US-APWR Sump Strainer Stress Report

Non-Proprietary Version

June 2013

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Revision History (Sheet 1 of 3)

Revision	Page (Section)	Description
0 (Dec-2008)	All	Original issued
1 (Mar-2011)	2	Table of Contents - Changed page numbers
	3	List of figures: - Changed the figure and table pages
	4	Section 1.0, second paragraph first bullet: - Changed number of disks per strainer from 27 to 21
	6	Section 1.0, Figure 2 - Changed figure 2 to incorporate drawing changes
	10	Section 4.1, first paragraph - Analysis method changed from independent Strainer/Cover Plate model to dependent Strainer/Cover Plate model
	11	Section 4.1 Detailed Stack Disk Finite Element Model - Changed Disk size and number of disks per strainer
	13	Section 4.1, Figure 3 - Updated graphics shown in figure
	16	Section 4.1, Reduced Detail Stack Disk Model - Changed original number of segments from 27 to 23
	17	Section 4.1, Figure 6 - Updated graphic shown in figure
	18	Section 4.2, first paragraph - Last sentence deleted Section 4.2, Strainer Plenum Model, first paragraph - Reduced detail stack disk model changed from 9 to 7. Full detail model used for remaining strainers. Section 4.2, Strainer Plenum Model, second paragraph - Added full detail strainer model to first sentence Section 4.2, Strainer Plenum Model, third paragraph - Third paragraph added - Changed diameter of flow holes in plenum
	20	Figure 8 – Strainer Plenum Structural Model - Full detail Stacked Disk Model incorporated at two strainer locations. - Changed location of two full detail Stacked Disk models

Revision History (Sheet 2 of 3)

Revision	Page (Section)	Description
1 (Mar-2011)	21	Section 5.1, Debris Loads - Changed calculated Debris Weight for Strainer and Plenum. Added Plenum Debris Weight value used for structural analysis
	22	Section 5.1, Seismic Inertial Loads - Changed damping value
	23	Section 5.1, Figure 9 - Changed Horizontal Response Spectra curve
	24	Section 5.1, Figure 10 - Changed Vertical Response Spectra curve - Changed Sloshing Loads from 500 lbf to 465 lbf
	26	Section 5.2, Table 3 - Changed Load Combinations 4 and 10
	27	Section 5.2, Load Combinations THmtl - Changed POST LOCA accident temperature
	30	Section 6.0, Table 5 - Changed Acceptance Criteria for Fillet Weld Stress and Bolting Shear Stress
	31	Section 6.0, Note 9 - Clarification of shear plane considerations
	33	Section 7.0, Table 6 - Changed Interaction Ratios and added components to table Section 7.0, Table 7 - Changed Interaction Ratios
	33	Section 9.0 - Changed References 1, 2, 3, 4, 5, 6, 11, 12, 13, 14 and 15
2 (June-2013)	General	Correct editorial errors. Note that revision bar related to these editorial corrections is removed.
	4	Section 1.0 - Updated reference document due to change of floor response spectra.
	7	Section 2.0 - Updated reference document due to change of floor response spectra. - Changed edition of ASME code used for this evaluation.
	21	Section 5.1 - Changed debris load (L_{debris}) from 275 lbf to 175 lbf. - Changed emergency letdown piping sparger discharge (L_{sparg}) from 9.2 psi to 8.60 psi. - Changed drain & vent line discharge (L_{jet}) from 384 lbf to 522 lbf. - Corrected reference document number from [6] to [2].

Revision History (Sheet 3 of 3)

Revision	Page (Section)	Description
2 (June-2013)	22	Section 5.1 - Changed reference document referred in the third and fourth paragraph. - Changed elevation and damping value of the response spectra curve in third paragraph.
	23	Section 5.1, Figure 9 - Changed response spectra curve.
	24	Section 5.1 - Changed response spectra curve.
	24	Section 5.1 - Changed sloshing load from 700 lbf to 900 lbf.
	26	Section 5.2, Table 3 - Changed load combinations.
	27	Section 5.2 - Changed post LOCA accident temperature from 256 °F to 270 °F.
	29	Section 6.0 - Added reference. - Changed abbreviation from CSS to CS.
	30 and 31	Section 6.0, Table 5 - Changed number of Notes to arrange the Notes in numerical order.
	33	Section 7.0, Table 6 and 7 - Revised interaction ratio of strainer stack assembly and plenum assembly.
	34	Section 8.0 - Changed edition of ASME code.
	35	Section 9.0 - Updated references.

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Abstract

The standard US-APWR design utilizes a passive disk layer type of strainer system, “Sure-Flow Strainer (SFS)”, supplied by Performance Contracting Inc. (PCI)”. The qualification of structural integrity of the SFS specially designed for the standard US-APWR was subcontracted to the vendor, and the stress report was provided hereto.

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PCI-9082-S06
Revision 3

Summary Report

US-APWR Sure-Flow® Strainer Assembly
Structural Analysis Summary Report

Prepared for:

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Table of Contents

List of Figures

3

List of Tables

1.0 Introduction

The purpose of this report is to summarize the evaluation of the structural components of the Emergency Core Cooling (ECC) and Containment Spray (CS) Systems sump strainer assembly to meet the design requirements as stated in the US-APWR Purchase Specification (Reference [1]), Technical Specification (Reference [2]), MHI Letter 4CU-UAP-20130003 (Reference [3]), and Design Control Document (Reference [4]). 3

The strainer stack is a series of perforated plate disks "sandwiched" onto a central core tube with gap spacers, tension rods and seismic rods serving the purpose of keeping the required spacing between disks and maintaining the stability of the structure. The ECC/CS sump strainer assembly is composed of the following two sub-assemblies:

- A strainer stack assembly composed of 21 individual disks fabricated from perforated stainless steel sheet and bolted together in vertical stacks (see Figure 1). The disks are separated by spacers to form a stacked disk configuration. Each strainer stack has an interior core tube which channels the flow of water down to the underlying plenum. There are 9 vertical strainer stacks per sump which are supported by the stainless steel plenum assembly.

- A stainless steel plenum for each sump spans over the top of the sump opening and provides structural support for the strainer stacks (see Figure 2). The plenum also serves to direct the flow from each of the nine strainer stacks to the sump opening. The plenum is tightly fit to the containment floor to form a seal to prevent debris from entering the sump.

The remainder of this summary report overviews the design Codes and Standards (Section 2.0), Materials (Section 3.0), Analysis Methodology (Section 4.0), Loads and Load Combinations (Section 5.0), Acceptance Criteria (Section 6.0), Evaluation Results (Section 7.0), Conclusions (Section 8.0), and References (Section 9.0).

