRBRP HTS piping all support anchor bolts will be installed before the pouring of concrete, thus the use of the recommended nominal margin of four on the seismic-only margin for the embedments given in Reference 1 for anchor bolts in concrete is conservative.

3.3 Designed-in Seismic Reserve Capacity

In the previous section, the reserve seismic margin for HTS piping was quantified on the basis of piping system seismic response prediction conservatisms and the piping structural strength reserve capacity. In addition to these, there are other seismic reserves incorporated in the design of the piping system as a result of designer/analyst conservatisms. These are more difficult to quantify, but from experience it is known that they exist. These seismic reserves are present due to some or all of the following:

(a) Design of most of the piping is controlled by the OBE, since the allowables are more restrictive.

(b) The OBE equals 50% of the SSE, but OBE piping loads are greater than 50% of the SSE loads.

(c) Use of linear-elastic dynamic and stress analysis.

(d) Envelope spectra for a multiple-supported piping system.

(e) Use of response spectrum analysis methods versus time-history analysis (in most cases).

(f) Exclusion of non-structural elements.

(g) Structural redundancy of the piping elements.

(h) Absolute combination of seismic loads with other loads.

It should be noted that Items (a) and (b) above are due specifically to lower damping for the OBE than for the SSE.

3.4 Margin Analysis Results Summary

Seismic design margins were calculated as a result of seismic response conservatisms and piping system structural strength reserve capacity. The evaluation procedure used was that as discussed in Section 2.1 and shown in Figure 2-1. The minimum margins obtained for the HTS piping system are identified on Figure 3-7. These results show that the mechanical snubbers have the minimum seismic reserve, but even those margins are close to 2.0. In addition, the analysis assumes that a snubber or support failure means a failure of the piping system itself. In most cases this will not be true because a failure of single support will only cause a redistribution of seismic loads within the piping system with only small increases in piping stresses.

Accounting for the conservatisms in the predicted piping system seismic response, the overall seismic reserve capacity for the HTS piping system is 2.74. This translates into a reserve margin earthquake of 0.685 g's. The results obtained for the HTS piping are very comparable to those obtained for the CRBRP buildings, structures, and equipment in Reference 2.

TABLE 3-2. PHTS 36" HOT LEG

LOCATION [1]	σ_{cn} (CYCLE 17-U)	σ_c (CYCLE 18-U)	σ_{cs} ($\sigma_c - \sigma_{cn}$)	K (σ_{cs}/σ_c)	DESIGN MARGIN DM	NOMINAL MARGIN NM	ACTUAL MARGIN AM	SEISMIC ONLY MARGIN SOM
1-BEG	1.69	13.28	11.59	.8727	3.4586	1.2531	4.3339	4.820
-MID	5.46	12.35	6.89	.5579	3.7190	1.2531	4.6602	7.561
-END	0.92	7.91	6.99	.8837	5.8066	1.2531	7.2761	8.102
2-BEG	0.94	7.45	6.51	.8738	6.1651	1.2531	7.7254	8.697
-MID	1.57	14.76	13.19	.8936	3.1118	1.2531	3.8993	4.245
-END	2.00	11.75	9.75	.8298	3.9089	1.2531	4.8982	5.698
3-BEG	0.78	9.51	8.73	.9180	4.8297	1.2531	6.0519	6.503
-MID	0.85	11.54	10.69	.9263	3.9801	1.2531	4.9873	5.305
-END	1.47	11.60	10.13	.8733	3.9595	1.2531	4.9616	5.536
4-BEG	1.35	10.00	8.65	.865	4.5930	1.2531	5.7554	6.498
-MID	5.14	14.47	9.33	.6448	3.1742	1.2531	3.9775	5.618
-END	1.27	8.49	7.22	.8504	5.4099	1.2531	6.7790	7.796
5-BEG	2.56	9.63	7.07	.7342	4.7695	1.2531	5.9765	7.778
-MID	8.01	14.32	6.31	.4406	3.2074	1.2531	4.0191	7.852
-END	1.13	6.71	5.58	.8316	6.8450	1.2531	8.5773	10.112
6-BEG	1.24	7.65	6.41	.8379	6.0039	1.2531	7.5234	8.785
-MID	1.61	11.90	10.29	.8647	3.8597	1.2531	4.8365	5.437
-END	1.12	6.08	4.96	.8158	7.5543	1.2531	9.4661	11.378
7-BEG	2.40	9.06	6.66	.7351	5.0695	1.2531	6.3525	8.281
-MID	7.55	14.56	7.01	.4815	3.1545	1.2531	3.9529	7.133
-END	.98	7.80	6.82	.8744	5.8885	1.2531	7.3787	8.295
8-BEG	.95	6.99	6.04	.8641	6.5708	1.2531	8.2338	9.371
-MID	1.41	10.81	9.40	.8696	4.2488	1.2531	5.3241	5.973
-END	1.30	9.31	8.01	.8604	4.9334	1.2531	6.1820	7.023

Material: SS316

Temperature: 1015°F

S_U = 57.554 ksi

$S_A = 3 \times S_m$ = 45.93 ksi

1-See Figure 3-1 for elbow locations.

