QUAD CITIES NUCLEAR STATION, UNITS 1 and 2
DRESDEN NUCLEAR STATION, UNITS 2 and 3

ALTERNATE SEISMIC EVALUATION CRITERIA/METHODOLOGY

Prepared for:

NUCLEAR REGULATORY COMMISSION

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1.0 INTRODUCTION

This document proposes a set of alternate criteria and methodologies for use on the Dresden and Quad Cities Stations to evaluate seismic events. These alternates are a supplement to the current FSAR criteria and methodologies, which are retained as the principal design basis. Only piping systems are addressed in this document.

Both Stations were originally designed in the late 60's and early 70's, using the design techniques of that period. Since that time, there have been considerable advancements in dynamic analysis and design methods, particularly over the last five years. In general, these advanced methods show that previous methods overpredict the response of piping systems to a seismic event. This has resulted in complex support systems which actually reduce the maintainability and reliability of the piping systems. Such complex support systems also reduce the desirable ability of piping systems to behave in a ductile manner during normal operations. The purpose of this document is to apply these advancements to Dresden and Quad Cities, in a manner consistent with the current FSAR criteria and methodologies.

Three alternates to the current FSAR criteria and methodologies have been developed. Each alternative retains at least the same design margins as the current criteria, where design margin is defined as (allowable - actual)/allowable. Each alternative is also a discrete package such that features within one alternative may not be used with all or some features from another alternative. Taken together with the current FSAR criteria and methodologies, these alternatives represent a comprehensive and consistent package of design techniques for Dresden and Quad Cities. One of the alternates is appropriate only for interim operation, i.e., until the next scheduled refueling outage. The conclusions reached using this interim operation alternate must be confirmed by one of the other criteria/methodologies in order to justify long-term operation. The current FSAR criteria, or either of the other two alternatives, may be used for new designs or for continued operation evaluations.

2.0 METHODOLOGY

The following paragraphs define alternate methods of analysis. Section 4 provides a convenient summary of those methods and criteria which will be used together.

2.1 Load Generation

The in-structure floor response spectra developed using the methods described in the Quad Cities/Dresden FSARs will be used for subsystem analysis. Alternatively, for the Reactor Building and Turbine Building, these spectra may be refined by using the following methods. These methods reflect techniques not available at the time that the original analyses were performed.

2.1.1 Soil-Structure Interaction

Refined SSI analyses will be performed to generate new floor response spectra. These analyses will explicitly include a continuum representation for soil with frequency-dependent soil impedances, as discussed, for example, in References 11-21. The free field motion will be applied at the level of the foundation, both for surface-founded and embedded structures. Floor spectra will be broadened to include variations in soil properties.

2.1.2 Direct Generation Method

New floor response spectra may be calculated using the direct generation method as described, for example, in Reference 8. This method can consider the effects of tuned primary and secondary structures. This method has been validated by the time history method.

2.2 Large Bore Piping Analysis Methods

Large bore piping analyses will consider the effects of pressure, thermal, deadweight, hydraulic transients and seismic loadings. Present FSAR analysis methods include time history, uniform (envelope) spectra and static-equivalent methods. The proposed linear methods augment the above with recent data on damping and multilevel response spectral analysis.

2.2.1 Linear Analysis Methods

In general, the envelope response spectra method will be used. Should more precise analysis methods be warranted, then the multiple level response spectra (independent support motion analysis) can be employed.

2.2.1.1 Envelope Response Spectra Method

This method is the most commonly used method of piping analysis.

Direction/Mode Combinations

The three directions of earthquake motions will be combined by SRSS, as per Regulatory Guide 1.92. Modes will be combined by SRSS, as described in NUREG 1061, Volume 4, page 2-3. Missing mass effects, to account for the contribution of modes above the dynamic analysis cutoff frequency (high frequency modes), will be considered using methodology consistent with volume 4, Appendix B, of NUREG 1061.

Peak Shifting

The spectra peak shifting methodology, as outlined in Reference [2], may be adopted in this analysis.

Damping

PVRC recommended damping values, as outlined in Reference [5], will be used in this analysis.

Seismic Anchor Motions

Seismic Anchor Motion (SAM) effects on pipe stresses will be evaluated, if applicable. SAM effects on pipe support loads will be combined with inertia effects by SRSS method, as described in Volume 4 of Reference [7].

2.2.1.2 Multiple Level Response Spectra Method

This method is a commonly used method of piping analysis. The method will remove some conservatism introduced in the envelope response spectra method, when the input spectra at different levels in the structure have wide variations.