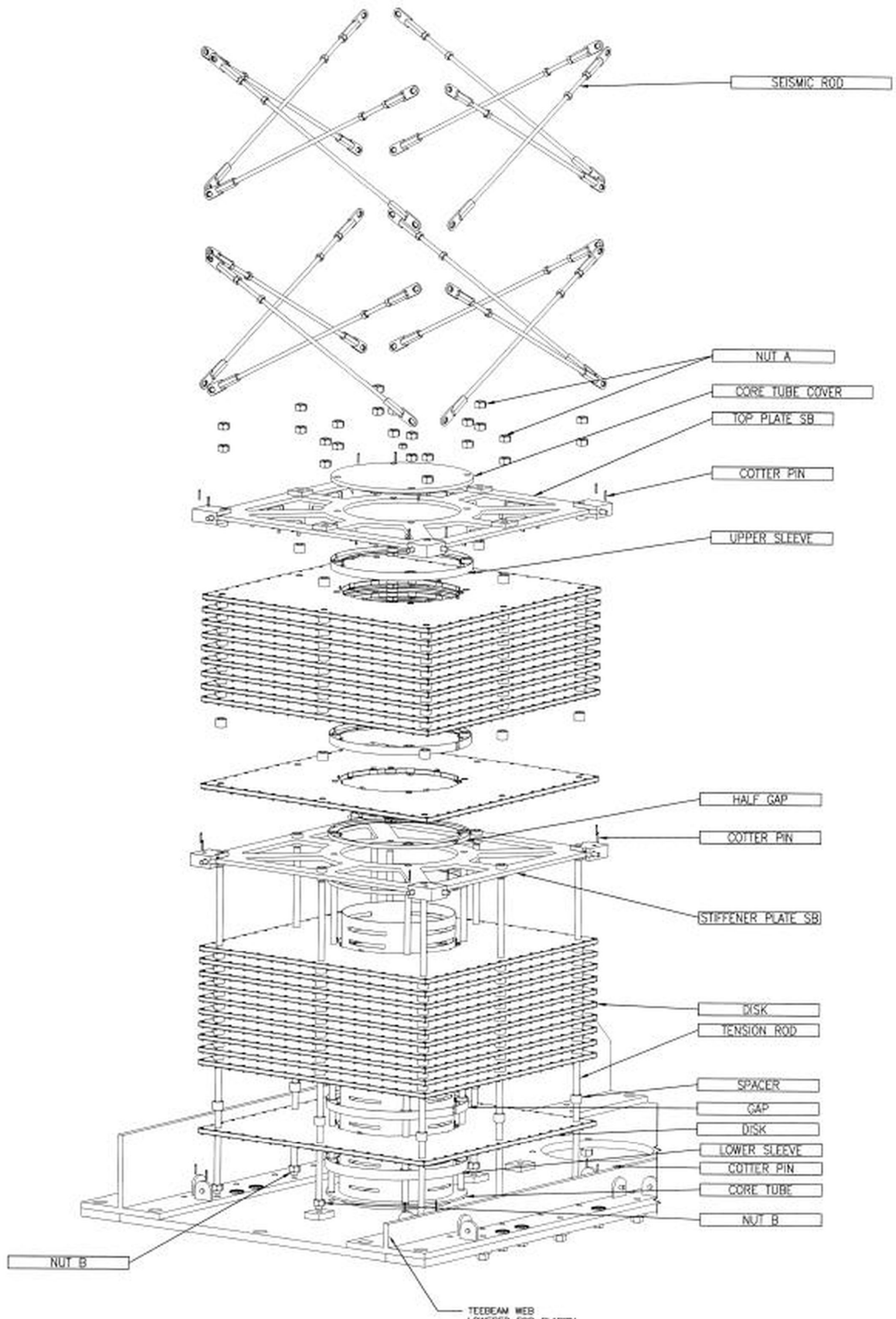
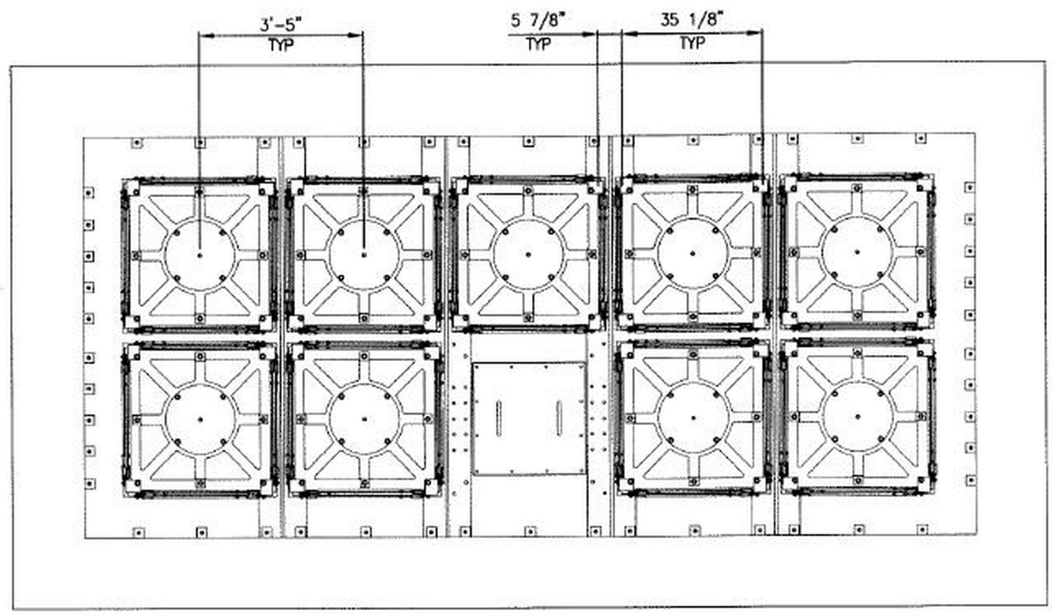


Figure 1 – Strainer Stack Assembly



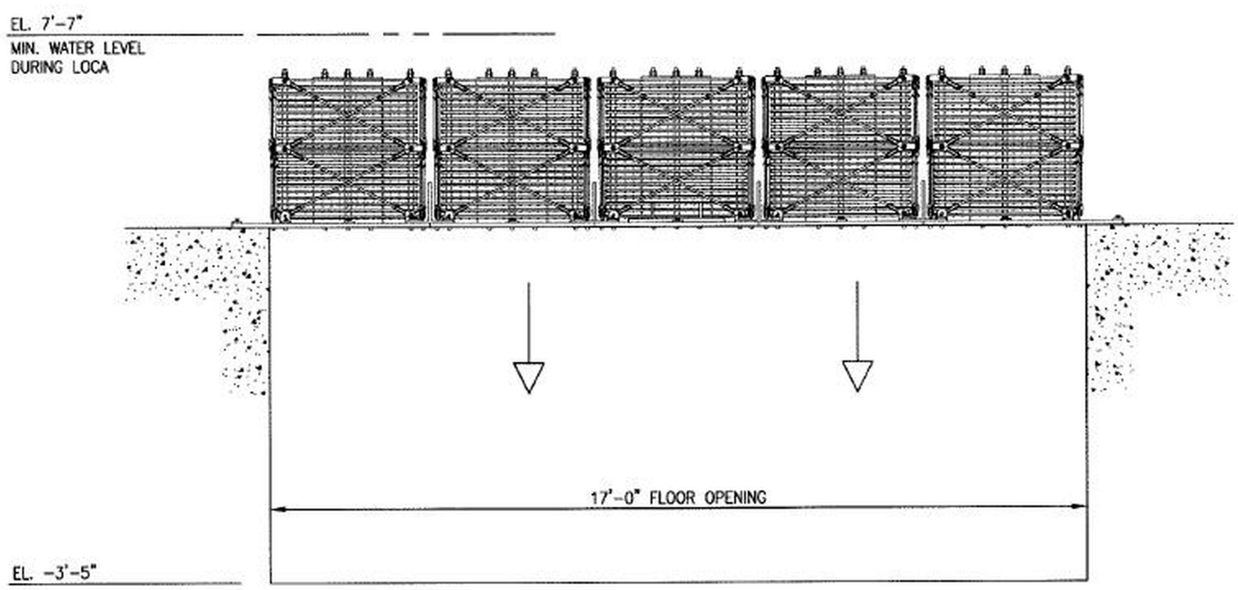


Figure 2 – Strainer Plenum Assembly

2.0 Codes and Standards

The governing design Code for the US-APWR ECC/CS strainer assembly is specified in the US-APWR Technical Specification (Reference [2]), MHI Letter 4CU-UAP-20130003 (Reference [3]), and the Design Control Document (Reference [4]).

In accordance with the Design Control Document (Reference [4]) and MHI Letter 4CU-UAP-20130003 (Reference [3]), the ECC/CS strainer assembly is classified as an ASME Boiler and Pressure Vessel Code, Section III, Division I, Class 2 component subject to the design rules of the 2007 Edition (up to and including the 2008 Addenda) of the ASME Code (Reference [5]). Accordingly, the pressure retaining components of the strainer stack and plenum (the perforated plates and plenum cover plates, respectively) are evaluated for compliance with the ASME Code, Subsection NC. The remaining components are considered component supports and are evaluated for compliance with the ASME Code, Subsection NF. Material properties are taken from the appropriate appendices of the ASME Code.