TABLE 3-3. PHTS 24" HOT LEG

LOCATION[1]	σ_{cn} (CYCLE 17-U)	σ_c (CYCLE 18-U)	σ_{cs} $(\sigma_c - \sigma_{cn})$	K (σ_{cs}/σ_c)	DESIGN MARGIN DM	NOMINAL MARGIN NM	ACTUAL MARGIN AM	SEISMIC ONLY MARGIN SOM
1-BEG	4.89	6.06	1.17	.1931	7.5792	1.2531	9.4974	45.005
-MID	7.34	12.46	5.12	.4109	3.6862	1.2531	4.6191	9.808
-END	4.47	7.28	2.81	.386	6.3091	1.2531	7.9058	18.891
2-BEG	4.41	8.15	3.74	.4589	5.6356	1.2531	7.0618	14.210
-MID	4.76	10.30	5.54	.5379	4.4592	1.2531	5.5878	9.529
-END	4.58	5.48	0.9	.1642	8.3814	1.2531	10.5026	58.872
3-BEG	4.27	9.78	5.51	.5634	4.6963	1.2531	5.8849	9.670
-MID	5.54	10.52	4.98	.4734	4.3660	1.2531	5.4709	10.444
-END	4.39	8.16	3.77	.4620	5.6287	1.2531	7.0532	14.102
4-BEG	4.45	8.95	4.50	.5028	5.1318	1.2531	6.4306	11.801
-MID	5.58	16.49	10.91	.6616	2.7853	1.2531	3.4902	4.764
-END	4.25	13.13	8.88	.6763	3.4981	1.2531	4.3834	6.003
5-BEG	4.80	12.52	7.72	.6166	3.6685	1.2531	4.5970	6.834
-MID	6.93	16.94	10.01	.5909	2.7113	1.2531	3.3975	5.057
-END	4.23	9.19	4.96	.5397	4.9978	1.2531	6.2627	10.751
6-BEG	4.22	8.98	4.76	.5301	5.1147	1.2531	6.4091	11.204
-MID	4.29	13.84	9.55	.6900	3.3186	1.2531	4.1585	5.578
-END	4.44	11.79	7.35	.6234	3.8957	1.2531	4.8816	7.226

Material: SS316
Temperature = 1015°F
S_U = 57.554 ksi
$S_A = 3 \times S_m$ = 45.93 ksi

1-See Figure 3-2 for elbow locations.

TABLE 3-4. PHTS 24" COLD LEG

LOCATION[1]	σ_{cn} (CYCLE 11-U)	σ_c (CYCLE 15-U)	σ_{cs} ($\sigma_c - \sigma_{cn}$)	K (σ_{cs}/σ_c)	DESIGN MARGIN DM	NOMINAL MARGIN NM	ACTUAL MARGIN AM	SEISMIC ONLY MARGIN SOM
1-BEG	3.42	14.44	11.02	.7632	3.2202	1.2361	3.9806	4.905
-MID	4.07	18.20	14.13	.7764	2.5549	1.2361	3.1582	3.780
-END	3.55	7.25	3.7	.5103	6.4138	1.2361	7.9283	14.577
2-BEG	3.72	9.77	6.05	.6192	4.7595	1.2361	5.8833	8.886
-MID	3.56	13.97	10.41	.7452	3.3286	1.2361	4.1145	5.179
-END	3.39	11.71	8.32	.7105	3.9710	1.2361	4.9086	6.501
3-BEG	3.44	15.49	12.05	.778	3.0019	1.2361	3.7108	4.484
-MID	3.53	18.54	15.01	.8096	2.5081	1.2361	3.1003	3.594
-END	3.58	11.26	7.68	.6821	4.1297	1.2361	5.1048	7.018
4-BEG	3.79	12.44	8.65	.6953	3.7379	1.2361	4.6206	6.207
-MID	5.89	17.78	11.89	.6687	2.6153	1.2361	3.2328	4.339
-END	3.82	8.59	4.77	.5553	5.4133	1.2361	6.6915	11.249
5-BEG	3.25	10.3	7.05	.6845	4.5146	1.2361	5.5806	7.692
-MID	3.24	12.74	9.5	.7457	3.6499	1.2361	4.5118	5.709
-END	3.71	10.03	6.32	.6301	4.6361	1.2361	5.7308	8.508
6-BEG	4.04	10.60	6.56	.6189	4.3868	1.2361	5.4226	8.146
-MID	4.75	16.03	11.28	.7037	2.9008	1.2361	3.5858	4.675
-END	3.70	11.45	7.75	.6769	4.0611	1.2361	5.0201	6.939
7-BEG	4.37	12.90	8.53	.6612	3.6047	1.2361	4.4558	6.227
-MID	4.94	19.97	15.03	.7526	2.3285	1.2361	2.8783	3.496
-END	4.63	14.02	9.39	.6698	3.3167	1.2361	4.0999	5.628
8-BEG	3.22	14.47	11.25	.7775	3.2135	1.2361	3.9724	4.823
-MID	3.24	23.28	20.04	.8608	1.9974	1.2361	2.4691	2.707
-END	4.26	17.89	13.63	.7619	2.5992	1.2361	3.2130	3.905
9-BEG	4.50	13.52	9.02	.6672	3.4393	1.2361	4.2515	5.873
-MID	6.78	15.73	8.95	.5690	2.9561	1.2361	3.6542	5.665
-END	5.77	18.85	13.08	.6939	2.4668	1.2361	3.0493	3.953

Material: SS304
Temperature = 750°F
S_U = 57.48 ksi
$S_A = 3 \times S_m$ = 46.50 ksi

1-See Figure 3-3 for elbow locations.

TABLE 3-5. IHTS 24" HOT LEG

LOCATION[1]	σ_{cn} (CYCLE 17-U)	σ_c (CYCLE 19-U)	σ_{cs} $(\sigma_c - \sigma_{cn})$	K (σ_{cs}/σ_c)	DESIGN MARGIN DM	NOMINAL MARGIN NM	ACTUAL MARGIN AM	SEISMIC ONLY MARGIN SOM
1-BEG	6.88	13.35	6.47	.4846	3.4764	1.2868	4.4736	8.168
-MID	10.47	16.85	6.38	.3786	2.7543	1.2868	3.5443	7.720
-END	6.13	11.47	5.34	.4656	4.0462	1.2868	5.2068	10.035
2-BEG	6.21	10.70	4.49	.4196	4.3374	1.2868	5.5815	11.919
-MID	7.89	12.53	4.64	.3703	3.7039	1.2868	4.7663	11.171
-END	6.09	8.99	2.90	.3226	5.1624	1.2868	6.6432	18.493
3-BEG	6.15	8.28	2.13	.2572	5.6051	1.2868	7.2128	25.156
-MID	8.35	11.50	3.15	.2739	4.0357	1.2868	5.1932	16.309
-END	6.01	9.23	3.22	.3489	5.0282	1.2868	6.4704	16.679
4-BEG	5.98	8.82	2.84	.322	5.2619	1.2868	6.7712	18.923
-MID	6.66	9.87	3.21	.3252	4.7021	1.2868	6.0509	16.532
-END	6.66	10.28	3.62	.3521	4.5146	1.2868	5.8095	14.660
5-BEG	5.73	8.94	3.21	.3591	5.1913	1.2868	6.6803	16.818
-MID	5.87	9.72	3.85	.3961	4.7747	1.2868	6.1442	13.987
-END	6.18	10.05	3.87	.3851	4.6179	1.2868	5.9425	13.834

Material: 316SS
Temperature = 965°F
S_U = 59.22 ksi
$S_A = 3 \times S_m$ = 46.41 ksi

1-See Figure 3-4 for elbow locations.