Direction/Mode/Level Combinations

Modes and the three directions of earthquake will be combined as explained above. Response due to individual levels of support motion will be combined by absolute sum unless the inputs are from different structures or from phase uncorrelated motions in the same structure . In the latter case, SRSS will be used.

Damping

The methodology described in Subsection 2.2.1.1 will be used.

Seismic Anchor Motion

The methodology described in Subsection 2.2.1.1 will be used.

2.2.2 Nonlinear Analysis Methods (Energy Balance)

General

The energy balance method will compare the earthquake energy input to the piping to the strain capacity of the piping. If the pipe strains meet the acceptance criteria, the pipe will be shown to be functional. The energy balance method will be used as an interim checking method only.

Damping

The method described in Subsection 2.2.1.1 will apply.

2.3 Small Bore Piping and Tubing

The small bore piping and tubing analysis for Quad Cities/Dresden was performed with walkdowns and chart methods. As an alternative, small bore piping and tubing may be evaluated using the analysis methods described in Section 2.2.

2.4 Pipe Supports

Pipe supports will be evaluated against the criteria in Section 3.3. If a support has yielded or failed, the piping will be reevaluated to determine whether it can maintain functionality. The adjacent supports will be reevaluated to determine whether they can support the additional load.

3.0 ALTERNATE DESIGN CRITERIA

3.1 Large Bore Piping

Present Criteria

The FSAR design criteria for piping is USAS B31.1, 1967, as follows:

1. pressure + weight = Sh
2. pressure + weight + OBE = 1.2Sh
3. pressure + weight + DBE = Sy
4. thermal expansion = Sa
5. pressure + weight + thermal expansionn = Sh + Sa

where Sh, Sa and Sy are taken from USAS B31.1, 1967. Load combinations and criteria for Torus attached piping are extensively described in Reference 10 for Dresden, with similar combinations and criteria for Quad Cities.

In lieu of equations (2) and (3) above, an alternate criteria is proposed similar to that described in Reference 7, Volume 2, Section 2.5. This criteria is described below.

Proposed Alternate Criteria (Non-Linear)

The large bore piping criteria are based on the requirement that the piping systems remain functional. Piping is functional if it maintains its rated flow. The criterion used to evaluate piping capacity is strain criterion.

The strain criterion states that the elastically calculated piping stress, as defined for the DBE Service Condition, is to be modified by an elastic/plastic correction factor, K, and converted to strain.

$$\frac{PD_o}{4t} + i\,\frac{M_a + M_b}{Z} = \sigma$$

$$\frac{K\sigma}{E} = e < .01$$

where

- P = Internal maximum operating pressure, psig
- D_o = Outside diameter of pipe, in
- t = Nominal wall thickness of pipe, in
- Z = Section modulus, in^3
- i = Stress intensification factor as listed in Appendix D of USAS B31.1, 1967 [6]
- M_a = Resultant moment due to gravity loads, in-lbs
- M_b = Resultant moment due to design inertia, as calculated by linear elastic methods, in-lbs
- K = Elastic/Plastic correction factor, calculated based on para. NB-3228.5 of Section III of the ASME B&PV code [1]
- E = Young's modulus at design temperature
- σ = Elastically calculated stress
- e = Strain (Limited to 1% for both carbon and stainless steel piping).

In addition to the strain criterion, the piping is checked to ensure sufficient cyclic margin, assuming 5 cycles of DBE loading and 50 cycles of OBE loading and using Markl's original fatigue equation with a seismic usage of .12. This results in:

$$\frac{i\ M_B}{Z} = 28 \text{ ksi (OBE inertia + SAM)}$$

$$\frac{i\ M_C}{Z} = 55 \text{ ksi (DBE inertia + SAM)}$$

The FSAR stress allowables for carbon steel piping are 18 ksi for equation 2 and 35 ksi for equation 3. Thus, the strain criterion above increases the allowables approximately 50%.

In cases where the energy balance method is used, the piping strain criterion can be used. The allowable strains in piping components are again one percent strain for carbon and stainless steel.

3.2 Small Bore Piping and Tubing

Rigorous stress criteria can be used to qualify small bore piping and tubing. These criteria are described in Section 3.1.

3.3 Pipe Supports

Present Criteria

The FSAR design criteria for pipe supports is the AISC manual [4] for structural steel used in supports or SP-58 and SP-69 for component supports [9]. The current load combinations and criteria are:

6. deadweight + thermal = S
7. deadweight + thermal + OBE = S
8. deadweight + thermal + DBE = 1.33S

where S is the standard allowable from AISC or manufacturer's data. Load combinations and criteria for Torus attached piping supports are extensivey described in Reference 10. Concrete anchor bolts use a safety factor of 4 (wedge) or 5 (shell) for all conditions.

