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Technical Report 9

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AP1000 Standard Combined License Technical Report

Containment Vessel Design Adjacent to Large Penetrations

Revision 3

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1.0 INTRODUCTION

This report summarizes the final design of containment vessel elements (reinforcement) adjacent to concentrated masses (penetrations). The requirements for these analyses are identified in the AP1000 Design Control Document (DCD, Reference 1) Subsection 3.8.2.4.1.2. The completion of these analyses is identified as COL Information Item 3.8-1 (FSER {Reference 2} Action Item 3.8.2.4.1.2-1) in DCD Subsection 3.8.6.1 to be completed by the Combined License applicant and documented in the ASME Code design report.

> COL Information Item 3.8-1: "The final design of containment vessel elements (reinforcement) adjacent to concentrated masses (penetrations) is completed by the Combined License applicant and documented in the ASME Code design report in accordance with the criteria described in subsection 3.8.2.4.1.2."

This report also describes the final design of penetration reinforcement for the main steam and feedwater penetrations.

This report also addresses the effect of extending the applicability of the AP1000 containment vessel design to soil sites. The global effects of soil sites are addressed in Reference 3. Comparisons of containment vessel response are provided in this report and demonstrate that the design for the hard rock site is also applicable at soil sites.

This report and the associated design calculations available for NRC audit will permit this Combined License information item to be closed.

The containment vessel and the penetrations are described in subsection 3.8.2 of the DCD.

The containment vessel design specification states that analyses are not required for cyclic operation. During an audit, the NRC staff had asked that this provision be confirmed based on the six (6) stipulated conditions of ASME subsection NE-3221.5(d).

Westinghouse calculation note APP-MV50-GEC-001was prepared to validate and show that the AP1000 containment vessel does not require analysis for a cyclic loading, per the ASME Section III, Division 1, Subsection NE-3221.5. A reference to this calculation has been added in Table 2-10.

2.0 TECHNICAL BACKGROUND

Westinghouse design calculations for the general portions of the containment vessel were reviewed by the NRC as part of the AP1000 design certification review. Methodology was described in the DCD (Reference 1) for more detailed analyses in the vicinity of the two equipment hatches and the two personnel airlocks. These more detailed analyses were identified to be completed by the Combined License applicant. These detailed analyses have now been completed and are summarized in this technical report. A design summary report has been prepared summarizing the design and analyses of the containment vessel.

The penetrations and penetration reinforcements are designed in accordance with the rules of ASME III, Subsection NE. The design of the large penetrations for the two equipment hatches and the two airlocks use the results of finite element analyses which consider the effect of the penetration and its dynamic response. These analyses and evaluations are described in the following sections.

2.1 3D model of containment vessel

A 3-D shell, finite element model of the containment vessel (Figure 2-1) was developed in ANSYS in order to consider the effect of the penetrations and their dynamic response. The large masses and local stiffness of the personnel locks and equipment hatches are discretely modeled. The polar crane is represented by a beam model (Figure 2-2). The bottom of the model is fixed at elevation 100' where the containment vessel is embedded in concrete.

The frequencies and mode shapes were calculated both with and without the polar crane included. The modal data without the polar crane was favorably compared to those of the axisymmetric model described in the DCD with the masses of the large penetrations smeared around the circumference, but without the mass of the polar crane.

The 3-D model was also used to solve one static load case representing the dead weight of the polar crane. The static results were favorably compared to results from the axisymmetric model for the same loading.

2.2 Dynamic analyses of 3D model

Time history seismic analyses were run to obtain the local responses of the large penetrations by applying the AP1000 ground motion time histories at the base of the containment vessel model (elevation 100'). This motion is applicable for a hard rock site as shown by the comparison in Figures 2-3 to 2-5 between the response at elevation 100' and the ground motion. This motion is also reasonable for soil sites as discussed in section 2.5.

Table 2-1 shows the maximum absolute accelerations on the axis of the four penetrations. These are given in polar coordinates along and normal to the axis of each penetration. Table 2-2 shows the equivalent static accelerations specified in the containment vessel design specification which are those obtained from the seismic analyses of the nuclear island stick models given in Table 3.7.2-6 of the DCD. As shown in Tables 2-1 and 2-2, the maximum accelerations from the time history analyses are similar to or lower than those specified in the design specification for the tangential and vertical directions. Note that the penetrations are generally on the east side so the tangential response can be compared to the north-south (X) equivalent static acceleration. In the radial direction accelerations are about 50% higher due to the shell flexibility. For the upper penetrations there is significant radial response and rotation of the airlock in the frequency range of 5 to 6 hertz. This is less noticeable for the lower penetrations due to the restraint at elevation 100'.

The equivalent static accelerations from the design specification impose an east-west global acceleration of 0.37g at elevation 112.5 and 0.54g at elevation 141.5. This is close to the radial direction since the azimuths of the centers of the penetrations range from -67 degrees to – 126 degrees (-23 to 36 degrees from east-west). The additional acceleration to be applied due to shell flexibility is the radial acceleration from Table 2-2 minus these global values as shown in Table 2-3. There is also a rotational acceleration to be considered, particularly for the airlocks which cantilever from the shell. Since the global accelerations of Table 2-2 do not cause rotational response, the full magnitudes shown in Table 2-1 are applied.

2.3 Static analyses of 3D model

Static analyses were performed on a finite element model having greater detail around the penetrations than that described in section 2.1 and used for the time history dynamic analyses in section 2.2. The mesh in the panels around the personnel locks and equipment hatches was refined using elements with a size less than 0.25 $\sqrt{(Rt)}$. Three sub-models were generated, one for the upper personnel lock, one for the upper equipment hatch, and one combined sub-model for the lower personnel lock and equipment hatch. The coarsely meshed panels around the openings in the dynamic model were replaced by the refined mesh panels. The refined model used in static analyses to evaluate the large penetrations is shown in Figure 2-6(a). The refined submodel for the upper equipment hatch is shown in Figures 2-6(b) and 2-6 (c).

Individual Load Cases

Static analysis runs were made for internal pressure, dead load (including the polar crane in the parked position), thermal loads and seismic loads. The seismic cases consider both global accelerations and local axial and rotational accelerations about the horizontal and vertical at the large penetrations. Each containment load is calculated individually in the analysis. The following loads are considered:

- Dead load
- Unit internal pressure load (1 psi internal pressure)
- Thermal load
    - Normal operation in cold weather
    - Design basis accident in hot weather
- Vessel global seismic load
    - Acceleration in N-S direction (x-axis in the model)
    - Acceleration in E-W direction (y-axis in the model)
    - Acceleration in Vertical direction (z-axis in the model)
- Local penetration seismic load
    - Acceleration in radial direction (axial direction of the penetrations)
    - Rotational acceleration about horizontal axis
    - Rotational acceleration about vertical axis

Global seismic loads were applied in three load cases using the accelerations from the nuclear island stick model given in DCD Table 3.7.2-6 (X, Y, Z parallel to the three global axes of the containment vessel model). These equivalent static accelerations vary as a function of elevation. They are applied to the model using nodal forces. The forces are calculated for each node in the model using the product of acceleration times mass at a node. The acceleration is linearly interpolated based on the elevation of the node. The mass is the total contributing mass from all the elements at the node. Seismic loads from the polar crane were also applied as equivalent static forces.

The global loads described in the previous paragraph do not include the local amplified response of the large penetrations. These amplified local responses are included separately. Three individual seismic cases consider local axial and local rotational accelerations about both horizontal and vertical axes for each of the four penetrations, making a total of twelve cases, as shown in Table 2-3. The local accelerations were applied to the mass of each large penetration and its reinforcement and a band of shell plate surrounding the reinforcement. The linear acceleration is applied parallel to the axis of the penetration. This linear acceleration is additive to the acceleration already applied to the penetration as part of the global accelerations. The rotational accelerations are applied about the horizontal and vertical axes orientated perpendicular to the axis of the penetration (tangential to the shell and vertical). The three axes, radial, tangential and vertical have their origins at the intersection of the axis of the penetration and the mid-surface of the vessel shell.

The local accelerations were applied to the model using forces acting at the penetration neck/reinforcement junction. The linear/rotational mass of the penetration, neck, reinforcement and surrounding shell was multiplied by the linear/rotational acceleration, respectively. The total force due to a local acceleration was distributed around the neck/reinforcement junction using forces acting parallel to the axis of the penetration. The distribution was uniform for the linear acceleration; and varied by the cosine and sine functions (local polar coordinates along axis of penetration) for the two rotational accelerations, respectively.

Combination of SSE loads

The twelve local analysis cases are based on the maximum radial and rotational accelerations from the time history analyses. These cases then represent the local shell response in individual modes. Global and local acceleration loads are assumed in-phase and stress results are added algebraically.

- The North-South (X) global results are combined with the local "rotation about the vertical axis" acceleration results.
- The East-West (Y) global results are combined with the "radial" local results.
- The Vertical (Z) global results are combined with the local "rotation about the horizontal axis" acceleration results.