TABLE 3-6. IHTS 24" COLD LEG

LOCATION[1]	σ_{cn} (CYCLE 1-U)	σ_c (CYCLE 18-U)	σ_{cs} $(\sigma_c - \sigma_{cn})$	K (σ_{cs}/σ_c)	DESIGN MARGIN DM	NOMINAL MARGIN NM	ACTUAL MARGIN AM	SEISMIC ONLY MARGIN SOM
1-BEG	6.24	11.42	5.18	.4536	4.1874	1.2091	5.0629	9.957
-MID	6.44	14.39	7.95	.5525	3.3231	1.2091	4.0179	6.462
-END	6.60	11.51	4.91	.4266	4.1546	1.2091	5.0233	10.431
2-BEG	7.14	13.33	6.19	.4644	3.5874	1.2091	4.3374	8.187
-MID	9.64	15.69	6.05	.3856	3.0478	1.2091	3.6850	7.963
-END	6.70	10.58	3.88	.3667	4.5198	1.2091	5.4648	13.176
3-BEG	6.76	10.52	3.76	.3574	4.5456	1.2091	5.4960	13.580
-MID	7.39	13.84	6.45	.4660	3.4552	1.2091	4.1776	7.819
-END	6.99	12.81	5.82	.4543	3.7330	1.2091	4.5135	8.734
4-BEG	6.45	11.31	4.86	.4297	4.2281	1.2091	5.1121	10.570
-MID	6.72	14.94	8.22	.5502	3.2008	1.2091	3.8700	6.216
-END	6.85	11.82	4.97	.4205	4.0457	1.2091	4.8915	10.254
5-BEG	6.31	12.27	5.96	.4857	3.8973	1.2091	4.7121	8.643
-MID	6.41	16.09	9.68	.6016	2.9720	1.2091	3.5934	5.311
-END	6.54	11.85	5.31	.4481	4.0354	1.2091	4.8792	9.657
6-BEG	6.39	11.33	4.94	.4360	4.2207	1.2091	5.1031	10.411
-MID	6.86	15.42	8.56	.5551	3.1012	1.2091	3.7495	5.953
-END	6.50	12.14	5.64	.4646	3.9390	1.2091	4.7626	9.099

Material: SS304
Temperature = 690°F
S_U = 57.818 ksi
$S_A = 3 \times S_m$ = 47.82 ksi

1-See Figure 3-5 for elbow locations.

