5.0 MODELING FOR ANALYSIS

5.1 Structural Boundaries

The model of a piping system typically begins and ends at anchor points, such as stiff equipment nozzles or fully constrained wall penetrations. These are points that effectively restrain all six degrees of freedom. If there are no anchors, the model could become very large and difficult to analyze. One solution would be to “decouple” and “overlap” the model.

“Decoupling” means that branch lines are excluded from the model of the main line. This can be done reasonably well if the branch line is small compared to the run pipe, for example

$$I_{run} > 25\ I_{branch}$$

Then, in the model of the branch line, it will be necessary to apply the run displacements at the decoupled point. In the run pipe analysis and the branch pipe analysis, it is necessary to include the branch stress intensification factor.

Also, the response spectrum for the branch analysis should consider the elevation of support attachments on the run pipe, close to the branch.

“Overlap” means that the model is terminated at a support point A and the next continuing model starts at a point B within the first model, goes through point A and continues on. The pipe section AB is common to both models. It is an overlap region that should contain at least two bi-lateral supports.

5.2 Model Accuracy

The accuracy of the piping model must be commensurate with the analysis technique and the seismic qualification margins. With static calculations, the precision on span lengths and weights is not as important as with seismic response spectra analysis, which relies on the prediction of system and component frequency. Also, if the seismic loads are well below the allowable limits, the accuracy of the model and predictions is less important than for systems stressed close to the allowed limit. Therefore, only general guidelines are provided here [ASME III, NCIG-05, WRC 316]. The precision of the model must be decided on a case basis.

(1) In no case should the tolerance affect the order of fittings and components along the line

(2) The direction of the pipe centerline should be within 10^o, and models of valve operators should be oriented within 15^o of the field installed condition.

(3) Restraint locations should be within 6” for NPS 2 and smaller (small bore piping), and the greater of 12” or one pipe diameter for pipe larger than NPS 2. These tolerances should be reduced by half close to active equipment. For stress analysis and load predictions, the direction of action of restraints should be within 10^o.

(4) The tolerance on pipe segment length is indicated in Table 5.2-1.

Pipe Segment length	Tolerance
Up to 5’	3”
5’ to 10’	6”
10’ to 15’	9”
15’ to 20’	12”
20’ to 25’	15”
25’ to 30’	18”
30’ to 35’	21”
Over 35’	24”

Table 5.2-1 Tolerance on Pipe Segment Length

5.3 Equipment Flexibility

Piping system models often originate or terminate at equipment nozzles (pump, heat exchanger, vessel or tank nozzle). These nozzle connections are not infinitely rigid; they are not “perfect anchors” for two reasons:

(1) The “local” flexibility of the nozzle itself and the equipment shell.

(2) The “global” flexibility of the equipment supports (legs, skirt, concrete anchor bolts, etc.).

5.3.1 Local Shell Flexibility

To illustrate the effect of vessel or tank shell flexibility consider the following simple example: A 12 ft long, 6” sch.40 gas pipe is connected at one end to a vessel nozzle, and at the other end the pipe is simply supported vertically. The vessel is 10 ft diameter and 10 ft high, with the radial nozzle at mid-height.

Four cases are analyzed: In the first case, the vessel is infinitely stiff; in the second, third and fourth cases the vessel has a wall thickness of 0.5”, 0.4” and 0.3” respectively, which makes the vessel shell more and more flexible (able to bend when subject to piping loads). A 6” displacement is imposed at the simply supported end. Table 5.3.1-1 summarizes the results of the analysis for this “simple” configuration.

Table 5.3.1-1 illustrates two important facts, which complicate modeling and design by analysis of piping systems:

(1) Including the equipment shell flexibility in the analysis reduced the reaction loads at the nozzle. However, under the same applied load, the pipe displacement is larger if the equipment flexibility is included in the analysis. Because of this contradictory effect (an increase in displacement and a decrease in nozzle loads), it is difficult to predict whether simplifying the

model by excluding the vessel shell flexibility will be over-predict or under-predict the loads in the system.

(d) Including the equipment shell flexibility in the analysis will reduce the system's natural frequency. This could result in either larger or smaller seismic loads, depending on the relative position of the response spectral peak frequency compared to the piping natural frequency. Therefore, it is again difficult to predict whether excluding the vessel shell flexibility will be conservative in design.

	Anchor	0.5" Wall	0.4" Wall	0.3" Wall
Radial k (kips/in) (1,4)	infinite	136	86	47
Circumf. k (ft-kip/deg) (1,4)	infinite	5	3	1
Longit. k (ft-kip/deg) (1,4)	infinite	8	5	3
Shear at nozzle (kips) (2)	5	1	0.8	0.5
Moment at nozzle (ft-kip) (2)	57	14	10	6
First mode freq. (Hz) (3)	12	4	3	2

Notes:
(1) "Radial k" is the linear stiffness of the vessel shell against a radial push or pull. "Circumferential k" is the bending stiffness of the vessel shell against bending along the circumference. "Longitudinal k" is the bending stiffness of the vessel shell against bending along the length of the vessel.
(2) "Shear and moment at nozzle" is the load at the vessel-pipe nozzle due to the 6" displacement imposed at the simply supported end of the pipe.
(3) "First mode frequency" is the natural vibration frequency of the pipe connected to the vessel at one end and vertically simply supported at the other end. This first mode (natural) frequency corresponds to a lateral "fixed (vessel end) – free (vertical support end)" vibration of the 12 ft long 6" pipe span.
(4) The vessel shell stiffness is calculated following the method of Welding Research Council (WRC) Bulletin 297. This stiffness calculation is part of most modern piping analysis software.