The combined global and local seismic load cases are then combined for the three directions of input using either the square root sum of the squares method or the 100%, 40%, 40% method (as described in DCD subsection 3.7.2.6) and then added with dead weight, pressure and thermal stress results in accordance with the load combinations given in DCD Table 3.8.2-1. External pressure is scaled from the internal pressure load case. The load combinations are shown in Table 2-4. Each load combination is uniquely identified in this table and results are shown in subsequent tables using these designations.

2.4 Stress and buckling evaluation adjacent to large penetrations

2.4.1 External pressure and thermal loads

Design conditions for the containment vessel are specified as:

- Design Pressure — 59 PSIG at design temperature of 280°F
- External Pressure — 2.9 PSIG at design temperature of 70°F

Both the maximum external pressure and the temperature conditions are affected by the ambient temperature. Combinations of normal temperature and external pressure are evaluated as service conditions as follows:

Service Level A

- Dead load, uniform temperature of 70F, design external pressure of 2.9 psid
- Dead load, cold weather temperature distribution after inadvertent actuation of active containment cooling , reduced pressure of 0.9 psid after inadvertent actuation of active containment cooling in cold weather. This conservatively includes the low probability inadvertent actuation of active containment cooling in cold weather event as a normal operating condition.

Service Level D

- Dead load, uniform temperature of 70F, SSE, design external pressure of 2.9 psid
- Dead load, cold weather temperature distribution after inadvertent actuation of active containment cooling, SSE, reduced pressure of 0.9 psid after inadvertent actuation of active containment cooling in cold weather

Two temperature conditions are considered corresponding to plant operation during cold weather with the outside air temperature at the minimum value of -40F and during hot weather with the outside air temperature at 115F. The cold weather operation results in a significant temperature differential in the vicinity of the horizontal stiffener at elevation 131' 9". The vessel above the stiffener is exposed to the outside air in the upper annulus. This cold weather condition is assumed concurrent with the pressure reduction resulting from inadvertent actuation of active containment cooling and is conservatively assumed as a normal operating condition. It is evaluated during normal operation as a Service level A event. It is also evaluated under Service level D in combination with the Safe Shutdown Earthquake.

The external pressure of 0.9 psid is based on conservative analyses as described in DCD subsection 6.2.1.1.4.

2.4.2 Stress and buckling evaluation

2.4.2.1 Stress evaluation

Stresses are evaluated against the stress intensity criteria of ASME Section III, Subsection NE. Hand calculations are used to check Primary General Membrane stresses (P_m). ANSYS output is used directly to make the other ASME Code stress checks. The results of these evaluations are shown in summary tables as follows:

- Primary General Membrane stresses (P_m) – see Table 2-5.
- Primary stresses - Local Membrane (P_L) – see Table 2-6
- Primary and Secondary Stresses ($P_b + P_L + Q$) – see Tables 2-7 and 2-8

The ranges of the primary plus secondary stress intensity in the bottom head in Table 2-7 are larger than the $3S_{ml}$ limit for all cycles. These results are due to the restraint of thermal growth by the concrete at elevation 100' as shown by the stress summary in Table 2-8. These primary plus secondary stresses are evaluated using the simplified elastic-plastic analysis method in ASME Code, paragraph NE-3228.3. This evaluation showed 400 cycles of service level A with design basis accident and cold weather normal operation thermal loads are allowed. The range of primary plus secondary stress intensity limits are satisfied using simplified elastic-plastic analysis.

2.4.2.2 Buckling evaluation

Stability is evaluated against ASME Code Case N-284-1. Local stresses in the regions adjacent to the major penetrations are evaluated in accordance with paragraph 1711 of the code case. Stability is not evaluated in the reinforced penetration neck and insert plate which are substantially stiffer than the adjacent shell.

The ASME Code Case provides criteria for evaluation of shell stresses based on fairly large zones of the shell with uniform stress. ANSYS stress results were screened by applying the buckling criteria to every element in the shell within the local panels of the fine mesh around the large penetrations. Most elements satisfy the buckling criteria except for some local elements adjacent to the insert plates of the penetrations and/or the external stiffener at elevation 131′-9″. Elements that did not satisfy the criteria were then reviewed to better understand the local nature of the calculated stresses.

All cases where the evaluation of individual elements did not initially satisfy the buckling criteria are found to occur in very localized areas adjacent to the insert plates. The high stress area below the upper personnel lock also extends above and below the external stiffener. Due to the local nature of the stress in these areas, it is recognized that the buckling evaluation is very conservative when using allowable stresses for large zones of uniform stress from Code Case N-284-1. The high stresses are localized over a small sector of the circumference and a narrow band along the meridian.

Evaluations of these locations were made using two approaches. First, average stress components were used in accordance with paragraph 1711 of the Code Case. Second, theoretical buckling allowable stresses were calculated based on local buckling behavior.

- The junctions of the insert plates with the shell are discontinuity locations. Stress components are averaged over a distance of $0.5\sqrt{Rt}$ on each side of the discontinuity. The junction of the external stiffener with the shell is also a discontinuity location. The stiffener is large enough to be considered a bulkhead stiffener and as such, is assumed to provide a line of fixity. Stress components are averaged over a distance of $1.0\sqrt{Rt}$ from this stiffener.

- The size of an area of high compressive stress is considered for the theoretical buckling allowable stress calculations, i.e., the length of the shell around the circumference and the height of the shell along the meridian where the compressive stresses are high (but are also significantly reduced beyond the boundary of the area). Knowing the size of a potential buckle based on the size of this area, theoretical buckling stresses are calculated using classical shell equations. These critical stress values are reduced by capacity reduction factors and factors of safety as defined in the Code Case.

High local compression stresses also occur near the bottom tangent line of the vessel. The calculated hoop compression at this location, however, is not real because the inward deflection is prevented by the constraint of the concrete inside the containment shell up through elevation 107′-2″. For simplicity, this one directional constraint was not applied on the model.

Initial evaluations showed acceptability for all mechanical loads. Small overstresses existed when thermal stresses were combined with the stresses due to mechanical loads. Insulation was added in the vicinity of the equipment hatch and the airlock, at the operating deck level, to reduce thermal stresses. With these modifications, stresses and buckling safety factors have been shown to be within the allowable limits.

2.5 Application of AP1000 at soil sites

The containment vessel design for a hard rock site is described in DCD subsection 3.8.2. This uses seismic input from the nuclear island seismic analyses using the stick models as described in DCD subsection 3.7.2. The nuclear island seismic analyses have been updated and extended to soil sites in Reference 3. These analyses use a fixed base model in ANSYS for hard rock and SASSI for firm rock (FR), soft rock (SR), upper bound soft-to-medium soil (UB or UBSM), soft-to-medium (SM) and soft soil (SS). The models are 3D shell models for the concrete buildings and a stick model for the containment vessel.

Table 2-9 summarizes the maximum absolute acceleration at key elevations of the containment vessel. Figures 2-7 to 2-9 show floor response spectra at elevation 100' at the base of the containment vessel stick.

The second part of Table 2-9 compares the envelope of all soil cases against the design values imposed as equivalent static global accelerations. The acceleration from the controlling soil cases is shown in bold in the upper part of the table. These design values are the maximum accelerations from the nuclear island analyses of the stick model on hard rock described in the DCD. These design values exceed those from all soil cases except for the locations discussed further below which are shown in italics in the lower portion of the table.

Figure 2-10 compares the maximum member forces in the containment vessel stick model from each of the time history soil cases. The figure also shows the member forces in the stick subject to the equivalent static accelerations given in the second part of Table 2-9. The maximum member forces are enveloped by the equivalent static analysis.

Containment vessel global seismic loads

The containment vessel is designed for seismic loads by applying equivalent static accelerations at each elevation based on the maximum acceleration from the nuclear island stick models. The vessel has been evaluated for the equivalent static accelerations tabulated in DCD Table 3.7.2-6 and specified in the containment vessel design specification. These accelerations from the stick models are shown as the design values in Table 2-9.

In both horizontal directions the maximum envelope is less than the design values. In the vertical direction the hard rock results in the latest seismic analyses exceed the design values which were based on the previous hard rock analyses by about 5%. In addition at elevation 100' the soft to medium soil case is 31% higher than the stick model design values. This is due to the fundamental vertical mode of the nuclear island on the soil column. This is not significant to the design of the containment vessel since these accelerations are a relatively small contributor to the global member forces.

The global member forces from the equivalent static case exceed those from the soil cases as shown in Figure 2-10. Based on these comparisons the design acceleration values used for the global analyses are appropriate for both the hard rock and the soil sites.

Local response of large penetrations

The design in the vicinity of the large penetrations described in the previous paragraphs applies the free field ground motion at the base of the containment vessel. The comparisons shown in Figures 2-3 to 2-5 show this input motion is reasonable for the hard rock sites. Figures 2-7 to 2-9 show the floor response spectra at the base of the containment vessel from the seismic analyses on shell models for hard rock and five soil sites. The comparisons show that the free field horizontal ground motion which is similar to the hard rock response is also a reasonable assumption for all soil conditions for frequencies above 4 Hz. However, there is significant vertical amplification particularly in the 4 to 10 hertz range due to the nuclear island mass on the soil spring. Figure 2-9 shows peaks at 3.5 hertz for the soft soil, 4.5 hertz for the soft-to-medium soil and 5.5 hertz for upper bound soft-to-medium soil. These are the fundamental vertical frequencies of the nuclear island on the soil column.