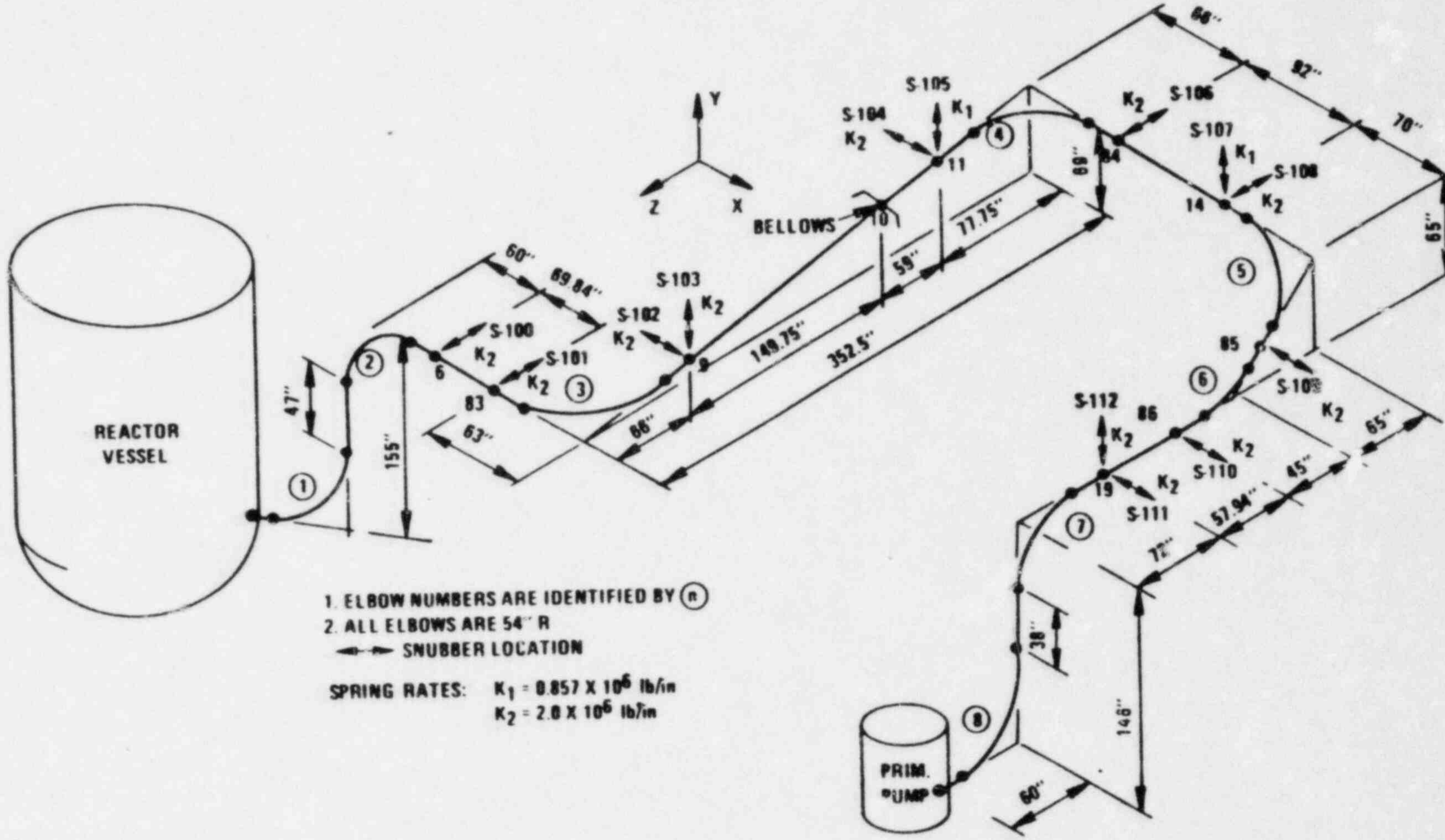


Figure 3-1 36" Primary Hot Leg Loop 1 Seismic Model

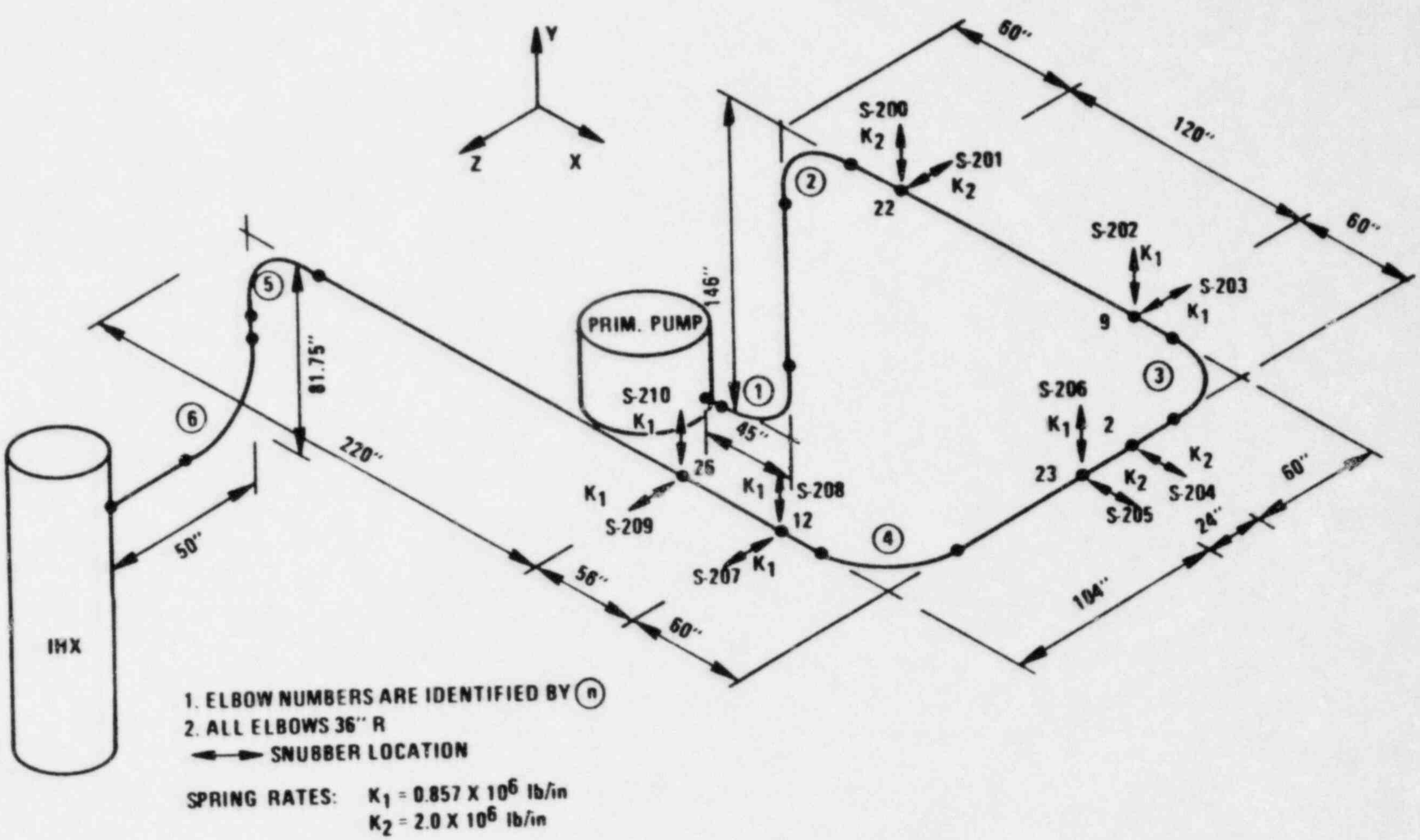


Figure 3-2 24" Primary Hot Leg Loops 1, 2 & 3 Seismic Model

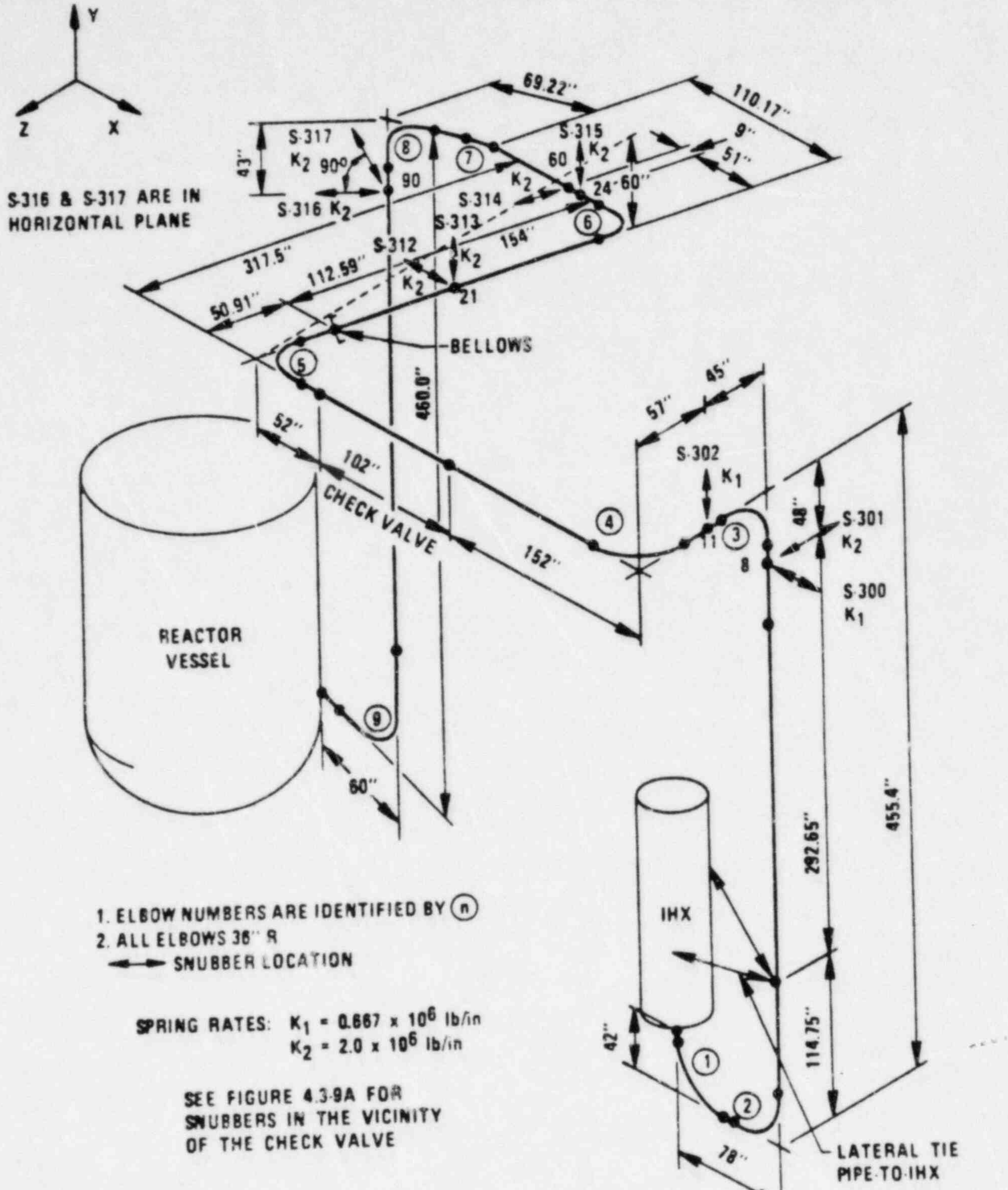


Figure 3-3 24" Primary Cold Leg Loop 1 Seismic Model

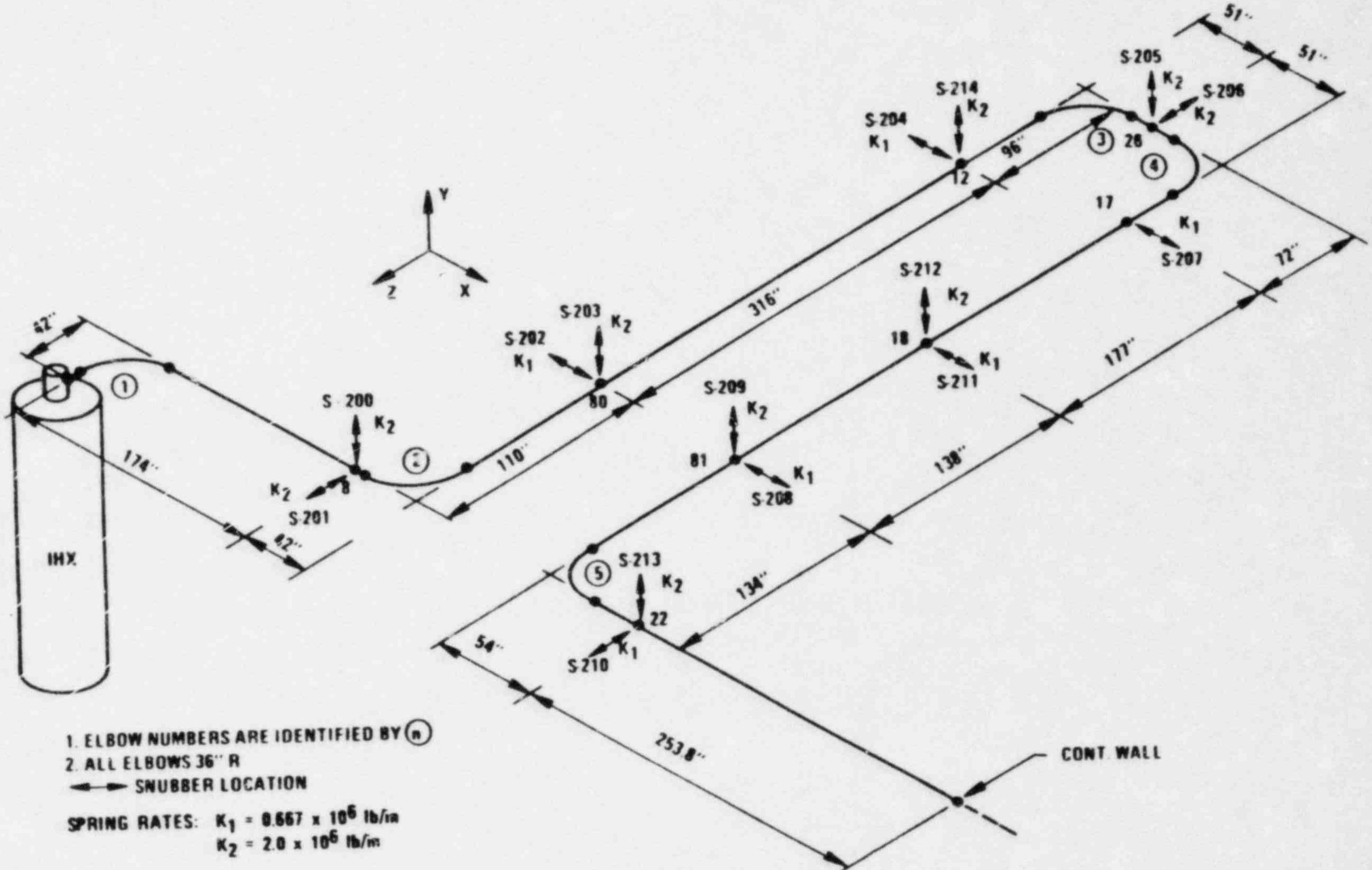


Figure 3-4 24" Intermediate Hot Leg Loop 1 Seismic Model

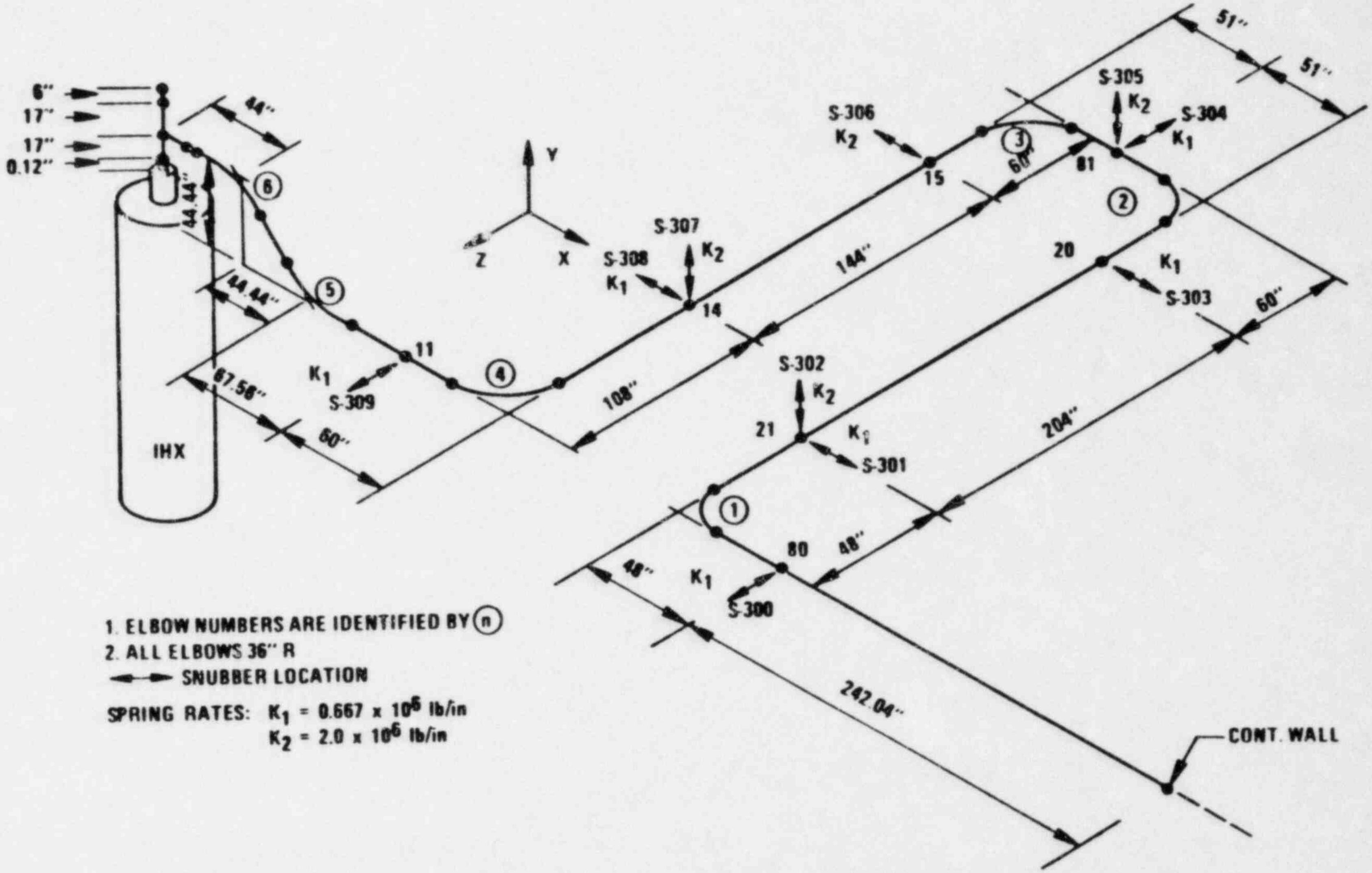


Figure 3-5 24" Intermediate Cold Leg Loop 1 Seismic Model

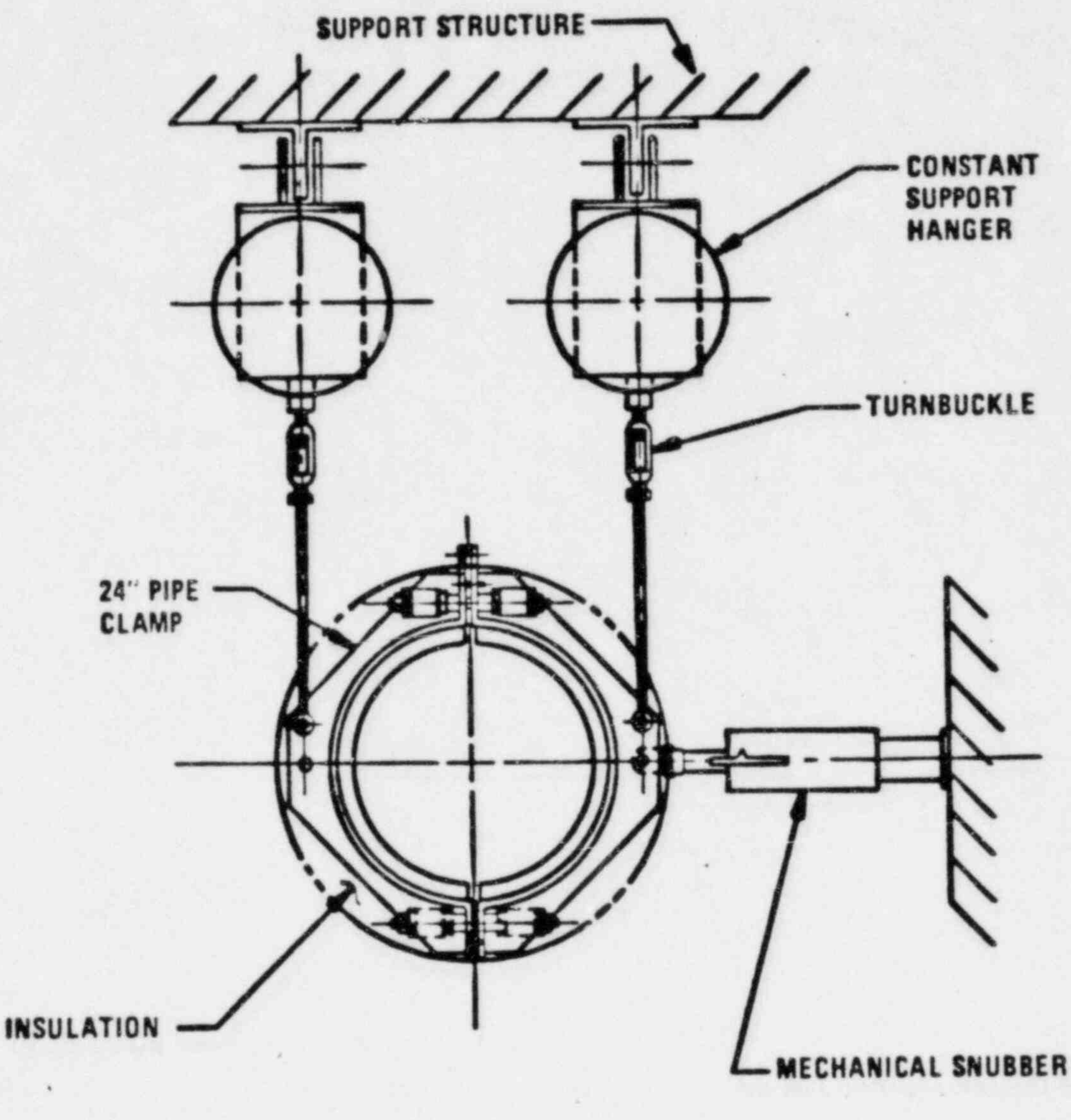


Figure 3-6. **Typical 24" Pipe Restraint Assembly for CRBRP**

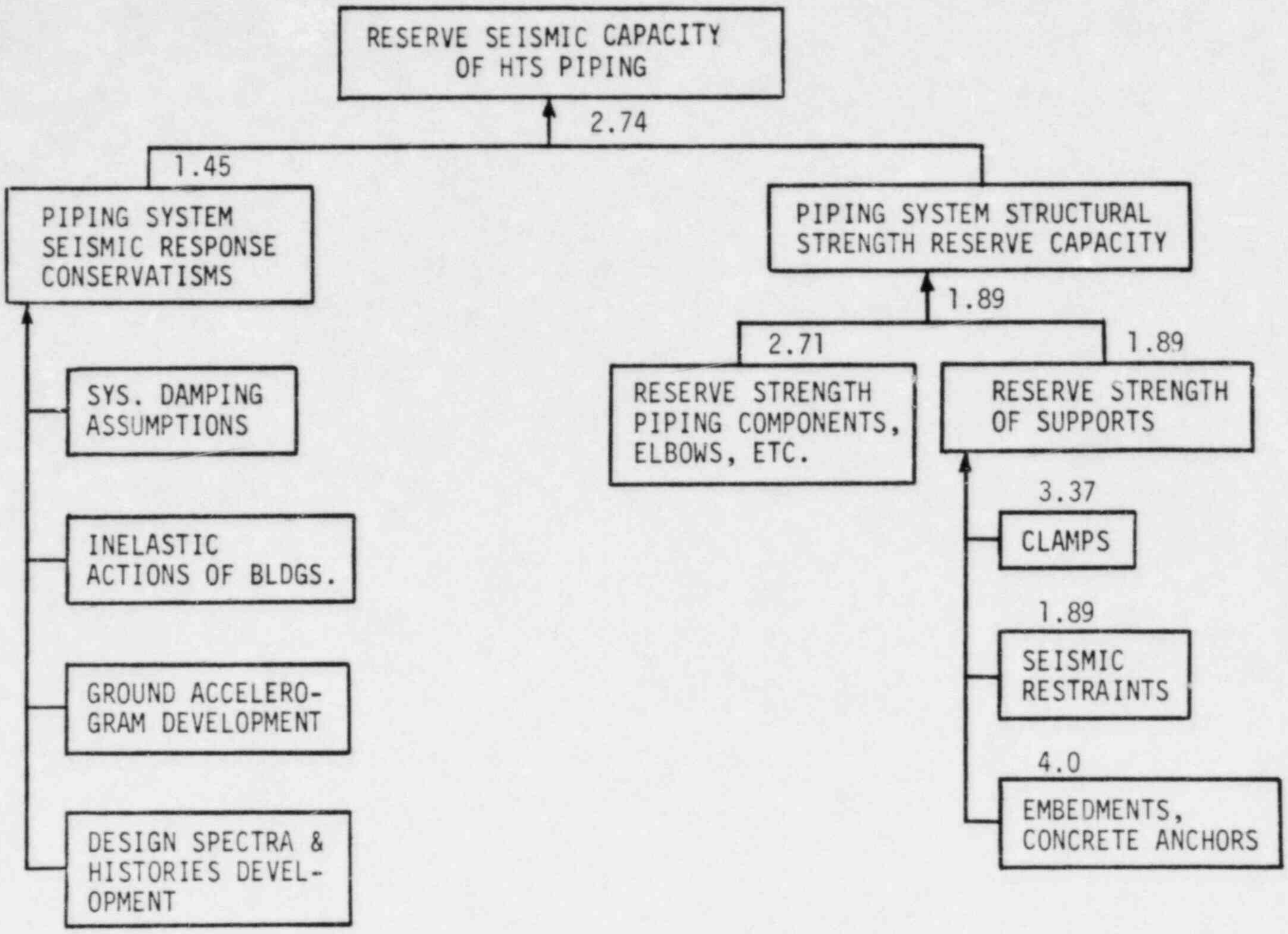


FIGURE 3-7

CRBRP HTS PIPING SYSTEM MINIMUM
RESERVE SEISMIC CAPACITY RESULTS

4.0 SUMMARY AND CONCLUSIONS

The inherent reserve capacity of the CRBRP heat transport system large-diameter incontainment has been determined using the approach developed by Rodabaugh and Desai in NUREG/CR-2137. The sources of reserve seismic capacity were divided into the following three broad categories:

(a) Conservative predictions of the piping seismic response,

(b) Conservative definitions of structural and functional performance limits, and

(c) Reserve seismic capacity incorporated by means of designer/analyst conversatisms.

Reserve seismic capacities from Items (a) and (b) were considered in arriving at seismic margins for the piping system. Reserve seismic capacities from Item (c) are listed and discussed, but not quantified.

The reserve seismic margin was determined by combining the design margin for the SSE event and the nominal margin (margin between ASME Code allowable and ultimate failure). The various margins were defined as follows:

$$\text{Design Margin (DM)} = \frac{\text{Allowable Stress}}{\text{Calculated Stress}} = \frac{S_A}{\sigma_c}$$

$$\text{Nominal Margin (NM)} = \frac{\text{Ult. Stress}}{\text{Allowable Stress}} = \frac{S_u}{S_A}$$

The actual or combined margin was determined from the product of the above two margins, or:

$$\text{Actual Margin (AM)} = \text{DM} \times \text{NM} = \frac{S_u}{\sigma_c}$$

If k is defined as the ratio of seismic-only stress or load to the total calculated stress (σ_c), the seismic only margin (SOM) was determined as follows:

$$\text{SOM} = \frac{(\text{NM} \times \text{DM} - 1)}{k} + 1.0$$

This margin was used directly to determine the reserve seismic capacity of the HTS piping system.

The reserve strength capacity for the HTS piping system was dependent on seismic-only margins (SOMs) for the piping components (elbows, tees, etc.) and the piping restraints system. The reserve margin calculations for the piping restraints system accounted for the behavior of the pipe clamps, restraints (or