3

3.0 Materials

The strainer stack (see Figure 1) is comprised of the following components fabricated from the materials indicated:

Table 1 - Strainer Stack Materials

Pressure Retaining Components	
Perforated Plate, Disks, Gap Rings	Stainless Steel, ASTM A-240, Type 304
End Cover Plate	Stainless Steel, ASTM A-240, Type 304
Grill Wire Stiffeners	Stainless Steel, ASTM A-493, Type 304 (Drafted to a min. yield strength of 70 ksi)
Rivets	Stainless Steel, Type 305 or ASTM A-240, Type 304
Component Supports	
Tension Rods	Stainless Steel, ASTM A-276, Type 304, Condition B
Nuts	Stainless Steel, ASTM A-194, Grade 8 (Heavy Hex)
Washers	Stainless Steel, ASTM A-240 or A-666, Type 300 Series
Stiffener Plates/Rings	Stainless Steel, ASTM A-240, Type 304
Spacers	Stainless Steel, ASTM A-312, Type 304
Seismic Rods	Stainless Steel, ASTM A-276, Type 304, Condition B
Seismic Rod Eyes	Stainless Steel, ASTM A-276, Type 304, Condition B
Seismic Rod Couplings	Stainless Steel, ASTM A-276, Type 304, Condition B
Connection Blocks	Stainless Steel, ASTM A-276, Type 304, Condition A
Connector Pins	Stainless Steel, ASTM A-276, Type 304, Condition B
Sleeves	Stainless Steel, ASTM A-240, Type 304
Long/Short Tabs	Stainless Steel, ASTM A-276, Type 304, Condition B
Weld wire/rod	Stainless Steel, ER308, ER308L, ER309, and ER309L electrodes

The strainer plenum (see Figure 2) is comprised of the following critical components fabricated from the materials identified:

Table 2 - Strainer Plenum Materials

Pressure Retaining Components	
Cover Plates	Stainless Steel, ASTM A-240, Type 304
Component Supports	
Tee beam	Stainless Steel, ASTM A-240, Type 304
Nuts	Stainless Steel, ASTM A-194, Grade 8 (Heavy Hex)
Washers	Stainless Steel, ASTM A-240, or A-666, Type 300
Bolting	Stainless Steel, ASTM A-193, Grade B8, Class 2(Heavy Hex)
Weld Wire/Rod	Stainless Steel, ER308, ER308L, ER309, and ER309L electrodes

4.0 Methodology

The strainer assembly is analyzed using elastic analysis methods for the loads defined in Section 5.1. The structural qualification of the strainer assembly is performed using a combination of manual calculations and finite element analyses employing the GTSTRUDL computer program.

4.1 Strainer Stack Analysis

The strainer stack is dependent on the cover plate for support, therefore the strainer stack model will be incorporated into the plenum model for analysis. Due to the similarity between strainer stacks, only one strainer stack is analyzed in detail. The strainer stack displacements are calculated and limited to prevent interference with adjacent stacks.

Four finite element models are used to evaluate the strainer stack; specifically a detailed strainer stack model, a gap assembly model, a perforated disk model and a reduced detail strainer stack model for use with the plenum model. These models are shown in Figures 3, 4, 5 and 6, respectively.

The strainers are always submerged underwater. This effect is considered by accounting for the added inertial mass of the surrounding water acting with the strainer components. This is a conservative evaluation method because the increased damping associated with the strainer submergence is not considered. The analysis assumes the water is not moving during the earthquake. In reality, the water surrounding the strainer stack will be moving during an earthquake, resulting in additional drag loads on the strainers. These additional drag loads are applied as an equivalent static load.

The pressure retaining components of the strainer disk sub-assemblies (namely the perforated plate and supporting wire stiffeners) are qualified for the applicable load combinations (see Section 5.2) by hand-calculations using a simplified, conservative one-way beam-action elastic model (where pressure is the controlling load). Where pressure isn't the controlling load (vertical upward seismic), a GTSTRUDL finite element model is used (see Perforated Disk Model below).

Detailed Stack Disk Finite Element Model

The detailed strainer stack model is comprised of a central 14” diameter core tube, 35 -$^1/_8$ in x 35-$^1/_8$ in disks (21 in total) with an intermediate stiffener and a top stiffener plate. The strainer stack is fastened to the plenum via the bottom end of the 12 tension rods and the 8 cross bracing seismic rods. The flexibility of the supporting plenum steel is modeled as springs at the base support joints of the model. The strainer disks are modeled as a composite structure including the tension rods, while the intermediate and top stiffener plates are modeled individually. The disk faces, gap assemblies, sleeve assemblies, grill wire stiffeners, and end cover are not directly included in the model, however their mass is included by adjusting the density of modeled members.

The tension rods and spacers are modeled coincident to one another. The rods are not connected to the spacers, rather they are allowed to move relative to one another along the axis of the rods, but are constrained to move together in the lateral directions.

The spacers are pinned at the bottom of the strainers (where they connect to the cover plate of the plenum). The spacers which connect to the top and intermediate stiffener plates are considered fixed in the model due to the compressive preload (torquing of the tension rods) creating a clamping action. Note the seismic connecting blocks take the place of the typical spacer at the corners of both the intermediate and top stiffener plates.

The spacers have the capacity to carry a certain amount of lateral load because they are pre-compressed. As long as the bending moments in the spacers do not result in an extreme fiber tension stress in excess of the preload, these spacers can carry lateral load. Once the bending moment reaches this point (a net tension in the extreme fiber of the spacer), the spacers can take no additional lateral load and any further lateral load is carried solely by the tension rods.

The outer tension rods not at the corners of the strainer are tied to the disk rims such that the disk rims stay rigid to themselves but are moment released to the tension rods and the spacers.

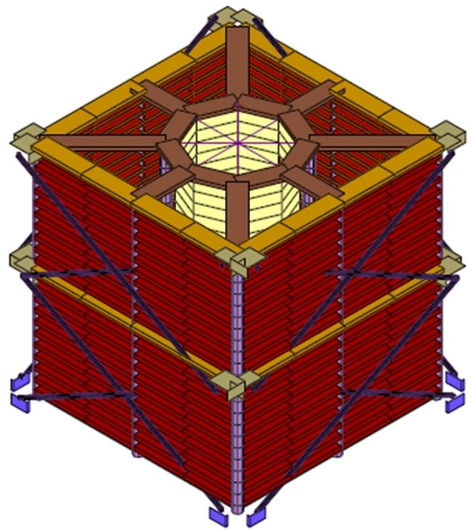
The intermediate and top stiffener plates are cut from one plate in a "cross and collar" pattern such that there are direct load paths between adjacent tension rods but fluid flow is not constrained. These plates are therefore modeled with beam-type members from tension rod to tension rod as shown in the Figure 3. The collar which surrounds the core tube is modeled as an octagon to represent the curved shape.

The seismic rods are long slender rods which laterally brace the strainer stack. These long slender rods have a very low slenderness ratio and will buckle under compression. Therefore, short slotted holes in the eyes at the ends of the seismic rods allow the rods to take tension but not compression (provided the negative node to node displacement of the rod is not greater than the hole length). The dynamic analysis of the strainer stack must account for this "tension only" action of the seismic rods. Unfortunately, the size and complexity of this model prevents the use of a non-linear model. The approach taken requires performing lateral static acceleration test cases on the strainer stack to determine which seismic rods go into tension and which go into compression. Once the tension members are known for the primary lateral bending mode of the strainer stack, separate dynamic analyses are run for each direction with only the "tension" members active for each specific analysis. This approach is discussed in more detail in Calculation PCI-9082-S01 (Reference [6]).

The base of the core tube is welded to a mating flange which fits over the inner rods and is secured in place by the spacers. The joints of the mating flange are connected to the inner tension rods such that the flange is rigid to itself but pinned to the inner tension rods. The core tube is connected to the mating flange via rigid links which have a calculated cross-sectional area mimicking the very low stiffness of the core tube in the radial direction. These links are moment released at their ends which connect to the flange.

The top end of the core tube is secured in the lateral directions via an end cover plug which fits inside the core tube (such that it provides a lateral-only constraint between the top stiffener plate and the core tube). The top of the core tube is therefore connected to the top stiffener plate by rigid links which are moment released at their ends which connect to the top stiffener plate. The core tube itself is released for moments and for axial displacement.