The vertical amplification has only a small effect on the equipment hatches but results in significantly higher response for the airlocks which are cantilevered from the vessel shell. The fundamental frequency of the airlock is in the frequency range of 5 to 6 hertz. The floor response spectrum at elevation 100' in

Figure 2-9 shows a response of about 1.8g for the broadened envelope of the soil cases and 1.1 g for the unbroadened hard rock. This increased response was evaluated by increasing the rotational acceleration about the horizontal axis by 60%. The evaluation showed that the vessel met the stress intensity and buckling criteria with this increased response.

2.6 Main Steam and Feedwater

The main steam penetration assembly is described in DCD subsection 3.8.2.1.5 and is in DCD Figure 3.8.2-4 (Sheet 1 of 6). This penetration has an inside sleeve diameter of 57". The penetration assembly is attached to the containment vessel by a flexible bellows. The feedwater penetration assembly is similar with a sleeve diameter of 38". The penetrations are combined into a common 3 ¾" thick insert plate as shown in Figure 2-11 of this report. The insert plate also includes the penetration for the 6" diameter startup feedwater pipe. This penetration assembly is shown in DCD Figure 3.8.2-4 (Sheet 2 of 6).

The insert plate is designed in accordance with NE-3330, "Openings and Reinforcement" of the ASME Code. There are no significant loads from the main steam and feedwater piping on this insert plate since the only connection is the expansion bellows.

2.7 Other Mechanical and Electrical Penetrations

This section describes the design procedure for the penetration reinforcement for containment penetrations except the equipment hatches, personnel airlocks, main steam, feedwater and start up feedwater, which are addressed in previous sections. It includes the piping and electrical penetrations, and the fuel transfer tube. The containment vessel includes the sleeve through the shell and the thickened insert plate. Other portions of the assemblies are designed as piping and equipment.

Typical design information for the penetrations is provided in the DCD. The mechanical penetrations are listed in DCD Table 6.2.3-1. Typical details are shown in DCD Figure 3.8.2-4. Penetration assemblies, such as those shown in the upper figure on DCD Figure 3.8.2-4 (sheet 4 of 6) are ASME Class 2. Expansion bellows and guard pipes are ASME Class 2 or Class MC. The penetration assemblies are welded to sleeves that are ASME Class MC. Process piping welded directly to the vessel, such as shown in the lower figure in DCD Figure 3.8.2-4 (sheet 4 of 6) is ASME Class 2.

The material of construction is SA738 Grade B for the vessel shell, insert plates and nozzle necks of penetrations with inside diameters greater than 24". For penetrations less than 24" inside diameter and greater than 2" nominal diameter, forgings of SA350 LF2 material are used for the nozzle neck.

Penetration reinforcement is designed by the area replacement method in accordance with the requirements of ASME Section III, Division 1, Subsection NE, Paragraph NE3330. Area is added to the shell by the addition of an insert plate that is thicker than the shell or by increasing the thickness of the nozzle neck or a combination of both. This piping penetration design is then evaluated for external loads on the penetration imposed by the piping system as follows:

- The penetrations are grouped together based on configuration and size. For each group, a spread sheet is provided by CV supplier to the piping analyst.
- The piping analyst uses the spread sheet to assure that the CV nozzle capacity satisfies the ASME stress criteria
- (Note: Loads on the nozzle are limited, if necessary to satisfy ASME stress criteria, by adjusting the support locations and flexibility of the piping)

The penetration reinforcement and local region of the vessel shell have been analyzed for unit external loads, for selected typical nozzle configurations, by finite element analyses. A typical finite element model is shown in Figure 2-6.1. Corresponding stresses were determined at selected points of interest, such as every 10 degrees around the circumference of the nozzle at the attachment fillet weld toe and at a distance of $.5\sqrt{(Rt)}$ from the nozzle wall.

Note: External loads on the penetrations are obtained from detailed piping and equipment analyses and are generally not available for inclusion in initial issues of the containment vessel design specification. The finite element models of each penetration are used to develop guidance on acceptable loading to the piping and equipment designer. Once the detailed piping and equipment loads are available, they are provided to the containment vessel designer as an addendum to the design specification, to document the adequacy of the penetrations designs in the CV Design Report.

It may be noted that many of the penetrations include expansion bellows which limit the load on the nozzle. Others are less than 2" in diameter where the strength will be limited by the piping.

2.8 ASME Code Design Specification and Design Report

Design documents for the AP1000 containment vessel are listed in Table 2-10. These documents are available for audit.

The ASME Design Specification is prepared by Westinghouse and specifies design requirements to the containment vessel supplier. This includes equivalent static seismic accelerations based on the seismic time history analyses described in section 3.7 of the DCD and extended to soil sites as described in Reference 3. It also includes additional equivalent static accelerations to be applied to each of the large penetrations based on time history dynamic analyses of the 3D model of the containment vessel.

The summary report plus the detailed calculations and drawings referenced therein is a major portion of the ASME Code Design Report. The ASME Code Design Report for each unit is completed and certified after construction deviations and site related detail design calculations, if any, are addressed. It will eventually include as-built information and will fulfill the ITAAC commitment for the as-built ASME Code Design Report.

The summary report and detail design calculations are available for audit. They include documents already reviewed by NRC as part of the AP1000 Design Certification. They include the analyses and evaluation of the regions adjacent to the large penetrations. They also include detail design documents prepared subsequent to the design certification review.

Table 2-1 Maximum Absolute Accelerations on Axis of Penetrations

NODE	Elev.	Azimuth	Location	Radial	Tang.	Vert.	Rotx*	Roty*	Rotz*
				Maximum absolute accelerations (g and radians/sec^2)					
Upper equipment hatch									
20001	141.50	-67.00	axis	0.750	0.382	0.447	0.104	0.535	0.452
Upper airlock									
20003	138.58	-107.00	axis	0.788	0.381	0.406	0.098	2.540	1.458
Lower equipment hatch									
20002	112.50	-126.00	axis	0.486	0.403	0.321	0.094	0.443	0.388
Lower airlock									
20004	110.50	-107.00	axis	0.568	0.331	0.323	0.083	1.493	1.865

Rotx, roty, and rotz are rotations about local x, y, and z axes, respectively, for each penetration.
The local coordinate system has x along the center line of the penetration, y horizontal and z vertical.

Table 2-2 Equivalent Static Accelerations Specified In Containment Vessel Design Specification (DCD Table 3.7.2-6)

Elevation	**N-S Direction**		**E-W Direction**		**Vertical Direction**	
	Mass center	Edge	Mass center	Edge	Mass center	Edge
			Accelerations (g)			
141.50	0.49	0.50	0.54	0.54	0.45	0.47
131.68	0.43	0.44	0.47	0.48	0.41	0.44
112.50	0.40	0.41	0.37	0.38	0.35	0.40
104.12	0.38	0.40	0.38	0.40	0.32	0.38

Table 2-3 Equivalent static accelerations to account for local shell flexibility

	Radial acceleration (g)	Rotational acceleration about horizontal axis (radians/sec^2)	Rotational acceleration about vertical axis (radians/sec^2)
Upper equipment hatch	0.21	0.54*	0.45
Upper airlock	0.27	2.54*	1.46
Lower equipment hatch	0.12	0.44*	0.39
Lower airlock	0.20	1.49*	1.87

* The rotational accelerations were increased by a factor of 1.60 for the large penetration design analyses to envelope the response at soil sites as described in Section 2.5.

Table 2-4 – Load Combinations for the Large Penetrations

Load			Design		Level A Service Limit			Level C Service Limit		Level D Service Limit		
	Con	Test	Des1	Des2	A1	A2	A3	C1	C2	D1	D2	D3
D	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
E_s								1.0		1.0	1.0	1.0
P_t		1.0										
T_t		1.0										
P_o									1.0			
P_i			1.0			1.0		1.0				1.0
P_e (2.9psid)				1.0			1.0			1.0		
P_e (0.9psid)					1.0						1.0	
T_o				(4)	(5)		(4)		(4)	(4)	(5)	
T_a			1.0			1.0		1.0				1.0

Notes:

1. Service limit levels are per ASME-NE.
2. Where any load reduces the effects of other loads, that load is to be taken as zero, unless it can be demonstrated that the load is always present or occurs simultaneously with the other loads.
3. Reduced pressure of 0.9 psid in inadvertent actuation of active containment cooling transient in cold weather.
4. Temperature of vessel is 70F.
5. Temperature distribution for inadvertent actuation of active containment cooling in cold weather.

Table 2-5 – General Membrane Stress Intensity and Limit

Load Case	Pressure (psi)	General Membrane Stress Intensity (ksi)		Stress Intensity Limit (ksi)
		Shell	Bottom head	
Test	66	29.45	27.28	$0.75\sigma_y = 45$
Construction	0.0	0.96	4.15	$1.0S_{mc} = 26.73$
Design1	59	26.33	23.95	26.73
Design2	-2.9	1.61	5.51	26.73
A1	-0.9	1.16	4.57	26.73
A2	59	26.33	23.95	26.73
A3	-2.9	1.61	5.51	26.73
C1	59	26.33	41.46	$1.0S_y = 52.3$ (300°F)
C2	1.0	1.19	3.69	$1.0S_y = 60$ (70°F)
D1	-2.9	5.54	23.13	$1.0S_f = 50.58$
D2	-0.9	5.09	22.20	50.58
D3	59	26.33	41.46	50.58

Note: Hand calculations are used to check Primary General Membrane stresses (P_m).

