7.0 ADVANCED ANALYSIS TECHNIQUES

7.1 Objective

When the seismic analysis of a piping system shows that certain piping components are overstressed, it is best to modify the design and support arrangement to reduce stresses to within the allowable limits. This may not be feasible in a few cases, such as seismic retrofit when the cost of modifications would be prohibitive. In this case, the designer may consider a more advanced, less conservative, analytical technique to try to solve the overstress. Several advanced techniques are presented in this chapter.

7.2 More Accurate SIF's

When the overstress is at a fitting, it may be due to the use of an overly conservative stress intensification factor (SIF) "i". Significant testing and analyses have been conducted in the 1980's and 1990's to obtain a better estimate of SIF's. In many cases this work has shown that the SIF values used in ASME B31 are conservative (larger than they should be). To take advantage of more precise SIF's, the Designer should refer to ASME Boiler & Pressure Vessel Code Section III Code Cases, and research bulletins published by the Pressure Vessel Research Council (PVRC, New York).

7.3 Analysis Technique for Faulted Loads

The rules of ASME B&PV Code Section III, Div.1 (Rules for Construction of Nuclear Facility Components), Appendix F (Rules for Evaluation of Service Loading with Level D Service Limit) may be followed to evaluate the seismic adequacy of piping system and components of good construction (per ASME B31 Pressure Piping Codes). The stress limits of ASME III Appendix F apply to one-time faulted events, as is the case for a Design Basis Earthquake. Some distortion of the piping may occur, but would not significantly affect flow area. Components and equipment have to be qualified separately for operability.

7.3.1 Elastic Analysis

Where the piping system is elastically analyzed, the stress-strain relationship is linear $\sigma = E\varepsilon$ and above yield the calculated stress is fictitious (Figure 7.3-1 (a)). The stress limits are

$$T < 42\%\ S_U$$
$$P_m < 70\%\ S_U$$
$$P_L + P_b < 105\%\ S_U$$

T = average primary shear across a section loaded in pure sheer, psi
S_U = minimum ultimate strength of the material, psi
P_m = primary membrane stress, psi
P_L = primary general or local membrane stress, psi

P_b = primary bending stress, psi

7.3.2 Plastic Analysis

The component model includes the actual stress-strain curve, including strain hardening in the plastic range (Figure 7.3-1 (b)). The stress limits using plastic analysis are

$$T < 42\%\ S_U$$
$$P_m < 70\%\ S_U$$
$$P_{max} < 90\%\ S_U$$

P_{max} = maximum primary stress intensity at any location, psi

7.3.3 Limit Analysis Collapse Load

The piping system elements are modeled as elastic-perfectly plastic ("limit analysis" assumes zero rigidity – or hinge mechanism - beyond yield. Because a piping system is redundant, several hinges may have to form before a span of the piping system collapses, as illustrated in Figure 7.3-1(c)). The load limit using static collapse analysis is

$$F < 90\%\ F_{LAC}$$

F = maximum permitted load applied to the system, lb
F_{LAC} = limit analysis collapse load, load that would cause a failure mechanism of an elastic-perfectly plastic model, lb

7.3.4 Plastic Analysis Collapse Load

The system is analyzed by plastic analysis (Figure 7.3-1(d)). The load limit using plastic instability analysis is

$$F < F_{PAC}$$

F_{PAC} = plastic analysis collapse load obtained by intersection of line Φ_2 with the stress-strain curve of the material, where [ASME BPV III Div.1 NB-3213]

$$\Phi_2 = \tan^{-1} (2 \tan\Phi_1)$$

7.3.5 Plastic Instability Load

The system is analyzed by plastic analysis (Figure 7.3-1(e)). The load limit using plastic instability analysis is

$$F < 70\%\ F_{PI}$$

F_{PI} = plastic instability load, where unbound plastic deformation can occur, lb

7.4 Alternative Methods

Several alternative methods for seismic analysis and qualification of piping systems have been compiled and published [WRC 379]. Alternative analysis techniques include: (1) Limit load, (2) Stress-strain correlation, (3) Synthetic average, (4) Time history analysis, (5) Energy balance, (6) Load coefficient, (7) Volumetric strain energy, (8) Secondary stress, (9) Inelastic response spectrum, (10) Dynamic / static margin, (11) fatigue – ratcheting, and (12) Incremental hinge methods. These methods could be investigated for the resolution of seismic overstress conditions.