The seismic connecting blocks provide the connection point between the seismic rods and the intermediate and top stiffener plates. Each connecting block is conservatively modeled as two members (cantilevered beams) perpendicular to one another. Since typically only one seismic rod is loaded on a block at any given time (as these are tension only members), this simplified approach is considered adequate. Also, the moment of inertia about the vertical axis for the blocks is increased to account for the bracing action of the intermediate/top stiffener. The moment of inertia is also adjusted such that the deflection of the model matches that of the actual scenario.



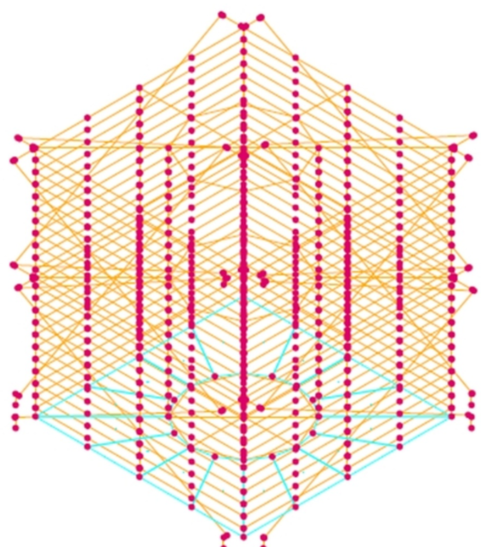


Figure 3 – Strainer Stack Structural Model

Gap Assembly Model

Due to the unique support design of the gap face and gap stiffener ring, a GTSTRUDL model (see Figure 4) was created to determine stresses in the gap ring. The model uses beam-type members to model the stiffening ring and plate elements to model the gap assembly perforated plate. Rigid links connect the ring to the perforated plate at each joint. Rigid links are also used to support the perforated plate at the spacers. Supports are located only at the four spacer locations. All of the joints are moment and lateral shear released at their end which connects to the plate elements. This allows the perforated plate to slide in the circumferential direction relative to the gap stiffening ring. All of the rigid links are compression-only members and a non-linear analysis is used to determine the stresses in the plate elements. Modeling the rigid links as compression only members mimics the actual situation where the perforated plate can pull away from the stiffening ring but is supported by the ring in the radially inward direction.

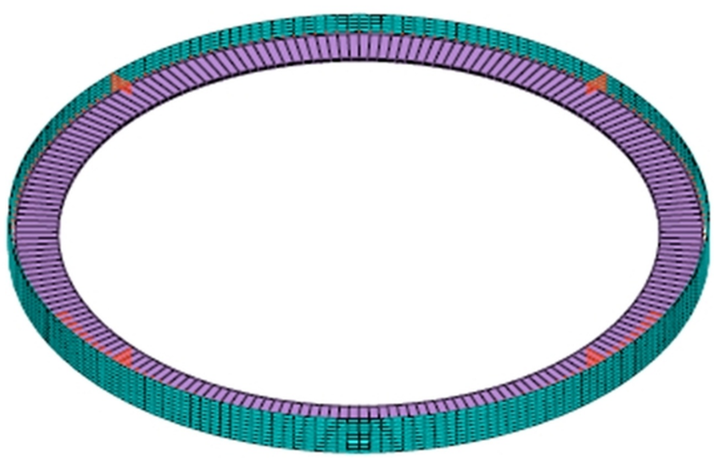


Figure 4 – Strainer Gap Assembly Structural Model

Perforated Disk Plate Model

To address the condition when the top or intermediate disk pulls away from the wire grill support (i.e., during an earthquake without the pressure load), the analysis of the intermediate and top perforated disk plates is achieved using a GTSTRUDL model. The same model is used for the intermediate and top perforated plates by controlling which support joints are activated to function as support points. The perforated disks are modeled using plate elements, and have pinned restraints at the core tube interface (gap stiffener ring) and at tension rods (spacers). The top perforated plate has restraints in the vertical direction to account for additional bar supports.

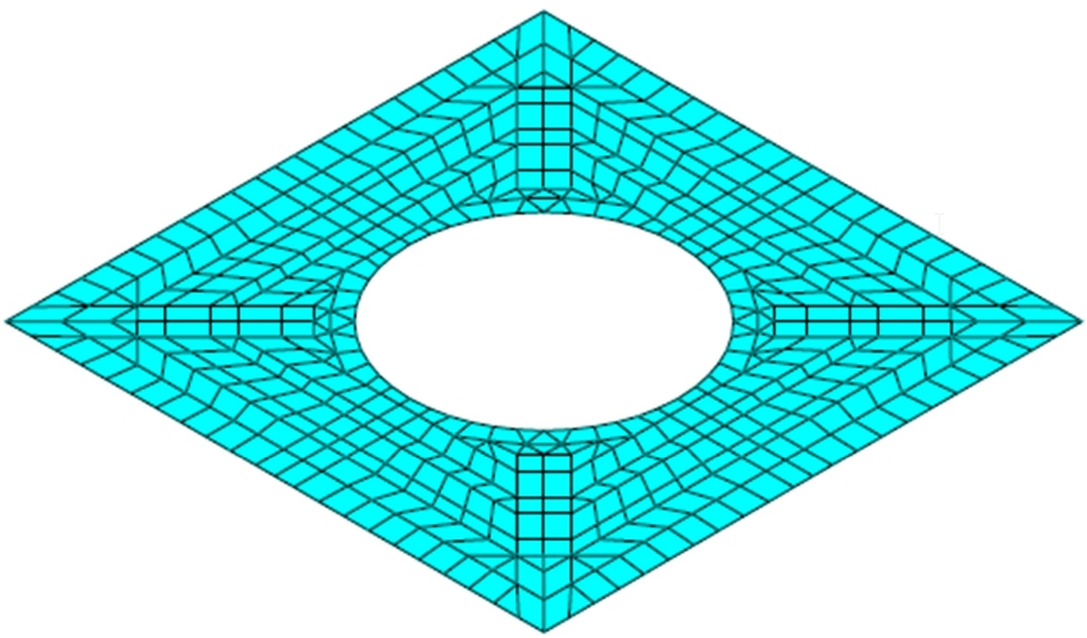


Figure 5 – Strainer Perforated Disk Structural Model

Reduced Detail Stack Disk Model

In order to effectively and efficiently analyze the plenum models, the strainer stacks need to be included. In an effort to reduce the complexity and solution time required, a reduced detail strainer structure with a more reasonable number of members and joints is used in the plenum model.

To achieve the greatest reduction in members and joints without altering the structural integrity of the model, the following changes are made to the detailed stack disk model:

- The disk rim members and joints were removed from the model
- The spacer members and joints were removed from the model
- The number of segments for the core tube and tension rods was reduced from 23 to 8
- The moment of inertias and cross sectional areas for the tension rods were manually adjusted
- The outer tension rods are tied to each other at two levels mimicking the effect of the disk rims.

The reduced detail model is intended to provide a realistic approximation of the mass and stiffness of the strainer stacks while greatly reducing the number of members and joints. A benchmarking process was done in the strainer calculation Reference [6], Section 7.0 to ensure the reduced model represents the same mass and stiffness as the full model.