Table 2-6 – Local Membrane Stress Intensity and Limit

Load Case	Maximum Local Membrane Stress Intensity (ksi)				Stress Intensity Limit (ksi)
	Shell	Bottom head	Insert Plate	Neck	
Test	39.56	22.69	35.22	37.03	$1.15\sigma_y = 69$
Construction	2.73	2.81	1.42	1.51	$1.5S_{mc} = 40.1$
Design1	35.52	20.22	31.59	33.18	40.1
Design2	2.71	2.99	2.11	2.25	40.1
A1	2.62	2.85	1.59	1.73	40.1
A2	35.52	20.22	31.59	33.18	40.1
A3	2.71	2.99	2.11	2.25	40.1
C1	37.99	23.42	33.33	35.30	$1.5S_y = 78.45$
C2	3.16	2.80	1.59	1.71	$1.5S_y = 90$
D1	12.65	13.71	6.60	7.25	$1.5S_f = 75.86$
D2	12.77	13.60	6.65	6.72	75.86
D3	37.99	23.42	33.33	35.30	75.86

Note: ANSYS output is used to make Local Stress Intensity Code check.

Table 2-7 – Primary plus Secondary Stress Intensity and Limit

Load Range	Maximum Primary plus Secondary Stress Intensity (ksi)				Stress Intensity Limit (ksi)
	Shell	Bot. head	Insert Plate	Neck	
A2 to zero	69.8	110.0	64.4	56.3	$3.0S_{ml} = 84.9$
A2 to A3	77.4	108.3	63.8	56.5	84.9
A2 to A1	78.7	117.1	66.6	55.4	84.9

Note: ANSYS output is used to make Primary plus Secondary Stress Intensity Code check.

Table 2-8 – Maximum Stress Intensity in the Bottom Head for Different Load Cases

Load Range	$P_l + P_b + Q$ with thermal stress (ksi)	$P_l + P_b + Q$ without thermal stress (ksi)	Q thermal stress (ksi)	P_m pressure stress (ksi)
A2 to zero	110.0	41.2	89.6	28.1
A2 to A3	108.3	45.2	89.6	29.5
A2 to A1	117.1	43.7	99.5	28.5

Note: ANSYS output is used to make Maximum Stress Intensity Code check.

Table 2-9 Maximum absolute acceleration of SCV stick for soil cases

Elev	HR	FR	SR	UB	SM	SS
			X-acceleration (g)			
100.00	**0.328**	0.312	0.306	0.327	0.299	0.228
131.68	**0.387**	0.362	0.358	0.373	0.347	0.239
169.93	**0.587**	0.483	0.470	0.430	0.412	0.270
224.00	**0.928**	0.811	0.800	0.612	0.513	0.322
281.90	**1.209**	1.089	1.083	0.829	0.627	0.360
			Y-acceleration (g)			
100.00	**0.343**	0.317	0.321	0.327	0.321	0.238
131.68	**0.471**	0.433	0.441	0.397	0.342	0.253
169.93	0.599	**0.604**	0.592	0.501	0.396	0.290
224.00	1.008	**1.064**	0.883	0.701	0.498	0.424
281.90	1.353	**1.464**	1.209	0.916	0.617	0.562
			Z-acceleration (g)			
100.00	0.311	0.323	0.347	0.373	**0.407**	0.320
131.68	**0.440**	0.394	0.364	0.394	0.427	0.328
169.93	**0.557**	0.441	0.393	0.414	0.442	0.333
224.00	**0.684**	0.489	0.464	0.441	0.458	0.339
281.90	**1.270**	0.751	0.774	0.565	0.498	0.351

The acceleration from the controlling soil cases is shown in bold above

Elev	**Envelope of soil cases**			**Maximum acceleration from stick model in DCD Table 3.7.2-6***		
	X	Y	Z	X	Y	Z
100.00	0.328	0.343	*0.407*	0.38	0.39	0.31
131.68	0.387	0.471	*0.440*	0.43	0.47	0.41
169.93	0:587	0.604	*0.557*	0.69	0.72	0.53
224.00	0.928	1.064	*0.684*	1.09	1.11	0.66
281.90	1.209	1.464	*1.270*	1.48	1.56	1.25

* Refers to Table 3.7.2-6 in DCD Revision 15.
DCD Table 3.8.2-5 to be included in DCD Rev 18 (see RAI-SRP3 8 2-SEB1-04).

See the text for a discussion of the values shown in italics

HR = Hard Rock
FR = Firm Rock
SR = Soft Rock
UB = Upper bound soft-to-medium
SM = Soft-to-medium
SS = Soft Soil

Table 2-10 Containment Vessel Design Documents

Document number	Title	Notes
APP-MV50-Z0-001, Rev 4	Containment Vessel Design Specification	(1)
APP-MV50-Z0C-001, Rev 0	Miscellaneous Calculations for Containment Vessel Design Specification (update of AP600 calculation MV50-S2C-001, Rev 1)	(2)
APP-MV50-S2C-009, Rev 0	Time history analyses of 3D Model of Containment	(2)
APP-MV50-S2C-003, Rev 0	Containment Vessel Pressure Capacity Capabilities	(4)
APP-MV50-S3R-003, Rev 0	Containment Vessel ASME Design Summary Report	(3)
APP-MV50-S2C-001, Rev 0	Containment Vessel Seismic Model (axisymmetric and stick models)	(4)
APP-MV50-S2C-002, Rev 0	Design of Containment Vessel for Internal and External Pressure	(4)
APP-MV50-S2C-004, Rev 0	Containment Vessel Design, Polar Crane Loads on Shell Analysis	(4)
APP-MV50-S2C-005, Rev 0	Containment Vessel Design, Seismic Analysis With Polar Crane	(4)
APP-MV50-S2C-006, Rev 1	Stress Evaluation Calculations	(4)
APP-MV50-S2C-007, Rev 0	Containment Vessel Displacements and Stresses due to Axisymmetric Temperatures	
APP-MV50-S2C-008, Rev 0	3D Model - Modal Analysis of Containment	
APP-MV50-S2C-010, Rev 0	3D Model - Analysis of Large Penetrations	
APP-MV50-S2C-012, Rev 3	Design Of Containment Vessel Penetration Reinforcement	
APP-MV50-S2C-013, Rev 1	Reconciliation of Containment Vessel Seismic Design for Soil Sites	
APP-MV50-GEC-001, Rev 1	Verification of AP1000 Containment Vessel not requiring analysis for "Cyclic Service Report"	(5)

Notes:

1. Rev 1 was basis for hard rock design certification
2. These documents provide inputs to the design specification
3. Summary report covers design in accordance with the ASME design specification. It references and summarizes design documents listed subsequently in this table.
4. These calculations were reviewed by NRC as part of AP1000 hard rock design certification
5. This calculation was reviewed by NRC during the audit in April 2009.