snubbers), and the embedments (concrete anchor bolts). The minimum reserve strength capacities obtained for these components are listed below:

(a) Piping Components = 2.71

(b) Clamp = 3.37

(c) Snubbers = 1.89

(d) Embedments = 4.0

In addition to the strength reserves, conservatism was introduced into the piping seismic response predictions. These result from such items as (a) system damping assumptions, (b) development of ground acceleration, (c) reduction of floor response spectra (or time histories) due to inelastic action of the buildings and (d) development of design response spectra (or time histories). The net effects of these items are responsible for a 1.45 factor on predicted seismic responses.

Combining the results for the reserve strengths and the response predictions conservatisms, gives an overall reserve seismic capacity of 2.74, which translates into a reserve margin earthquake of 0.685 g's.

5.0 REFERENCES

1. NUREG/CR-2137, "Realistic Seismic Design Margins of Pumps, Valves and Piping", E. C. Rodabaugh and K. D. Desai, June 1981.

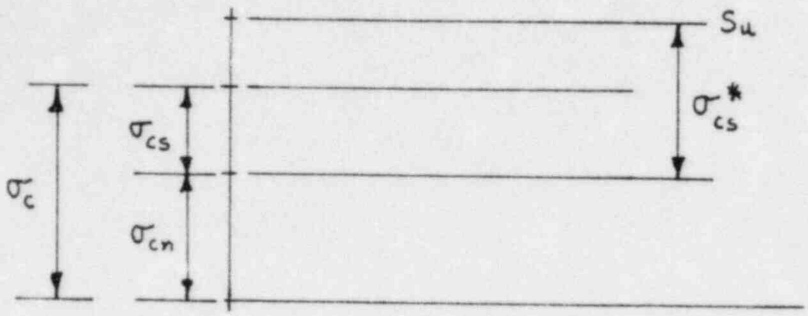
2. "CRBRP Reserve Seismic Margins", ACRS Presentation on February 11, 1983, A. Morrone.

3. ASME Boiler and Pressure Vessel Code, 1974, Section III, Nuclear Power Plant Components, with Addenda through Summer 1975.

4. TID-26666, Nuclear Systems Material Handbook.

APPENDIX A

DERIVATION OF SEISMIC-ONLY MARGIN (SOM)



Thus, $SOM = \frac{\sigma_{cs}^*}{\sigma_{cs}} = \frac{S_u - \sigma_{cn}}{\sigma_{cs}}$

$$= \frac{S_u - (\sigma_c - \sigma_{cs})}{\sigma_{cs}}$$

$$= \frac{\frac{S_u}{\sigma_c} - (1 - \frac{\sigma_{cs}}{\sigma_c})}{\sigma_{cs}/\sigma_c} \quad \text{if } k = \sigma_{cs}/\sigma_c$$

$$= \frac{AM - (1-k)}{k}$$

$$= \frac{(AM-1)}{k} + 1$$

or, $SOM = \frac{(NM \cdot DM - 1)}{k} + 1$