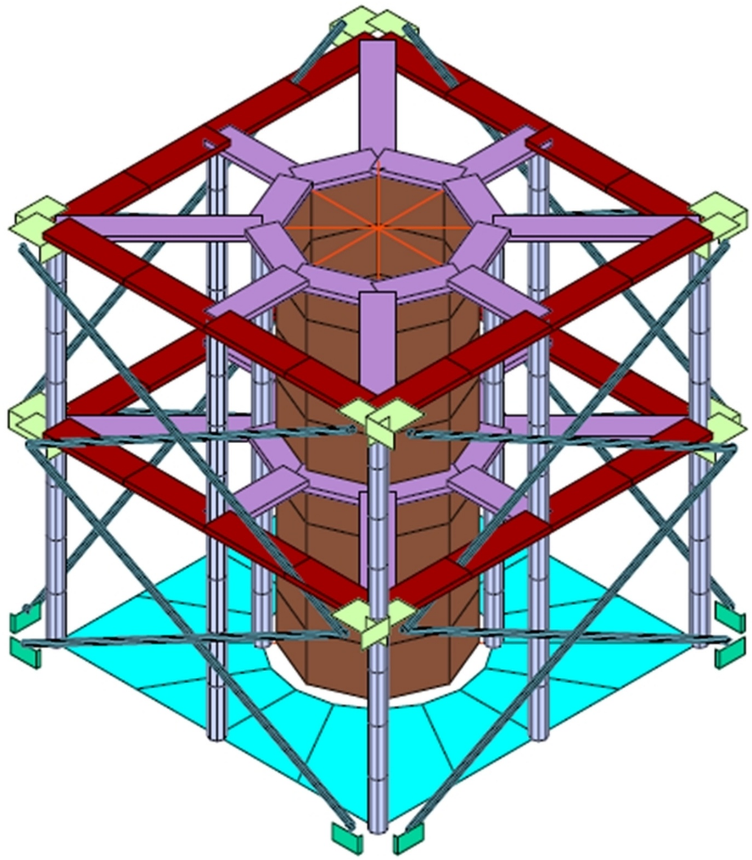


Figure 6 – Strainer Stack Reduced Detail Structural Model

4.2 Plenum Assembly Analysis

In order to accurately determine the state of stress in the strainer plenum, the strainer stacks need to be analyzed with the plenum. Since all four of the plenum structures are identical, one finite element model is used to analyze the strainer plenum. The main structural components of the strainer stacks are modeled with the plenum structure in one combined model.

Strainer Plenum Model

The finite element model of the strainer plenum includes all structural members and the cover plates. The cover plate includes nine, 13 $^{7}/_{8}$ inch diameter holes where the flow from each of the strainer stack core tubes penetrate the cover plate. In order to effectively and efficiently analyze the plenum model, the strainers need to be included. However, the finite element model of the strainer stack has a large number of members and joints and each plenum supports nine strainers. Therefore, in order to reduce the analysis time and level of complexity, a reduced detail stack disk model (See Section 4.1 for a more detailed description) with a more reasonable number of members and joints is used in place of 7 of 9 strainers in the combined plenum model. Full detailed stack disk models are used for the remaining two strainers.

The full and reduced detail stack disk models are attached on top of the strainer plenum model and a response spectra analysis is performed for the combined assembly to accurately determine the resulting forces in the strainer plenum. The seismic analysis is performed using the same methodology as for the detailed stack disk model. Pressure loads are applied to the plenum and strainer stacks to qualify the structure for an operating differential pressure between the outside and inside of the plenum. Loads representing a LOCA (Loss of Coolant Accident) transport through the vent and drain lines as well as loads resulting from relief valve discharge through the Letdown Piping sparger are also considered. Figure 8 shows a solid plot of the finite element model for the strainer plenum. The model is shown with the strainer stacks and plenum. The strainer stacks are represented without perforated plate disks as shown. 3

Placement of the full detail strainer model is determined by first running the combined assembly with all reduced detail strainer models. The interaction ratios of the strainer's major components are checked for maximum values. The strainer that consistently produces the highest interaction ratios is then replaced with a full detail strainer model. Furthermore, a review of the cover plate stress plots is used as a final confirmation of the full detail strainer model placement since high stresses in the cover plate indicate locations of displacement, forces and flexibility that influence the stresses in the strainers themselves. Since the stresses in two different reduced model strainers were considered significant, two full detail strainer models were included in the model.

Due to the size of the plenum cover plate, it cannot be constructed out of a single plate. Therefore, a splice is required where the plates meet. The tee beams provide the splice. Since the plates are not continuous, the cover plate is modeled with small gaps (1/8") between plates at the splice locations (see Figure 7).

The built up tee sections are made out of rectangular plates and are fastened over the edge of a cover plate to provide local stiffness to support the weight of the strainer.

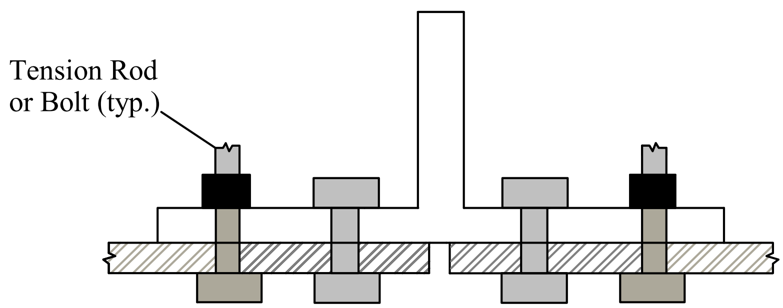


Figure 7 – Plenum Plate Splices

The cover plate is connected to the tee beams via bolts or tension rods. These connections are offset from the centroid of the tee beam. Therefore, rigid links are used to connect the beam centroid to the cover plate at the locations of the bolts or tension rods. All three moments are released at the cover plate.

The plenum is bolted to the concrete floor around the perimeter of the cover plate. There are slotted and oversized holes as required to facilitate thermal growth of the cover plate. The anchorage design is to be provided by others.

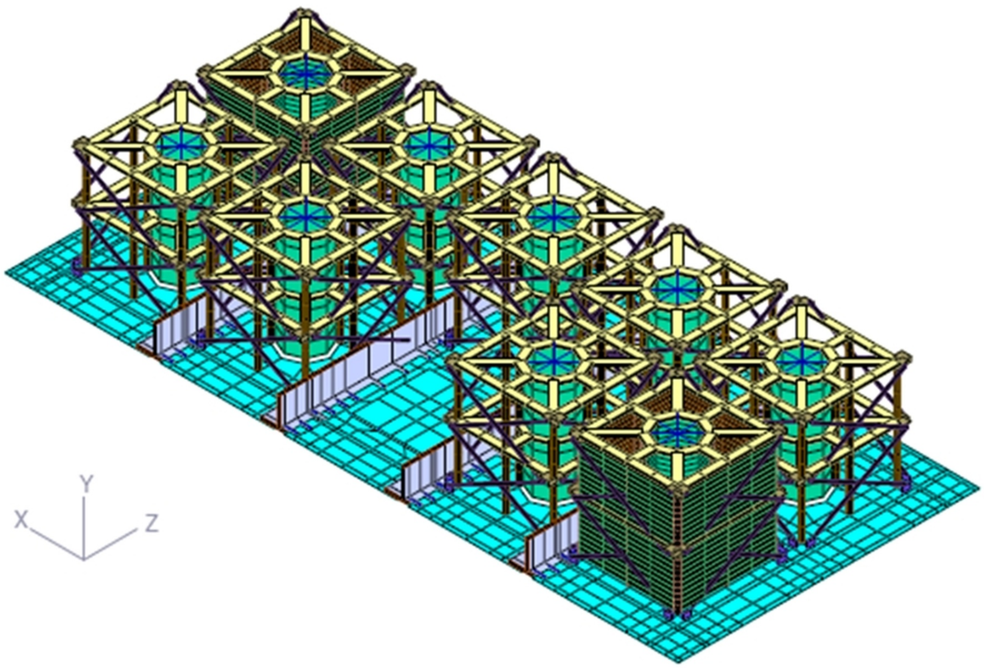


Figure 8 – Strainer Plenum Structural Model

5.0 <u>Loads and Load Combinations</u>

5.1 Loads

The following loads are considered in the strainer assembly design.

Deadweight (DL)

Deadweight loads include the weight of the steel that makes up the strainer stacks and plenum. The strainer assemblies are submerged, and therefore buoyancy effects exist on all of the components. To account for these effects, a buoyancy factor is calculated and applied to the deadweight load.