Figure 2-1 3D dynamic model of containment vessel

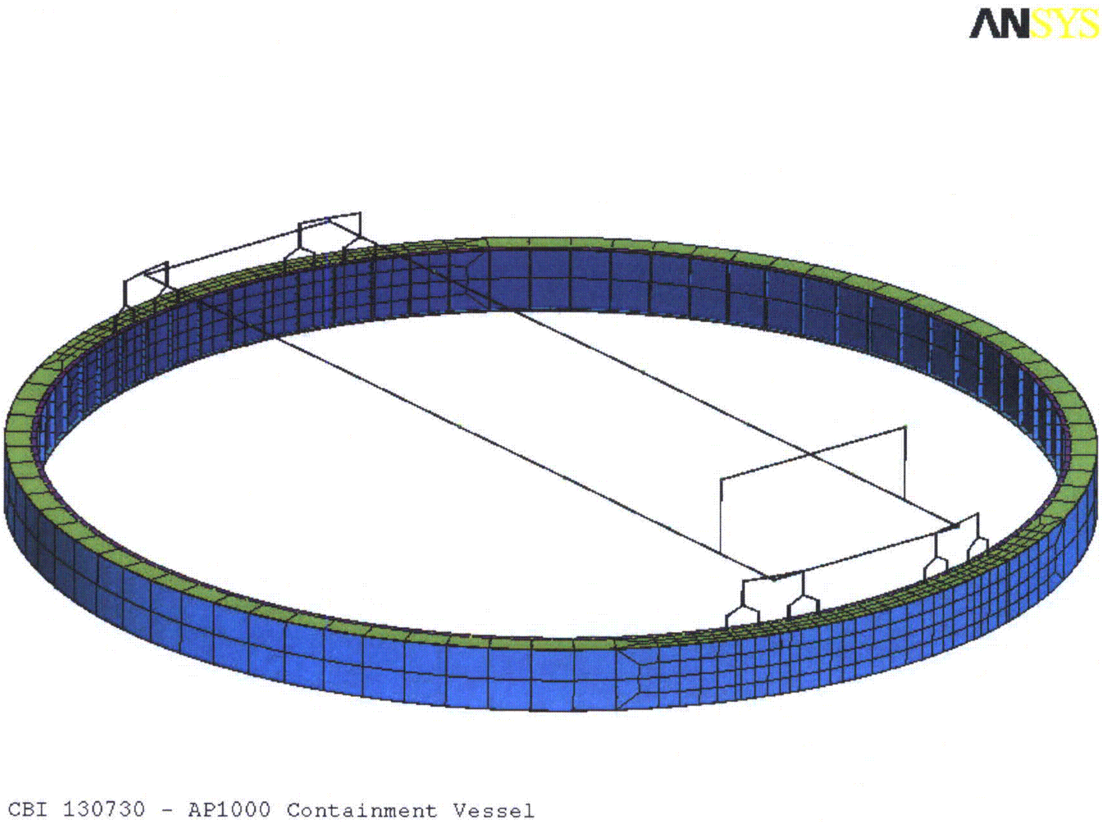

Figure 2-2 Polar crane and crane girder

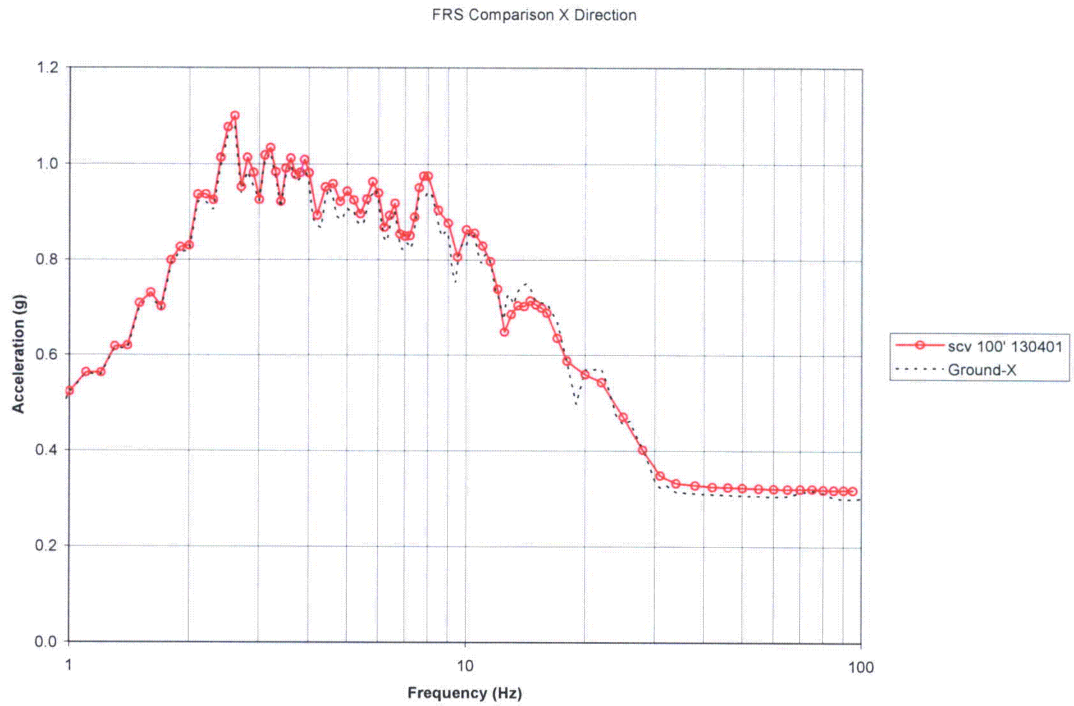

Figure 2-3 FRS (X) at base of NI10 containment vessel for hard rock versus ground input

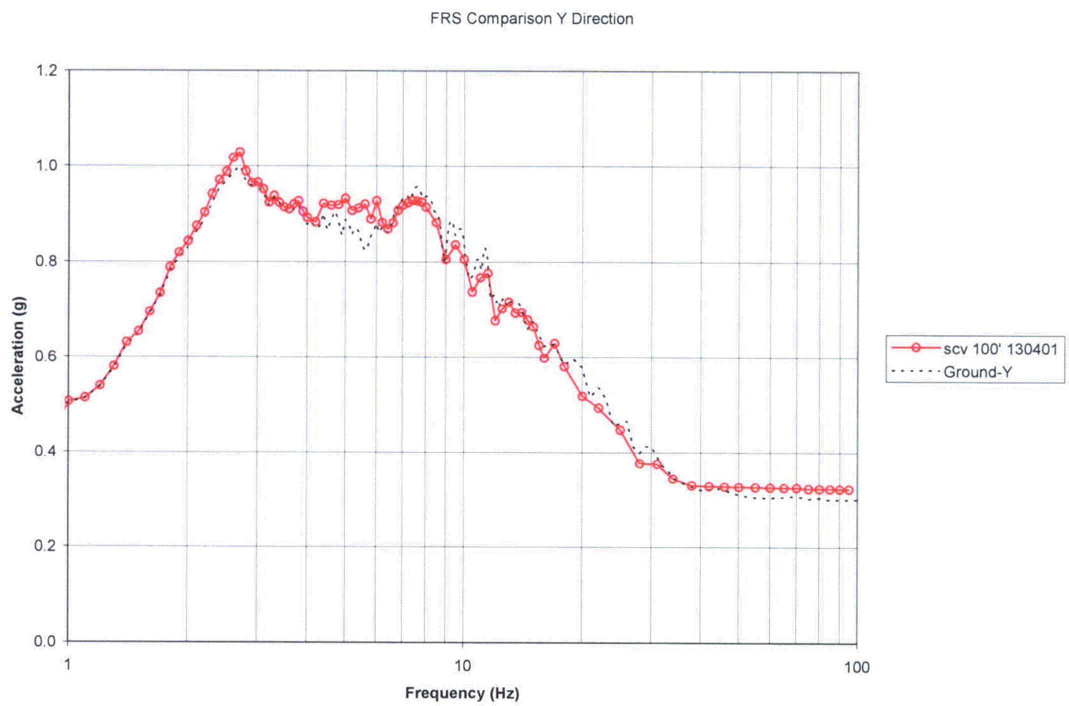

Figure 2-4 FRS (Y) at base of NI10 containment vessel for hard rock versus ground input

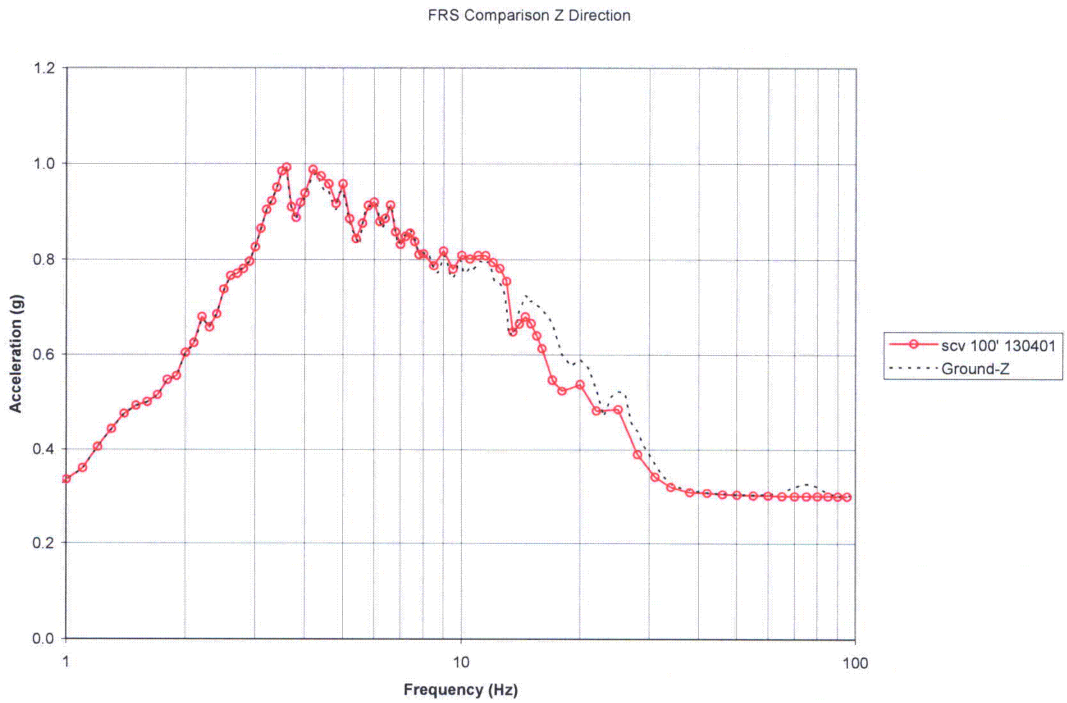

Figure 2-5 FRS (Z) at base of NI containment vessel for hard rock versus ground input