Table 5.3.1-1 Static and Dynamic Effects of Vessel Shell Flexibility

In summary, equipment flexibility will affect the displacements and loads in a piping system. The significance of this effect is difficult to predict, it is therefore advisable to include the equipment's flexibility in the analytical model of the piping system.

5.3.2 Global Equipment Flexibility

The global flexibility of equipment is due to (a) the equipment's bending flexibility, and (b) the equipment's support flexibility. In the simple case of a cylindrical vessel mounted on four legs made of steel angles, the global flexibility of the vessel is

$$1/K = 1/K_V + 1/K_L$$

K = total global stiffness of vessel assembly, lb/in
K_V = vessel stiffness, lb/in
K_L = total stiffness of support legs, lb/in

$$K_V = 12\ EI / H^3$$

E = Young's modulus, psi
I = moment of inertia of cylindrical vessel shell, in^4
H = height from support-vessel attachment to vessel's center of gravity, in

$$K_L = 4\ K_I$$

K_I = bending stiffness of individual leg in the direction of seismic input, lb/in

Other equipment stiffness and frequencies can be obtained from structural dynamics handbooks and publications [ASCE Petrochem, Pickey, Blevins].

5.4 Seismic Restraint Stiffness and Gap

5.4.1 Restraint Stiffness

New seismic restraints should be designed to be "stiff", which in practice means that they should not deform more than 1/8" under seismic load. In these cases, the supports can be modeled as rigid in the direction of action. For restraints that are not as rigid, the exact seismic analysis solution would require the support stiffness to be included in the analysis model. This could however cause unnecessary iterations when the installed support (and therefore its stiffness) does not exactly match the design. To avoid the complications and costs of an iterative reconciliation process, restraint stiffness should be modeled with approximate, rounded values. For example, supports may be grouped into three categories: Very stiff (K > 1E6 lb/in), stiff (K = 1E5 to 1E6 lb/in), and soft (K < 1E5 lb/in). Restraints within each category would then be assigned a nominal stiffness, with the very stiff supports modeled as rigid.

At the same time, all supports should be designed to a minimum seismic load, for example 100 times the pipe size. For example, a seismic restraint on a 6" line would be sized for the calculated seismic load, but no less than 600 lb. This would avoid future iterations on lightly loaded supports if the support stiffness or location changed, causing a change in seismic load.

5.4.2 Restraint Gap

It is common practice to provide a small gap between pipe and structural support steel to avoid binding during normal operation. Such a gap represents a rattle point during a seismic event. As a result there will be a local impact between the pipe and the support during the earthquake. The exact solution to this impact problem depends on several factors: the gap size, the pipe and support local and global stiffness, the pipe velocity at impact, the pipe and support mass, the elasticity of pipe and support [Kumar]. The study of earthquake damage indicates that this type of local impact through support gaps is mostly of little consequence, but needs to be considered in the following cases:

(a) The pipe span contains impact sensitive components (instruments, valve actuator controllers, etc.).

(b) A gas pipeline operating at high pressure (hoop stress close to 72% of yield), where a surface dent or gouge could cause the pipe to fail.
(c) For large gaps, in the order of the pipe radius for 2” NPS and smaller pipe, and 2” gap for larger pipe, the restraint load calculated on the basis of zero gap may be amplified by an impact factor of 2 to account for impact.

5.5 Flexibility of Fittings

The response of a piping system to a dynamic excitation, such as an earthquake, depends on the system’s natural frequencies, which – in turn – depend on the flexibility of its fittings (tees, elbows, bends, etc.). The flexibility of fittings must therefore be correctly modeled. The flexibility of a pipe fitting is defined by a flexibility factor “k” provided in the applicable ASME B31 code, and is automatically calculated in piping analysis computer codes. The difficulty arises when using non-standard fittings, for which a flexibility factor is not provided in the ASME B31 code. This is for example the case for grooved or flared pipe joints. If the fitting is “stiff” relative to the pipe span, the seismic load will tend to deflect the pipe as a uniformly loaded beam, in a U shape. If the fitting is “flexible” relative to the pipe span, the same seismic load will tend to deflect the span in a V shape, with hinge rotation around the joint. This difference in behavior can not be ignored, particularly if excessive rotation of the pipe at the joint can cause the joint to leak or rupture.

5.6 Stress Intensification Factors

The bending stress in a pipe fitting is obtained by multiplying the nominal bending stress in a straight pipe M/Z (M = moment, Z = section modulus) by a stress intensification factor “i” (SIF) specific to the fitting. This approach, and the first SIF’s, were developed in the 1940’s and 1950’s by Markl, George and Rodabaugh [Markl, et. al., Rodabaugh]. Stress intensification factors for standard (ASME B16) fittings are listed in the applicable ASME B31 Code. The SIF for fittings not listed in ASME B31 may be obtained by fatigue testing, similar to Markl’s tests.