Debris Loads (L_{debris})

Debris loads include the weight of the debris, or foreign substance, which accumulates on the strainer stack and plenum during post LOCA operation. The calculated debris weight is calculated as 131.1 lbf per strainer stack and 62.4 lbf (0.45 psf) on the plenum cover plates, however, the structural analysis conservatively uses 175 lbf per strainer stack and 1.10 psf on the plenum cover plates. 3

Emergency Letdown Piping Sparger Discharge (L_{sparg})

The emergency letdown piping discharge load is the waterhammer pressure load on the strainer stacks resulting from a CS/RHR (Containment Spray/ Residual Heat Removal) relief valve discharge or an emergency letdown. This load can occur at any time. The pressure load of 8.60 psi is applied to all of the strainer stacks (Reference [7]). 3

Drain & Vent Line Discharge (L_{jet})

The drain and vent line discharge load is the water jet impingement load that results from a postulated rupture of a pressurized reactor system pipe. This load only occurs during a LOCA and is applied only to the portion of the strainer stack directly below the vent line. The jet load is calculated to be 261 lb (Reference [8]), however the structural analysis of the strainer stack conservatively uses 522 lbf. 3

Differential Pressure (P_{DP})

As per Section 3.4 of the Technical Specification (Reference [2]), the strainer shall be qualified for full debris loading in conjunction with all design basis conditions, without collapse or structural damage. A maximum differential pressure of 10 feet of water (Reference [2]) shall be considered across the debris covered perforated plate. The pressure retaining components of the strainer are designed for this maximum 3 differential pressure. Because the differential pressure load is essentially balanced on all sides of the strainer, the effect of differential pressure on the strainer structural components is minimal. However, differential pressure is the controlling load for the end cover, the perforated plate, and the plenum assembly.

Seismic Inertial Loads (SSE_I)

The seismic inertial loads are divided up into two parts; the inertial loads due to building motion and the drag effects due to seismic sloshing.

The inertial loads due to building motion are determined from a response spectrum analysis. The Technical Specification (Reference [2]) indicated that the quality group classification of the strainer is "Equipment Class 2" and the seismic category of the strainers and their supporting elements are category 1. Seismic category 1 components are to be analyzed for OBE and SSE seismic loads. However, as stated in the Design Control Document (Reference [4]), the OBE is less than or equal to 1/3 the SSE. Therefore, the OBE load need not be evaluated. The SSE response spectra curves are provided as an attachment to Reference [2] (see Figures 9 & 10). The plenum will be attached to the floor at elevation 3'-7", therefore the response spectra curves for elevation 3'-7'' are used. The strainer assemblies are bearing bolted structures, therefore 7% damping is used (see Appendix A and Z, Reference [2]). 3

Conservatively, the bounding NS and EW horizontal response spectrum is applied in both horizontal directions. Per Section 3.7.2 of the Design Control Document (Reference [4]), the three spatial earthquake components from the response spectra analysis are combined using the SRSS method. Note, the modal responses are combined using the methodology in Regulatory Guide 1.92 (Reference [9]) which specifies the "Complete Quadratic Combination (CQC) method. 3

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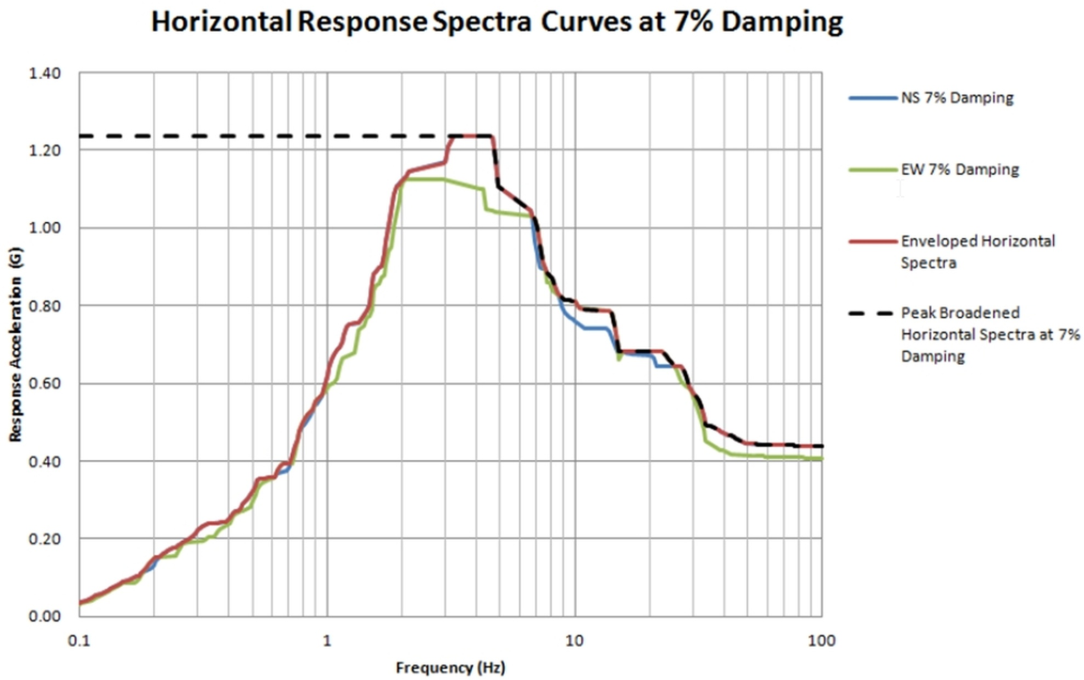

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Figure 9 – Horizontal SSE Response Spectra

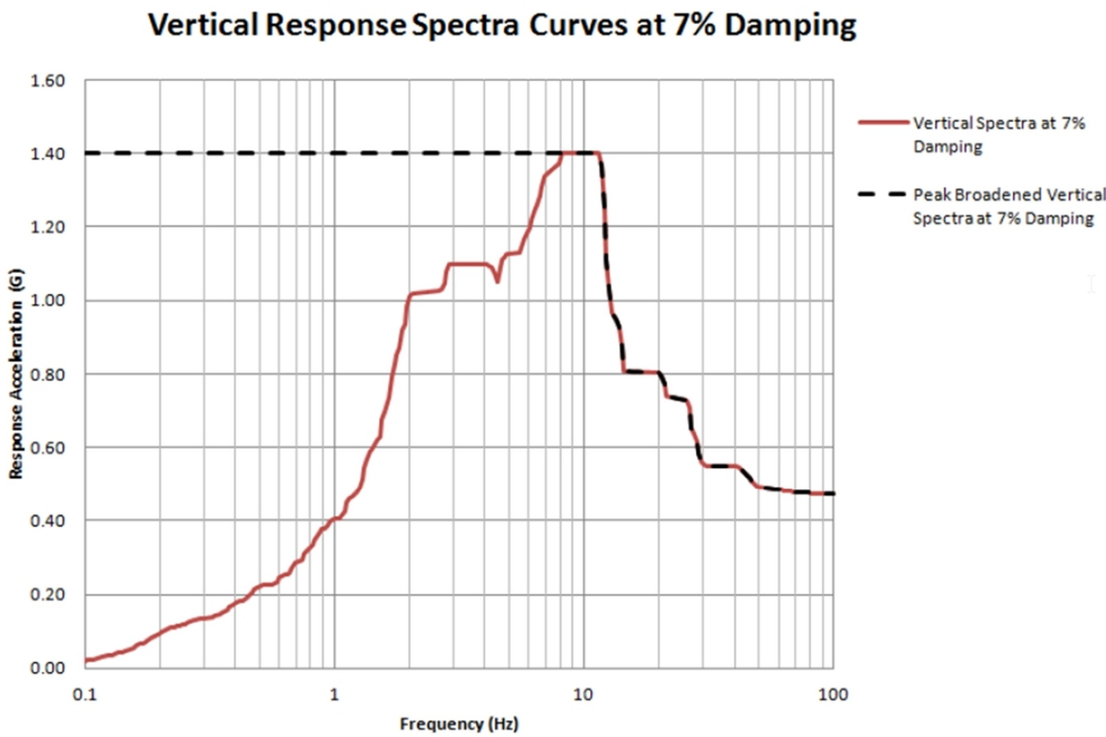

Figure 10 – Vertical SSE Response Spectra

The drag loads due to the motion of the water surrounding the strainer assembly, i.e., seismic slosh, are added to the seismic inertial load absolutely. The load is applied statically to all strainer stacks. The load acts on the ends and sides of the strainer assembly.