Figure 2-6(a) 3D static model of containment vessel

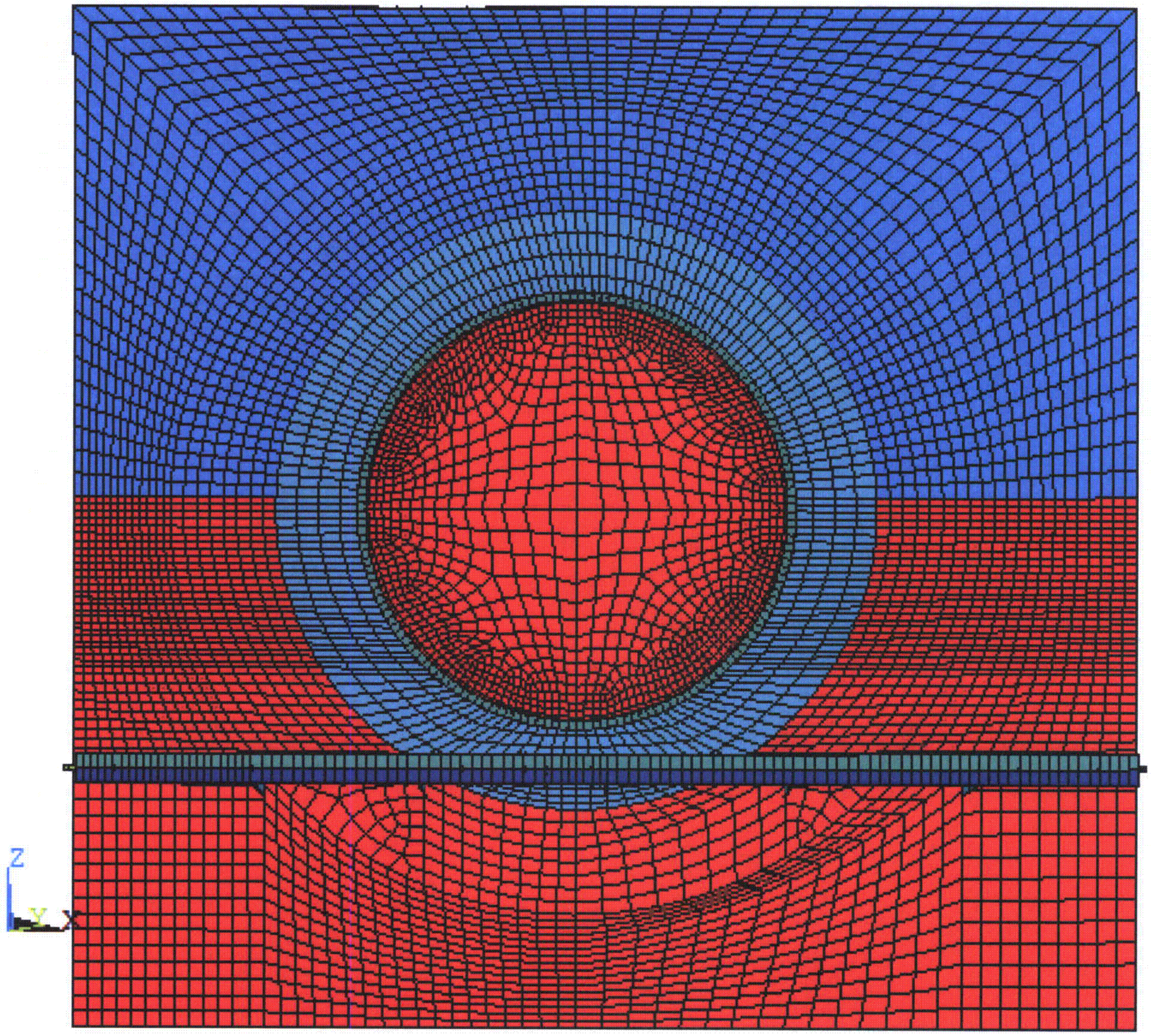

Figure 2-6(b) – Equipment Hatch (El. 141′-6″) Panel (Viewed from 67° azimuth)

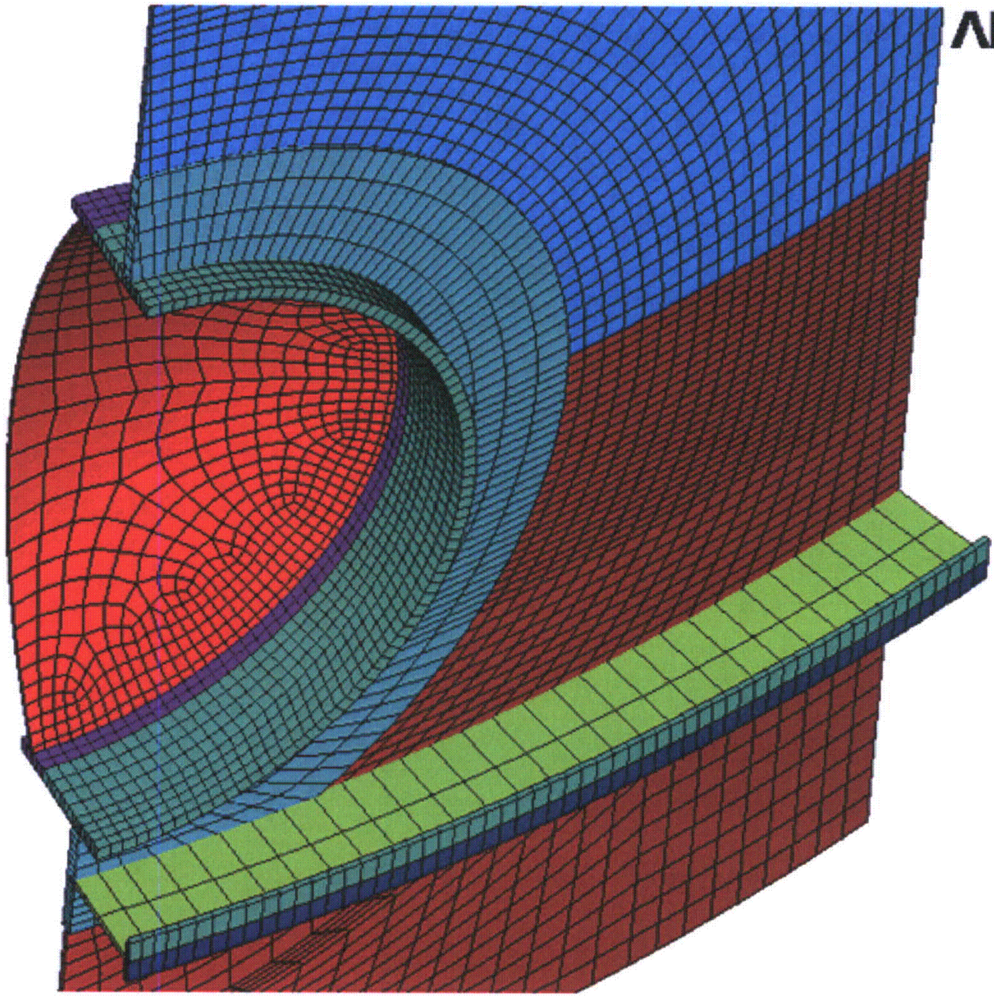

Figure 2-6(c) – Equipment Hatch (El. 141′-6″) Panel – Vertical Section
(Viewed from outside and above)