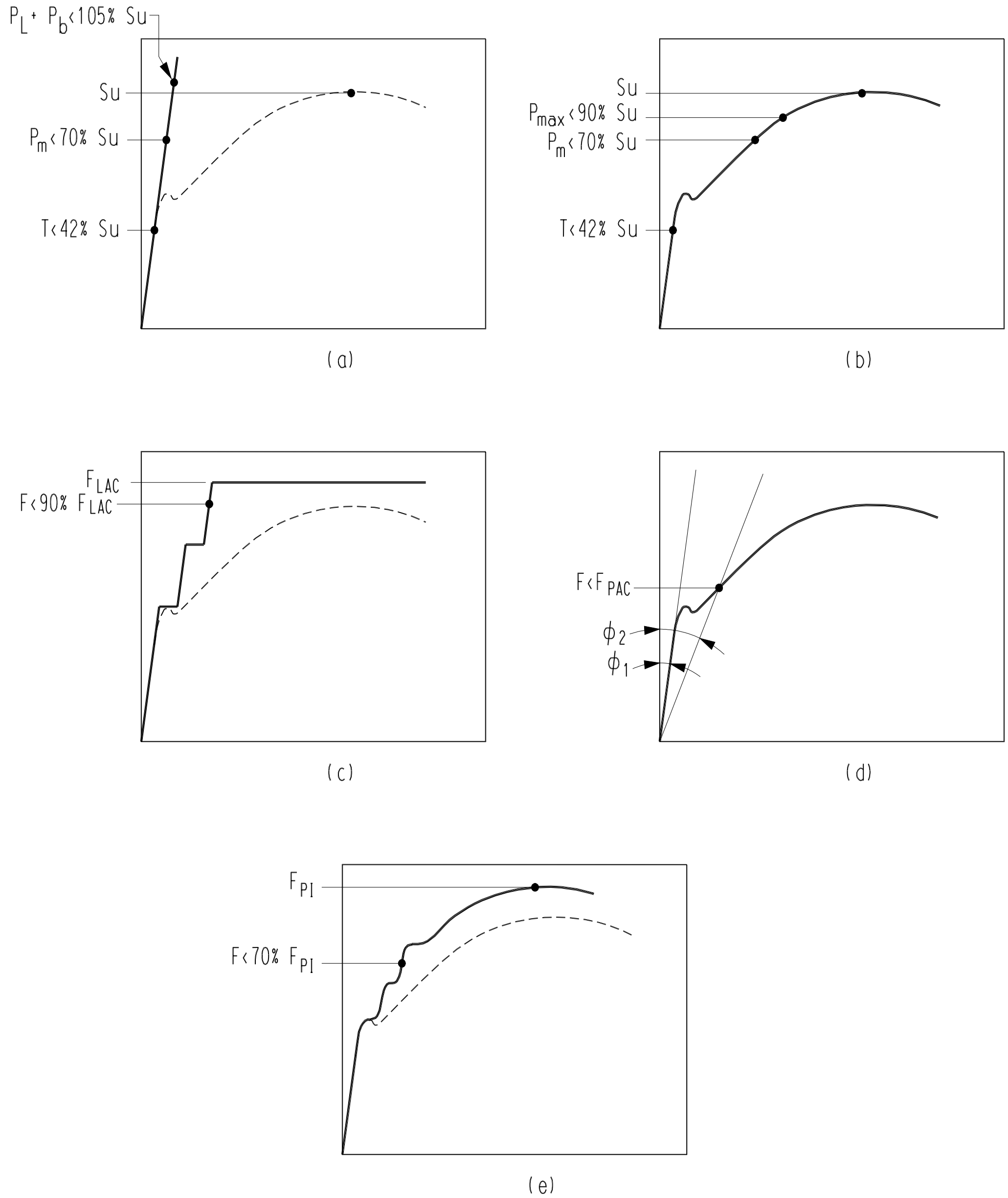

Figure 7.3-1 Analysis Techniques for Faulted Loads