In lieu of equations (6) (7) and (8) above, an alternate criteria is proposed to take advantage of recent test data on materials.

Proposed Alternate Criteria

The proposed pipe support criteria for the normal, OBE, and DBE conditions are developed for use with:

- Structural steel in pipe supports
- Concrete expansion anchor bolts

The criteria are presented in Table 3.3-1. The following subsections discuss the criteria in more detail.

3.3.1 Structural Steel Used in Pipe Support Design

The capacity of structural steel components are obtained by applying the design requirements for structural steel members. These are described in the AISC Manual for Steel Construction [4].

In applying the AISC rules, a departure will be taken for the qualification of steel supports. AISC values for material yield stress will be increased by 20 percent to represent the average rather than the lower bound yield stress and strain rate effects. This overstrength is based on the yield stress test results reported in Reference [3]. This allowance will be credited for only those materials at each site for which test results are applicable.

As an alternative to the linear criteria for support design, a non-linear approach, allowing support yielding, will be followed. In this approach, the allowable ductility is limited to three. It is calculated by comparing the elastically calculated loads to the resistance capacity (based on the plastic section capacity) of the member. In this case, however, no increase in material yield (as described above) will be used. Also, the effect of yielding on the piping will be evaluated.

3.3.2 Concrete Expansion Anchor Bolts

The allowable loads for concrete expansion anchor bolts will be obtained by using the manufacturer's reported ultimate capacity with a minimum factor of safety of four on wedge type anchor bolts and five on shell type anchor bolts. On a case-by-case basis, a factor of safety of two (2) will be used to qualify existing supports. A factor of safety of two will only be used if there are a minimum of four support anchor bolts, with not more than half the bolts subjected simultaneously to tension loads, and if the adjacent supports carrying load in the same direction are qualified elastically.

Table 3.3-1

DESIGN CRITERIA FOR PIPE AND EQUIPMENT SUPPORTS

Component Type	Stress Condition	Criteria[1]
Structural Steel	Tension, Bending	1.20 x AISC (2)
	Shear	1.20 x AISC (2)
	Compression	AISC
	Web Crippling	AISC
	Welds	AISC
Concrete Anchor Bolts	Shear, Tension, With Linear Interaction	F_u/F.S where F.S. = 4 for wedge type = 5 for shell type (see note 3).

Where F_u = Ultimate strength at design temperature

F.S. = Factor of safety

Notes:

(1) The above criteria apply to elastically evaluated pipe supports.

(2) The 20 percent increase in yield stress may be taken if substantiated by CMTR data.

(3) On a case-by-case basis, F.S. = 2 will be used (see Section 3.3.2).

4.0 SUMMARY

Three supplements to the FSAR criteria and methodologies have been presented. The FSAR continues to be the principal design basis, while these supplements offer alternatives which can be employed to evaluate or design piping systems. One of the alternatives is strictly a functionality criteria, which can be used to perform interim operation evaluations. Interim operation means until the next scheduled refueling outage. The remaining alternatives and the principal design basis apply to long-term, or continued, operation. Each alternative is exclusive. Some features from one alternate cannot be used with all or some of the features from another alternate. The following paragraphs briefly describe the alternatives.

Alternate 1 (Table 4-1) proposes additional piping analysis methods over the present FSAR, using PVRC damping, which should reduce the number of supports required for new system additions or the loads on existing systems. In order to generate spectra at PVRC damping ratios, Alternate 1 allows use of spectra-spectra (direct) generation techniques. In addition, Alternate 1 proposes three modifications to support criteria which do not reduce the number of supports, but will reduce the need for modification to existing supports. It is expected that Alternate 1 would be used in the modification of a full system, with savings in construction cost and exposures and a small increase in engineering.

Alternate 2 (Table 4-2) provides advanced criteria and methodology, reducing complex support systems and improving system reliability and maintenance. It proposes use of a strain criterion for piping acceptance which provides approximately 50% relief from present allowables. Regeneration of response spectra using modern soil-structure interaction is also proposed. Finally, allowance of pipe support yielding is proposed under Alternate 2.

Alternate 3 (Table 4-3), short term (functionality), does not reduce supports or loading, but allows the plants to continue operation while more detailed analyses are made. The benefits of the short-term methodology are relaxed support allowables and a simplified method to check piping acceptance.