The seismic slosh load is based on a closed form solution where the containment was modeled as an annular tank. An equivalent mechanical model of the slosh caused by a horizontal excitation of the tank is composed of a series of oscillating slosh masses supported by mechanical springs. The water masses are broken into two parts, a rigid mass which behaves like a mass that is rigidly attached to the tank, and a sloshing mass that oscillates between the tank walls. The model is used to determine the sloshing velocities, which in turn are used to calculate the drag forces on the strainer stacks. The critical parameters for this analysis are the geometry of the tank (i.e., size of containment), the magnitude of the ground motions, and the size of the stacks. The sloshing loads per strainer stack are conservatively taken as 882.635 lbf laterally and negligible in the vertical direction (Reference [10]). The structural analysis of the strainer stack conservatively uses 900 lbf.

Thermal Expansion Loads

The stainless steel strainer assemblies will expand due to elevated temperature within the sump environment. The strainer assembly will not experience significant thermal stresses due to expansion because the strainer assembly is a bolted structure, free to expand vertically, and is supported such that horizontally the strainer assembly can freely grow thermally. Therefore, internal forces caused by thermal growth are considered negligible and are not included in the GTSTRUDL strainer model.

5.2 Load Combinations

Load combinations are developed with guidance from the Design Control Document (Reference [4]) and MHI Letter 4CU-UAP-20130003 (Reference [3]). Since the strainer assemblies are always submerged, the load combinations are evaluated for the submerged conditions. The following load combinations are used for the design of the strainer assembly and are based on MHI Letter 4CU-UAP-20130003 (Reference [3]). 3

Table 3 – Strainer Assembly Load Combinations

No.	**Load Combination**	**Service Level**
1	$P + DL + L_{DM} + L_{EM}$	Design
2	$P_m + DL + L_{EM}$	A
3	$P_m + DL + L_{EM} + L_{DFN} + TH_{TRN} + TH_{MTL}$	A
4	$P_m + DL + L_{EM} + L_{DFU} + TH_{TRN} + TH_{MTL} + (SSE_I + SSE_A)$	B
5	$P_m + DL + L_{DFE} + L_{EM}$	C
6	$P_m + DL + L_{DFF} + L_{EM}$	D
7	$P_m + DL + [(SSE_I + SSE_A)^2 + DBPB^2]^{1/2} + L_{EM}$	D
8	$P_m + DL + RV_{OS} + SSE_I + SSE_A + L_{EM}$	D
9	$P_m + DL + L_{DFS} + [(SSE_I + SSE_A)^2 + DBPB^2]^{1/2} + L_{DFF} + L_{EM}$	D

3

Where,

P = Design Pressure, due to the holes in the perforated plate = **0.0 for strainer assembly**

P_m = Maximum Service Pressure, this load = **0.0 for service level A and B**
= Differential Pressure Load (P_{DP}) for the strainer assembly for Service Level C and D

DL = Dead Weight Load of strainer assembly components
= DL, Service Levels A & B (conservatively includes debris weight on strainer stacks)
= $DL + L_{debris}$, Service Levels C & D

L_{DM} = Design Mechanical Loads other than DL, includes Service Level A loads and Open Relief Valve Dynamic Loads that are Service Level B, this load = **0.0 for strainer assembly**

L_{EM} = External Mechanically Applied Loads, Including Equipment Nozzle-to-Pipe Reactions
= **0.0 or**
= Emergency Letdown Piping Sparger Discharge Loads (L_{sparg}), Service Level A & B
= Drain & Vent Line Discharge Load (L_{jet}), Service Level C & D or
= Emergency Letdown Piping Sparger Discharge Loads (L_{sparg}) and Drain & Vent Line Discharge Load (L_{jet}), Service Level C & D

L_{DFN} = ASME Service Level A (Normal) Dynamic Loads (Transient Valve Loads) including QV_c (Quick Valve Closure), RV_c (Relief Valve Closed System Sudden Opening), RV_o (Relief Valve Open System Sudden Opening), this load = **0.0 for the strainer assembly**

TH_{TRN} = Thermal Transient Loads, this load = **0.0 for the strainer assembly**

TH_{MTL} = Thermal Loading for ASME Service Conditions,
= 0.0 or
= TH_n, the thermal loads at maximum normal operating temperature of 120^o F
= TH_{loca}, the thermal loads at POST LOCA accident temperature of 270^o F 3

SSE_I = Safe Shutdown Earthquake Inertial Loads, include seismic sloshing loads

SSE_A = Safe Shutdown Earthquake Anchor Loads, this load = **0.0 for the strainer assembly**

L_{DFU} = ASME Service Level B (Upset) Dynamic Loads (Transient Valve Loads) including QV_c (Quick Valve Closure), this load = **0.0 for strainer assembly**

L_{DFE} = ASME Service Level C (Emergency) Dynamic Loads (Transient Valve Loads) including QV_c (Quick Valve Closure), this load = **0.0 for strainer assembly**

L_{DFF} = ASME Service Level D (Faulted) Dynamic Loads (Transient Valve Loads) including QV_c (Quick Valve Closure), this load = **0.0 for strainer assembly**

L_{DF} = Dynamic Loads (Transient Valve Loads) including QV_c (Quick Valve Closure), RV_c (Relief Valve Closed System Sudden Opening), RV_o (Relief Valve Open System Sudden Opening) associated with ASME Level A, B, C and D Service Conditions, this load = **0.0 for strainer assembly**

DBPB = Design Basis Pipe Break, this load = **0.0 for strainer assembly**

RV_{OS} = Relief Valve Open System Sudden Opening Sustained, this load = **0.0 for strainer assembly**

L_{DFS} = Sustained Dynamic Loads Associated with ASME Level A, B, C and D Service Conditions, this load = **0.0 for strainer assembly**

The following three load combinations and associated service levels result from enveloping the ten load combinations identified in Table 3. These load combinations are used in the GTSTRUDL strainer assembly finite element analyses.

Table 4 - Strainer Assembly Bounding Load Combinations

No.	Description	Justification	Service Level
LC1	$DL + TH_{loca} + L_{sparg}$	Envelopes LC's 1, 2 & 3	A
LC2	$DL + TH_{loca} + L_{sparg} + SSE_I$	Envelopes LC 4	B
LC3	$DL + TH_{loca} + L_{debris} + P_{dp} + L_{jet} + L_{sparg} + SSE_I$	Envelopes LC's 5-9	C

6.0 Acceptance Criteria

The strainer stack assembly is designed to meet the requirements as specified in the Purchase Specification (Reference [1]) and the Technical Specification (Reference [2]). Per References [1] and [3], the governing code is ASME, Section III. Therefore, the allowable stresses are primarily based on the ASME Code (Reference [5]) and are supplemented as required for stresses or special components and/or loading conditions. The strainer assemblies are considered part of the pressure boundary for the ECC and CS systems since they are used to prevent debris from entering these systems. From Table 3.2-2 of the Design Control Document (Reference [4]), the ECC and CS strainer assemblies are considered Equipment Class 2. From Table 3.2-3 of the Design Control Document, Equipment Class 2 components are analyzed in accordance with the ASME Code, Section III, Class 2 rules. Therefore, the detailed evaluations are performed using the rules, as applicable, of the ASME Boiler and Pressure Vessel Code, Class 2 Components, as presented in ASME Section III, Division 1, Subsection NC and applicable appendices (Reference [5]). The structural support components are evaluated as component supports per Subsection NF. 3

The ASME Class 2, strainer assembly pressure-retaining components are evaluated in accordance with ASME Section III, Division 1, Subsection NC, Section NC-3300 .

The ASME Class 2, component supports are evaluated in accordance with Subsection NF, NF-3350 which specifies the allowable loads from Section NF-3320 be used. A summary of allowable Level A stresses is provided below. The allowable stress increase factors for Service Level B and C load combinations are also provided below.