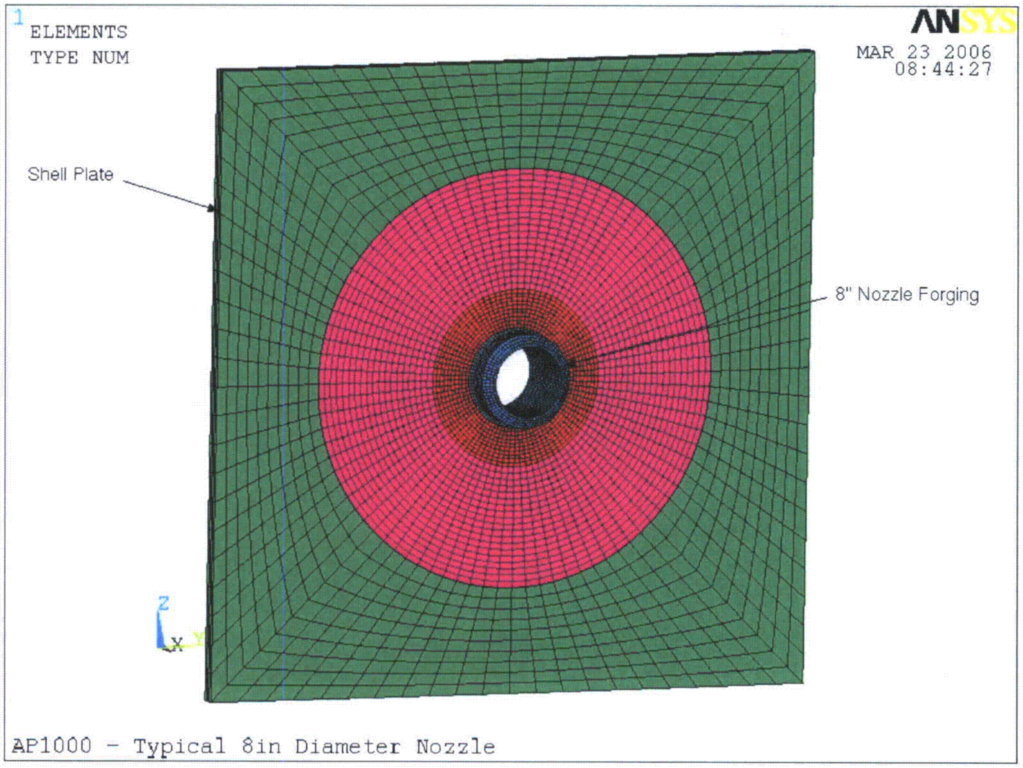

Figure 2-6.1 Typical Nozzle FEA Model

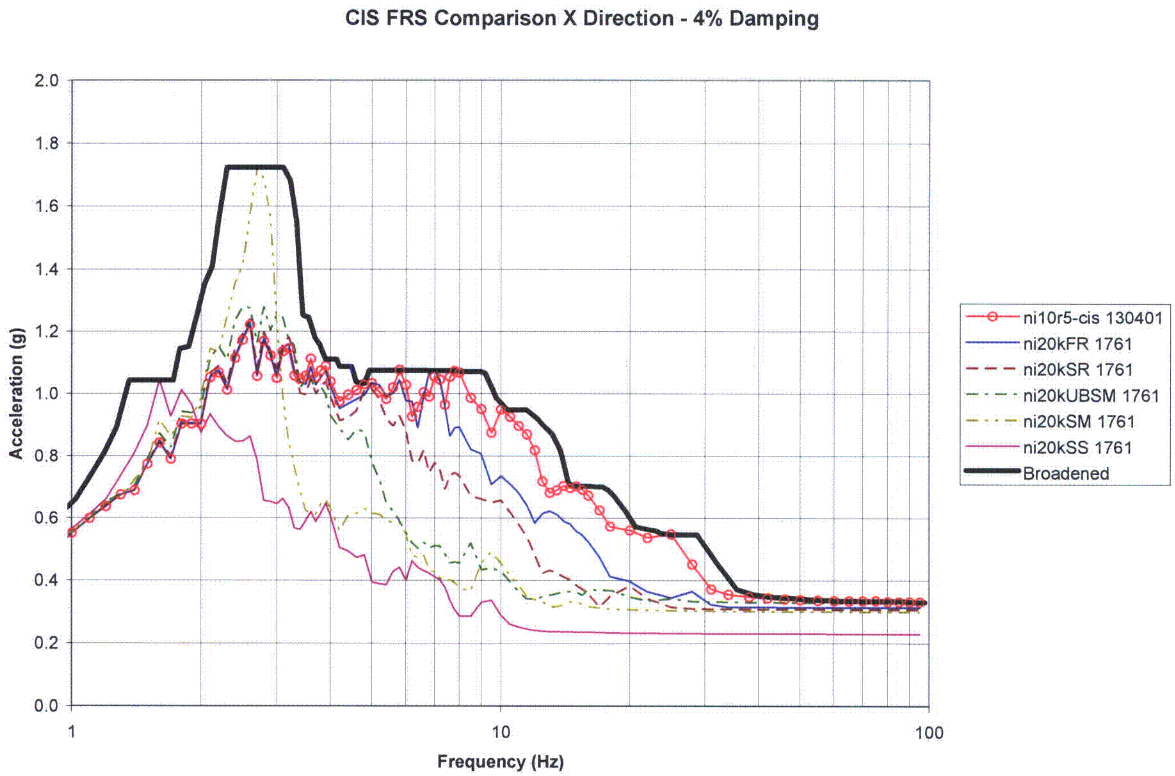

Figure 2-7 Floor Response Spectra (X) at Elevation 100' for Soil Cases

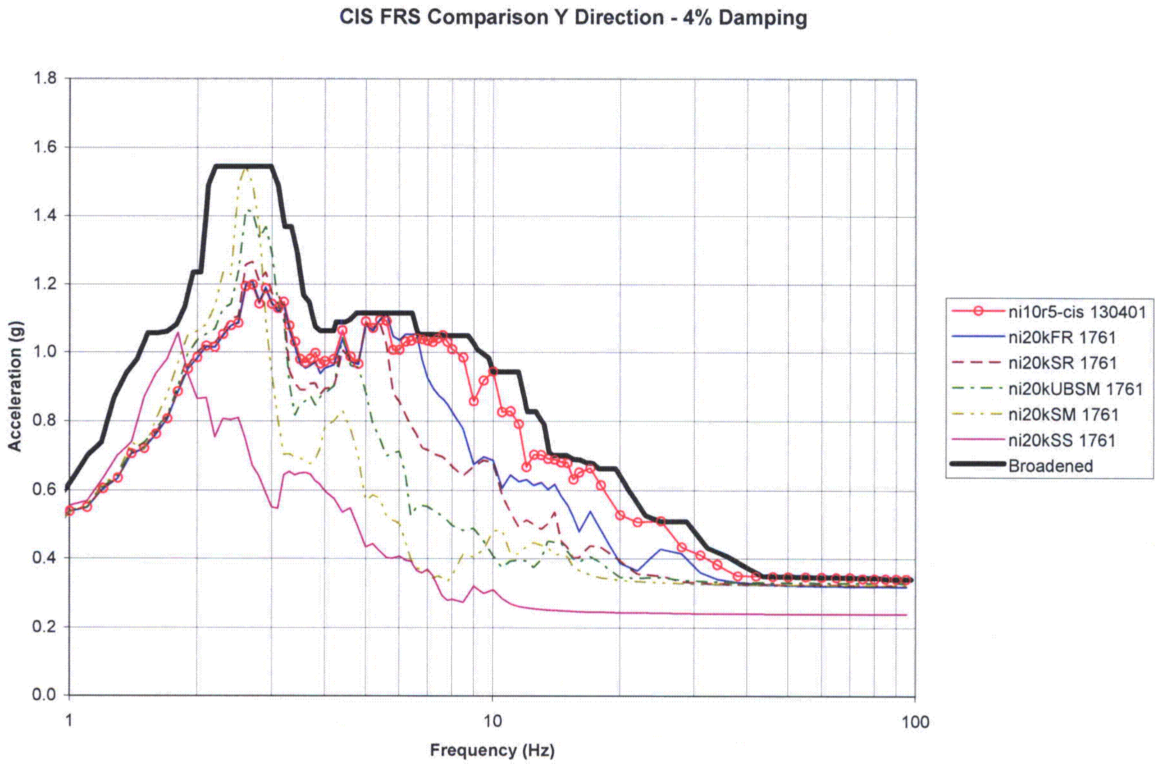

Figure 2-8 Floor Response Spectra (Y) at Elevation 100' for Soil Cases

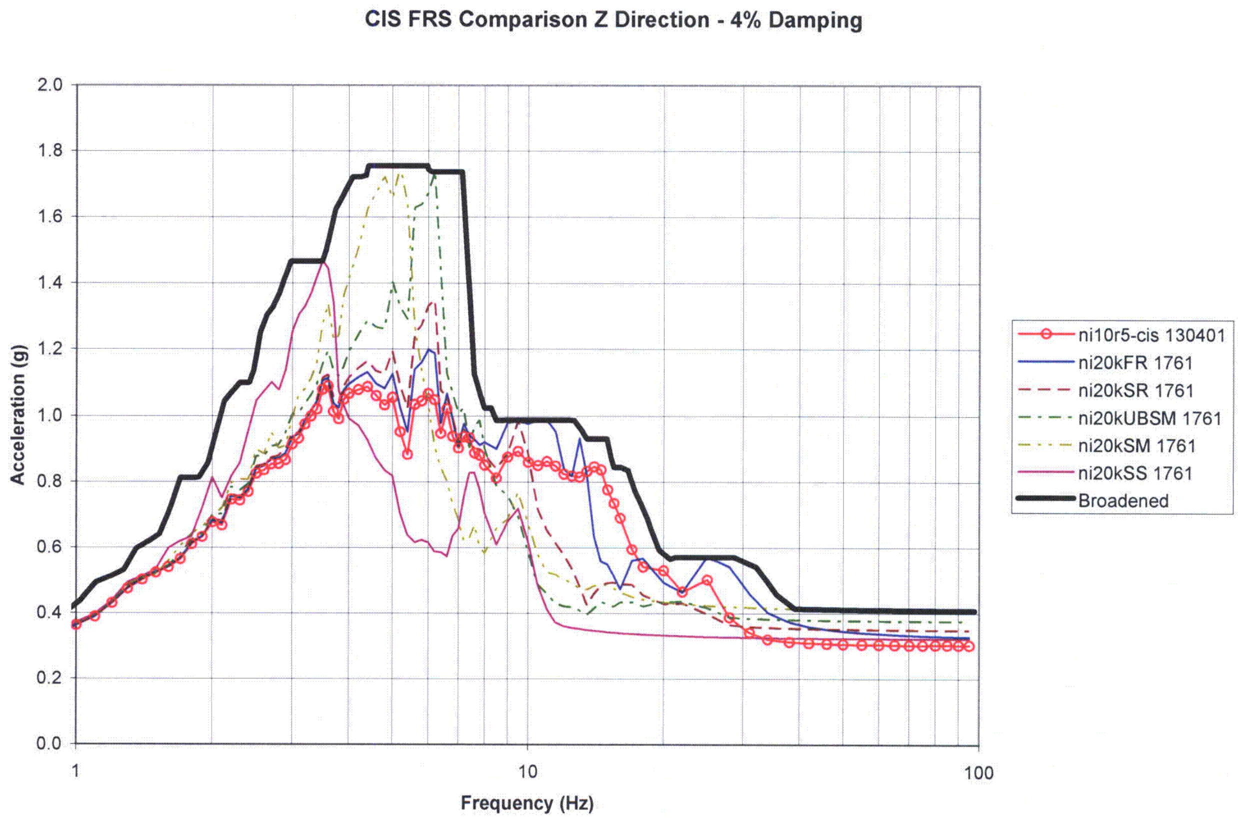

Figure 2-9 Floor Response Spectra (Z) at Elevation 100' for Soil Cases

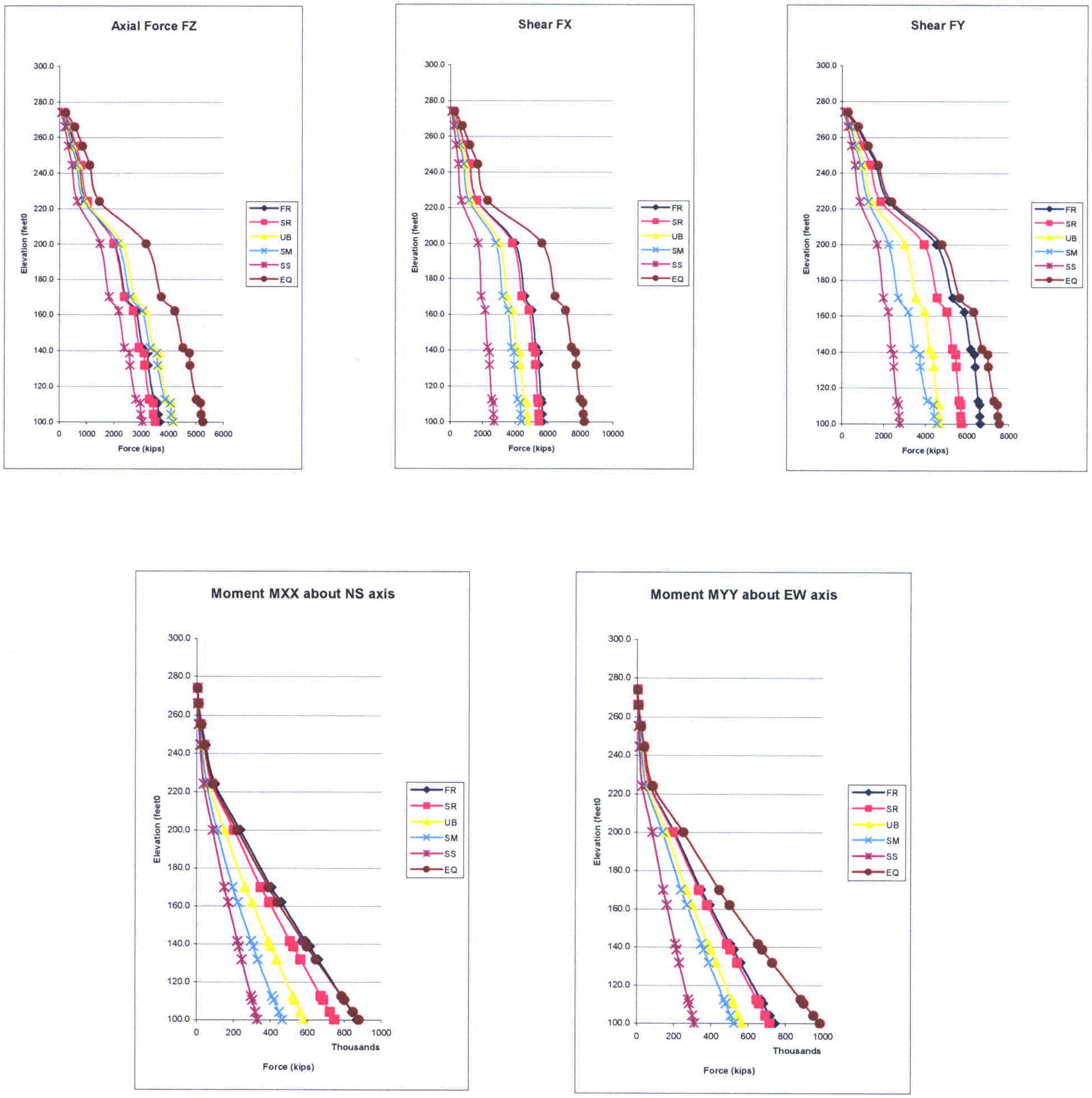

Figure 2-10 Member Forces in SCV Stick

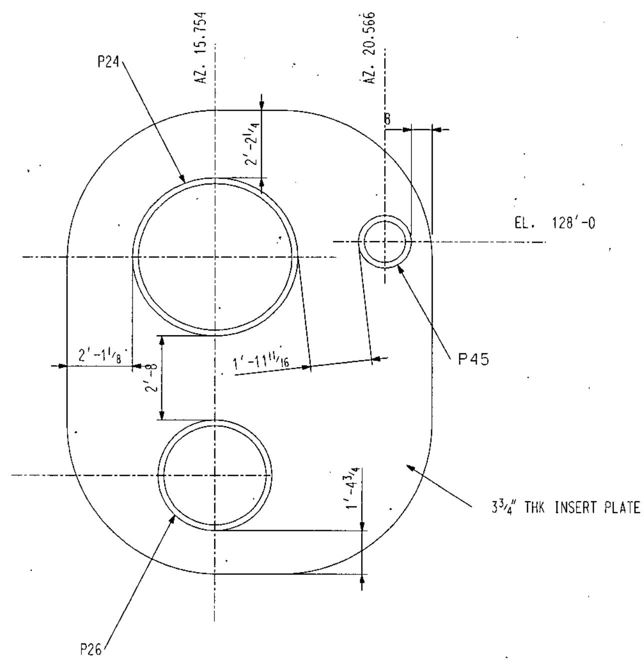

Figure 2-11 Combined Insert Plate for MS (P24), FW (P26) and SUFW (P45)

Note: This figure shows an elevation view of the insert plate assembly looking north from the inside of the containment. The axis of the sleeves is north-south. The openings in the shell are elliptical. Spacing dimensions shown are measured along the mid-surface of the insert plate.

3. REGULATORY IMPACT

The design of the containment vessel adjacent to the large penetrations is addressed in subsection 3.8.2.4.1.2 "Local Analyses" of the NRC Final Safety Analysis Report (FSER, Reference 2) write-ups. The completion of the analysis for the large penetrations is identified in the FSER as COL Action Item 3.8.2.4.1.2-1. Completion of the design of the large penetrations will impact these write-ups. The conclusions in the FSER about the local analyses are not altered.

The changes to the DCD presented in this report do not represent an adverse change to the design functions, including the pressure boundary integrity functions and the access function, or to how design functions are performed or controlled. The analysis of the large penetrations is consistent with the description of the analysis in 3.8.2.4.1.2 of the DCD. Therefore, the changes to the DCD do not involve revising or replacing a DCD-described evaluation methodology. The changes to the DCD do not involve a test or experiment not described in the DCD. The DCD change does not require a license amendment per the criteria of VIII. B. 5.b. of Appendix D to 10 CFR Part 52.