The three tables summarize all the methods/criteria proposed and the combinations in which they can be used. Taken together, they present a comprehensive list of criteria for piping and pipe support design and represent methods which are consistent with the original plant design basis.

TABLE 4-1

SEISMIC/PIPING ANALYSIS/PIPE SUPPORT CRITERIA/METHODOLOGY

ALTERNATE 1 - LINEAR METHODOLOGY

Seismic Input	either	a) Present FSAR spectra @ .5% damping,
	or	b) Generation of additional in-structure spectra at higher damping directly from existing spectra.
Piping Analysis	-	Piping will be analyzed as follows:
	either	a) FSAR dyanamic methods, which are, briefly, as follows: i) damping equal to 0.5%. ii) modal combination by SRSS. iii) direction combination is the largest horizontal response added absolutely with the vertical. iv) dynamic analysis of all modes up to 33HZ. v) spectrum used is that which envelopes the piping center of mass. vi) acceptance criteria is B31.1, 1967.
	or	b) Static equivalent FSAR methods, as explained in amendments 19/20 to the FSAR
	or	c) Response spectrum analysis with all the following requirements. i) PVRC damping values (ASME Code Case N-411). ii) Modal combination by SRSS. iii) Direction combination by Reg Guide 1.92. iv) Modal analysis to 33Hz, with higher frequency effects considered. v) Spectrum used equal to the envelope of all attachment points. vi) Present FSAR stress acceptance criteria (B31.1,1967). vii) Peak shifting per ASME Code Case N397 is allowed.

SEISMIC/PIPING ANALYSIS/PIPE SUPPORT CRITERIA/METHODOLOGY

ALTERNATE 1 - LINEAR METHODOLOGY

or d) Use of multi-level response spectra with the following requirements:

- i) PVRC damping
- ii) Modal combination by SRSS.
- iii) Direction combination by Reg Guide 1.92
- iv) Level combination by absolute sum, or by SRSS if the input motions are uncorrelated.
- v) Modal analysis to 33Hz, with higher frequency effects considered.
- vi) Present FSAR stress acceptance criteria

Pipe Support Design - Pipe supports will be designed using:

either a) Criteria defined in the FSAR, briefly summarized as follows:

- i) normal loads plus OBE limited to standard AISC or manufacturer allowables.
- ii) normal loads plus DBE limited to 1.33 times standard allowables.
- iii) anchor bolts limited to a safety factor of 4(wedge) or 5(shell) under all loading conditions.
- iv) material yield strengths equal to those published in the applicable AISC code.
- v) SAM, if applicable, combined ABS with inertia.

or in lieu of a) iii)-v), use b), c), and d) below.

b) A FS of 2 on anchor bolts under DBE loading provided

i) There are 4 bolts minimum in the plate, no more than half in tension.
ii) Adjacent supports in the same direction are qualified elastically and use a FS of 4 or 5 on all of their bolts.
iii) The overall FS is 4 or 5 for the base plate.

c) A yield strength of 1.2 times code minimum yield for those materials for which statistical results are applicable. No increase in weld strength above code minimums is allowed.

d) If applicable, SAM and inertia loads combined by SRSS.

FIGURE 4-1

ALTERNATE I - LINEAR METHODOLOGY
(REFER TO TABLE 4-1)