Table 5 – Strainer Assembly Stress Acceptance Criteria [1]			
Stress Type	Load Case 1 Service Level A	Load Case 2 Service Level B	Load Case 3 Service Level C
Plate Members			
▪ Primary Membrane Stress	1.0*S	1.1*S	1.5*S
▪ Primary Membrane + Bending Stress	1.5*S	1.65*S	1.8*S
Linear Type Component Supports[2]			
▪ Tension Stress	$0.6*S_y$	1.33*Level A	$1.5*\text{Level A} \leq 0.7*S_u$
▪ Shear Stress	$0.4*S_y$	$1.33*\text{Level A} \leq 0.42*S_u$	$1.5*\text{Level A} \leq 0.42*S_u$
▪ Compression Stress[3]	$0.47*S_y$	1.33*Level A	$1.5*\text{Level A} \leq 0.7*S_u$
▪ Strong Axis Bending Stress[4]	$0.66*S_y$	1.33*Level A	$1.5*\text{Level A} \leq 0.7*S_u$
▪ Weak Axis Bending Stress[5]	$0.75*S_y$	1.33* Level A	$1.5*\text{Level A} \leq 0.7*S_u$
▪ Fillet Weld Stress[6]	$0.3*S_{uw}$	1.33*Level A	$0.42*S_{uw}$
▪ Rivets[7] (closed end)	$\leq (F_{test}/\Phi_{closed})$	$\leq 1.33*(F_{test}/\Phi_{closed})$	$\leq 1.5*(F_{test}/\Phi_{closed})$
▪ Rivets[7] (blind end)	$\leq (F_{test}/\Phi_{blind})$	$\leq 1.33*(F_{test}/\Phi_{blind})$	$\leq 1.5*(F_{test}/\Phi_{blind})$
Bolting[8]			
▪ Bolting Tension Stress[9]	$S_u/3.33$	$1.15*\text{Level A} \leq S_y$	$1.25*\text{Level A} \leq S_y$
▪ Bolting Shear Stress[9,10]	$0.62*S_u/5$	$0.713*S_u/3.33$	$0.775*S_u/3.33$

3

Notes:

1. Where "S" is the allowable stress, "S_y" is the yield strength, and "S_u" is the tensile strength for the material. "S_{uw}" is the tensile strength of the weld material.

2. The stresses for linear type supports were multiplied by factors found in Table NF-3523(b)-1 of Reference [5].

3. The compression stress allowable for austenitic stainless steel is more complicated and is explained in more detail in the strainer and plenum detailed calculations (References [6] and [11]).

4. The strong axis bending stress allowable of 0.66 S_y is applicable only for compact sections. The allowable stress for non-compact sections is more complicated and is determined by GTSTRUDL in the code evaluation.

5. The weak axis bending allowable stress of 0.75 S_y is applicable only for round and rectangular bar sections. The allowable stress for weak axis bending for other sections is more complicated and is determined by GTSTRUDL in the code evaluation.

6. The weld stress is based on the effective throat of the weld. The shear stress on the base metal is limited to $0.4S_y$, $0.532S_y$ and $0.6S_y$ of the base metal for Service Levels A, B and C respectively.

7. Φ_{closed} and Φ_{blind} are the factors of safety from Reference [12] and F_{test} is the failure load identified in Reference [13] for the closed end and blind end rivets respectively

8. The stresses for bolting were multiplied by the factors in found in Table NF-3225.2-1 of Reference [5]

9. The bolt stress is based on the actual bolt area available. 3

10. All bolted connections are considered bearing type with threads excluded from the shear plane. Note, the threads are included in the shear plane for the evaluation of the tension rods.

<u>Special Considerations</u>

Disk Rims

The disk rims (channel shaped sections at the outer edges of each disk) and the attached perforated plate works as a combined section to resist bending loads. The effective width of the perforated plate that acts in combination with the disk rim is based on Section 2.3 of the ASCE Standard for Cold-Formed Stainless Steel Structural Members (Reference [12]), which provides design guidelines for very thin members such as the perforated plate. The effective width of the plate is limited by the width to thickness ratios such that local buckling of the plate will not occur for the compression face.

Welds

There are no pressure retaining welds for the strainer assembly.

Welds for non-pressure retaining strainer support components are qualified per the ASME Section III (Reference [5]), Subsection NF. AWS D1.6 (Reference [14]) was reviewed to ensure that any special qualification requirements associated with stainless steel welding are considered. Since the weld allowables provided in AWS D1.6 are essentially the same as allowed by the ASME Code, no special adjustments are to account for stainless steel. The welds are fabricated using qualified weld procedures.

Rivets

There are two areas in the strainer stacks where rivets are used as fasteners. The disk faces are fastened to the perforated disk rims using 3/16" blind rivets. The gap assembly perforated plate is fashioned into a ring using two 3/16" closed end rivets. The rivets' capacities are based on testing. From Reference [13], the capacities of the closed end and blind rivets are taken as the average value from six tests (six tests for shear and six tests for tension). A factor of safety is then calculated according to the ASCE Standard (Reference [12]) as supplemented by the AISI Code (Reference [15]) accounting for the capacities being found experimentally via a small sample group. The factor of safety is between 1.67 and 2.60 depending upon the Service Level, and whether the rivet is in tension or shear.

Seismic Rods / Tension Rods

The ends of the tension and seismic rods are threaded. Accordingly, the qualification of the threaded ends of the rod is based upon a bolted connection per the ASME Code, Section III, Subsection NF-3324.6 (Reference [5]).

7.0 Evaluation Results

Strainer Stack Assembly

The interaction ratios of the strainer stack components are as follows:

Table 6 - Strainer Stack Stress Interaction Ratios

Component	Interaction Ratio
Perforated Plate, Disks and Gap Assembly	0.92
Supporting Grill Wire Stiffeners	0.43
Core Tube and End Cover	0.65
Tension Rods/Spacers	0.58
Core Tube Mating Flange Weld	0.45
Seismic Rods (Cross Bracing)	0.40
Top and Intermediate Stiffener Plates	0.47
Connection Pins and Blocks	0.19
Seismic Tabs and Welds	0.58
Rivets	0.24

3

Plenum Assembly

The interaction ratios of the strainer plenum components are as follows:

Table 7 - Strainer Plenum Stress Interaction Ratios

Component	Interaction Ratio
Cover Plate	0.32
Tee Beam	0.46
Bolts & Tension Rods	0.57

3

8.0 Conclusions

The US-APWR Strainer Assembly is evaluated to the requirements set forth in the US-APWR Purchase and Technical Documentation and all components are in compliance with the Rules of the 2007 edition of the ASME Code, up to and including the 2008 Addenda. 3

9.0 References

1. Standard US-APWR, Purchase Specification, Design and Evaluation of Sump Strainer, 4CE-UAP-20080009, Revision 21. 3

2. US-APWR, Technical Information and Requirements for ECC/CS Sump Strainer, 4CS-UAP-20080045, Revision 18. 3

3. MHI Letter, 4CU-UAP-20130003, May 28, 2013, "Load combination and applicable ASME edition for sump strainer structural calculation" 3

4. MHI Design Control Document for the US-APWR, MUAP-DC003, Revision 3.

5. ASME Boiler & Pressure Vessel Code, Section III, Division 1, 2007 edition, up to and including 2008 Addenda. 3

6. Calculation PCI-9082-S01, Qualification of US-APWR Containment Sump Strainer Module, Revision 3. 3

7. Calculation PCI-9082-S05, Development of Emergency Letdown Piping Sparger Discharge Loads, Revision 2. 3

8. Calculation PCI-9082-S04, Development of Drain & Vent Line Discharge Loads Due to LOCA, Revision 2. 3

9. US NRC Regulatory Guide 1.92, “Combining Modal Responses and Spatial Components in Seismic Response Analysis,” Revision 2, July 2006.

10. Calculation PCI-9082-S03, Sloshing Evaluation for US-APWR RWSP, Revision 3. 3

11. Calculation PCI-9082-S02, Qualification of US-APWR Containment Sump Strainer Plenum Structure, Revision 3. 3

12. ASCE Standard SEI/ASCE 8-02, “Specification for the Design of Cold Formed Stainless Steel Structural Members.”

13. PCI Intra-company correspondence from Greg Hunter, Dated May 8, 2008, Subject: "Testing of 3/16” Blind Rivets with 22 ga. perf. 066” Holes”

14. ANSI/AWS D1.6, 1999, Structural Welding Code - Stainless Steel.

15. AISI Specification for the Design of Cold Formed Steel Structural Members, 1996 Edition.