Since completion of the local analyses does not change the design or design functions of the containment or penetrations, the DCD change does not affect resolution of a severe accident issue and does not require a license amendment based on the criteria of VIII. B. 5.c of Appendix D to 10 CFR Part 52.

The closure of the COL Information Item will not alter barriers or alarms that control access to protected areas of the plant. The closure of the COL Information Item will not alter requirements for security personnel. Therefore, the closure of the COL Information Item does not have an adverse impact on the security assessment of the AP1000.

4. REFERENCES

1. APP-GW-GL-700, AP1000 Design Control Document, Revision 17.
2. Final Safety Evaluation Report Related to Certification of the AP1000 Standard Design, September 2004.
3. APP-GW-S2R-010, Revision 3, Extension of Nuclear Island Seismic Analyses to Soil Sites

5. DCD MARK UP

5.1 DCD Changes from Rev 15 to Rev 16

The DCD changes from Rev 15 to Rev 16 were shown in Rev 0 and Rev 1 of this report. DCD Rev 16 has been issued so these changes have been deleted from this section of the Technical Report.

5.2 DCD Changes to Rev 16

The DCD changes from Rev 16 to Rev 17 were shown in Rev 1 of this report. DCD Rev 17 has been issued so these changes have been deleted from this section of the Technical Report.

5.3 DCD Changes to Rev 17

Revise note 3 to Table 3.8.2-1 as follows:

3. reduced pressure of 0.9 psid at one hour in inadvertent actuation of active containment cooling transient in cold weather.