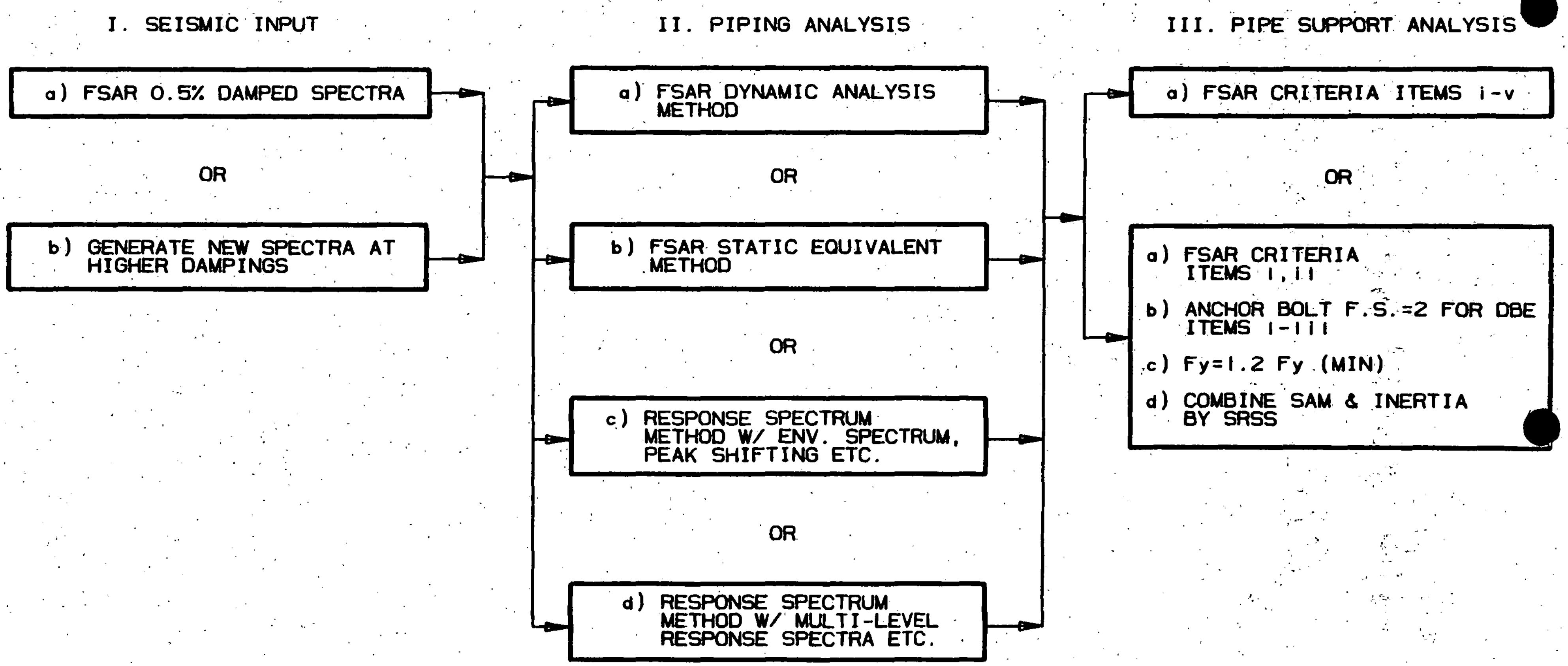


TABLE 4-2

SEISMIC/PIPING ANALYSIS/PIPE SUPPORT CRITERIA/METHODOLOGY

ALTERNATE 2 - LINEAR/NON-LINEAR METHODOLOGY

Seismic Input		a) Regenerate building spectra as follows: i) Develop 3 dimensional building models ii) Account for soil-structure interaction, considering frequency dependent soil springs and cross-coupling between building horizontal and rocking modes
	and	b) Generation of additional in-structure spectra directly from the spectra in a) above.
Piping Analysis		- Piping will be analyzed as follows:
	either	a) FSAR dynamic methods, which are, briefly, as follows i) damping equal to 0.5%. ii) modal combination by SRSS. iii) direction combination is the largest horizontal response added absolutely with the vertical. iv) dynamic analysis of all modes up to 33HZ. v) spectrum used is that which envelopes the piping center of mass. vi) acceptance criteria is B31.1, 1967.
	or	b) FSAR static equivalent methods, as explained in amendments 19/20 to the FSAR.

TABLE 4-2 (Cont'd)

SEISMIC/PIPING ANALYSIS/PIPE SUPPORT CRITERIA/METHODOLOGY

ALTERNATE 2 - LINEAR/NON-LINEAR METHODOLOGY

or c) Response spectrum analysis with all the following requirements.

- i) PVRC damping values (ASME Code Case N-411).
- ii) Modal combination by SRSS.
- iii) Direction combination by Reg Guide 1.92.
- iv) Modal analysis to 33Hz, with higher frequency effects considered.
- v) Spectrum used equal to the envelope of all attachment points.
- vi) Present FSAR stress acceptance criteria (B31.1,1967).
- vii) Peak shifting per ASME Code Case N397 is allowed.

or d) Use of multi-level response spectra with the following requirements:

- i) PVRC damping
- ii) Modal combination by SRSS.
- iii) Direction combination by Reg Guide 1.92
- iv) Level combination by absolute sum, or by SRSS if the input motions are uncorrelated.
- v) Modal analysis to 33Hz, with higher frequency effects considered.
- vi) Present FSAR stress acceptance criteria

or e) As an option to c) vi) and d) vi) above, 1% maximum strain acceptance criteria under DBE load conditions.

<u>TABLE 4-2</u> (Cont'd)

SEISMIC/PIPING ANALYSIS/PIPE SUPPORT CRITERIA/METHODOLOGY

ALTERNATE 2 - LINEAR/NON-LINEAR METHODOLOGY

Pipe Support Design		- Pipe supports will be designed using: a) Criteria defined in the FSAR, briefly summarized as follows: i) normal loads plus OBE limited to standard AISC or manufacturer allowables. ii) normal loads plus DBE limited to 1.33 times standard allowables. iii) anchor bolts limited to a safety factor of 4(wedge) or 5(shell) under all loading conditions. iv) material yield strengths equal to those published in the appiance AISC code. v) SAM, if applicable, combined ABS with inertia
	or	in lieu of a) iii-v, use b), c), and d) below. b) A FS of 2 on anchor bolts under DBE loading provided i) There are 4 bolts minimum in the plate, no more than half in tension. ii) Adjacent supports in the same direction are qualified elastically and use a FS of 4 or 5 on all of their bolts. iii) The overall FS is 4 or 5 for the base plate. c) A yield strength of 1.2 times code minimum yield for those materials for which statistical results are applicable. No increase in weld strength above code minimums is allowed.

TABLE 4-2 (Cont'd)

SEISMIC/PIPING ANALYSIS/PIPE SUPPORT CRITERIA/METHODOLOGY

ALTERNATE 2 - LINEAR/NON-LINEAR METHODOLOGY

d) If applicable, SAM and inertia loads combined by SRSS.

or

In lieu of a-d above,

e) Elastic/plastic methods

i) normal plus OBE limited to standard allowables.
ii) normal plus DBE limited by a ductility less than 3 check.
iii) piping and adjacent supports checked for effects of excessive deformation at the elastic/plastic support.
iv) SAM, if appicable, combined with inertia by SRSS.

FIGURE 4-2

ALTERNATE 2 - LINEAR/ NON-LINEAR METHODOLOGY
(REFER TO TABLE 4-2)

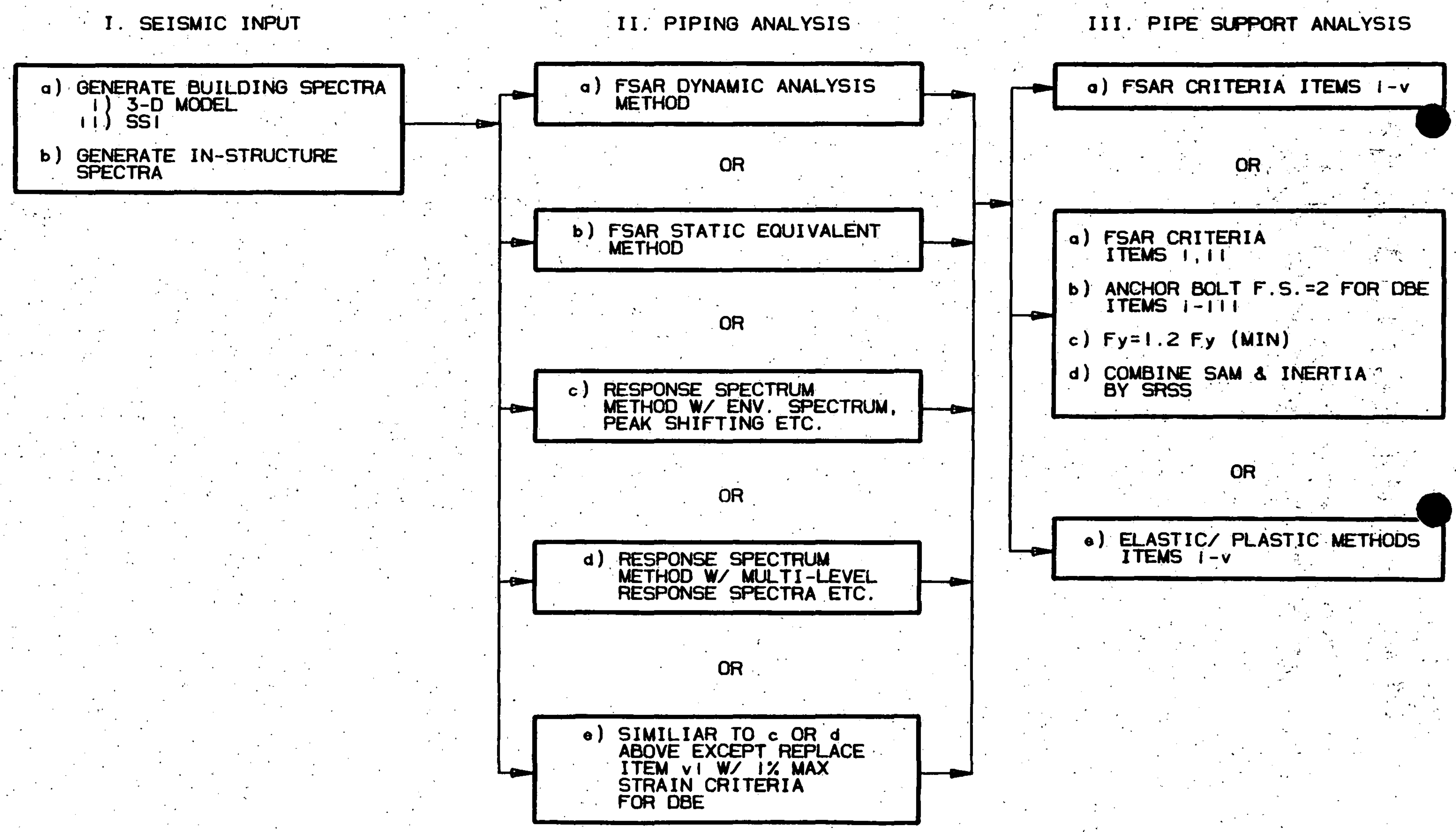


TABLE 4-3

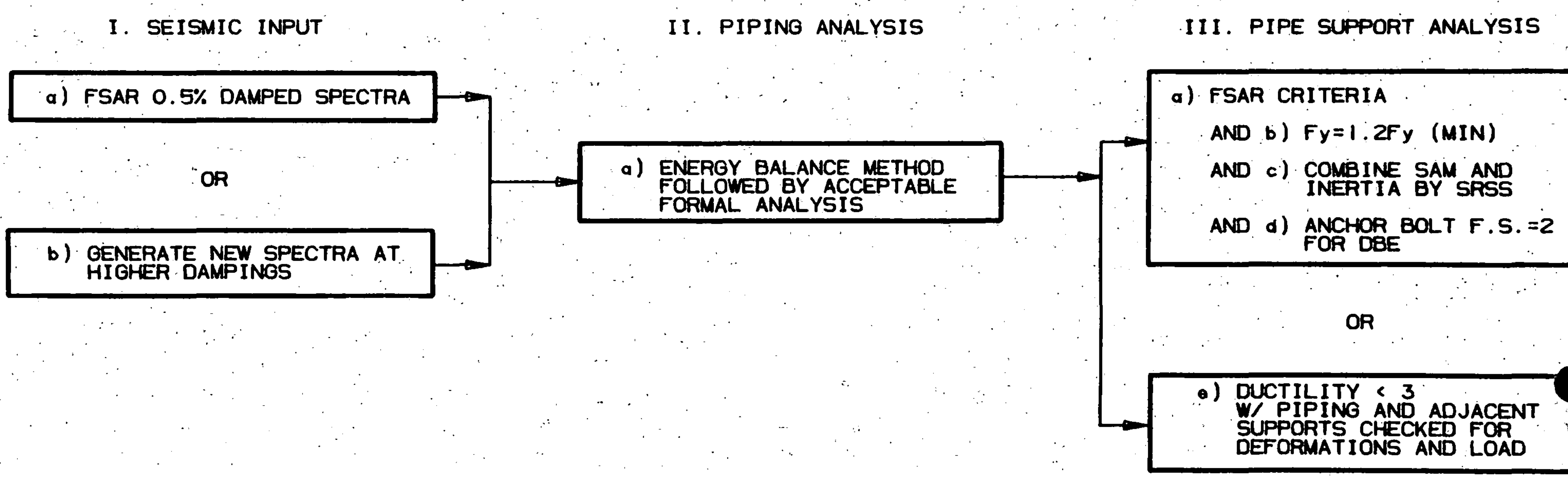
ALTERNATE 3 - SHORT TERM (FUNCTIONALITY) CRITERIA/METHODOLOGY

Seismic Input	either	a) Present FSAR spectra @ .5% damping.
	or	b) Additional spectra generated at higher damping by accepted methods.
Piping Analysis	-	Piping will be analyzed by
		a) For short term operation, use energy balance techniques to show piping acceptance. This must be followed by formal analysis against the alternative accepted at that time. Also, supports adjacent to the "failed" support must be acceptable for the increased loads.
Pipe Support Design	-	Pipe supports will be checked using:
	either	a) Present FSAR methods.
	and	b) A yield strength of 1.2 times code minimum yield, with no increase permitted for welds.
	and	c) SAM, if applicable, combined with inertia SRSS.
	and	d) A FS of 2 on anchor bolts under DBE loading, with the requirements noted in Table 4-2.
	or	e) Ductility less than 3 under normal plus DBE loading with adjacent supports and piping checked for the effect of deformation.

Note the above approaches are short term only. The piping and supports must be rechecked using whichever alternative has been licensed.

FIGURE 4-3

ALTERNATE 3 - INTERIM OPERATION (FUNCTIONALITY) CRITERIA/ METHODOLOGY
(REFER TO TABLE 4-3)



5.0 REFERENCES

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4. Manual of Steel Construction, AISC, Chicago, Sixth, Seventh, and Eighth Editions.

5. PVRC Technical Committee on Piping Systems of the Pressure Vessel Research Committee, Progress Report on Damping Values, 1983a (Incorporated to ASME B&PV Code, Code Case No. 411).

6. USAS B31.1 Code for Pressure Piping, 1967.

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13. Tabatabaie-Raissi, M., "The Flexible Volume Method for Dynamic Soil-Structure Interaction Analysis", PhD. Dissertation, Department of Civil Engineering, University of California, Berkeley, February 1982.

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A.3.1 Large Bore Piping

The piping fatigue criterion provides for a stress allowable of 28 ksi and 55 ksi for the OBE and DBE stresses, respectively. A similar technique has been suggested to the NRC in [A.1]. In lieu of this stress criterion, a piping strain criterion may be used. The allowable strains in piping components are one percent strain for carbon and stainless steel. A justification for this value is based on the following factors:

Testing Programs

Numerous testing programs have been conducted, or are in progress, to study the behavior of piping systems under severe seismic or other dynamic loading.

High-excitation testing to benchmark dynamic nonlinear analysis methods for piping is currently being conducted for EPRI [A.3]. One test has been completed on a 4-inch Schedule 40 ferritic steel piping system. The primary purpose of this initial test was to demonstrate the functional response of dynamically exciting piping systems to levels far in excess of current Code allowables. The maximum dynamic excitation level corresponded to seven to eleven times a typical Design Spectrum event for a plant in a low to moderate seismic region. This excitation level results in stresses which exceed Level D Code allowable stress limits by a factor greater than three. Permanent and visible deformations were observed, but there was no plastic collapse or loss of structural integrity in the pressurized piping. Input accelerations were greater than 14g, and response accelerations were greater than 21g in one elbow.

A limited amount of dynamic component testing has also been conducted [A.4, A.5, A.6]. A Japanese experimental study tested carbon and stainless steel elbows and tees well into the plastic range with harmonic excitation. No failure or structural instability was observed in any of these tests.

Dynamic versus Static Loadings

Current ASME Code elastic analysis stress response acceptance criteria do not differentiate between dynamic (such as seismic) and static loading events. Inelastic response of piping systems to seismic and other dynamic loadings is significantly different than inelastic response to static loadings of the same magnitude. Studies have demonstrated that the margin against failure of piping systems is significantly greater for dynamic loads than for static loads when the elastically computed responses are held to the same allowable stresses [A.7].

Operating Plant Experience

The El Centro Steam Plant [A.8] has been subjected to strong (over 0.5 g) earthquake motion without disruption to operation. Similarly, Lawrence Livermore Laboratory and the Hamaoka Units in Japan have been subjected to moderate earthquake motion without disruption of operation. Numerous other electrical and process plants have been subject to earthquakes with no failure of piping systems, as supported by the ongoing findings of the SQUG program. SRV discharge piping systems in both PWR and BWR plants have also been subjected to dynamic loads without damage, where conventional analysis indicates dynamic stresses well above current Code allowables.

Strain Limit for High Temperature Piping

In Code Case N-47 titled "Class 1 Component in Elevated Temperature Service" of ASME Boiler and Pressure Vessel Code [A.9], the deformation and strain limits for structural integrity are two percent strain at the surface due to bending.

Categorization of Seismic Loading

In current ASME Code rules, seismic inertia stress is categorized as the primary stress and evaluated in the Code Equation 9. Studies have been performed, or are in progress, to investigate the licensing support for the elimination of the primary stress requirement for seismic loading on piping [A.10]. If seismic inertia stress is categorized as the secondary stress, the fatigue limit shown above is an appropriate measure and the strain criteria ensures elastic shakedown.

A.3.3.1 Structural Steel

In a report by Smith et. al. [A.11], it is reported that the measured yield strength of over 60,000 specimens is found to be, on the average, 18 percent greater than the ASME Code reported minimum yield strength. Material overstrength is also substantiated in other references [A.12, A.13, A.14]. These allowances will be credited for those materials for which the test results are available.

Appendix A: References

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