ENCLOSURE 1

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2017/01/11
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30441R00030
Revision A

REACTOR-BASED MOLYBDENUM-99 SUPPLY SYSTEM PROJECT

MO-99 TARGET COOLING SYSTEM SEISMIC ANALYSIS DESIGN CALCULATION REPORT

Prepared by General Atomics
for the U.S. Department of Energy/National Nuclear Security Administration and Nordion Canada Inc.

Cooperative Agreement DE-NA0002773

GA Project 30441
WBS 1110

GENERAL ATOMICS

MURR® Matters...

nordion

REVISION HISTORY

Revision	Date	Description of Changes
A	11JAN17	Initial Release

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DESIGN CONTROL SYSTEM DESCRIPTION

	DISC	QA LEVEL	SYS
☐ R & D ☒ DV&S ☐ DESIGN ☐ T&E ☐ NA	N	II	N/A

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACRONYMS

Acronym	Description
AISC	American Institute of Steel Construction
ASCE	American Society of Civil Engineering
ASME	American Society of Mechanical Engineering
MDMT	Minimum Design Metal Temperature
GA	General Atomics
GR	Gravity
MDMT	Minimum Design Metal Temperature
P	Pressure

1 OBJECTIVE

The purpose of this document is to demonstrate that the Mo-99 Target Cooling System for the Once-Through Approach as part of the Reactor-Based Molybdenum-99 Selective Gas Extraction (SGE) meets the requirements of the ASME B31.3 2014 (Ref. 1) and seismic load conditions per ASCE 7-10 (Ref. 2).

Top level design requirements for the Mo-99 Target Cooling System are defined in the Molybdenum-99 Supply System Requirements Document (30441S00001).

The Once-Through Approach design will be developed and demonstrated under the RB-MSS project, co-funded by the Department of Energy, National Nuclear Security Administration (DOE-NNSA) and Nordion (Canada), Inc. It is intended that the MSS will be installed and operated at the University of Missouri Research Reactor (MURR) to begin production of commercially-significant quantities of Mo-99 (≥3000 6-day Ci/week) by the beginning of 2018.

This document provides the pipe stress calculations for the primary cooling loop, see Figure 1, excluding equipment. The analysis was performed using Bentley AutoPIPE CONNECT Advance Edition Version 10.00.00.10, a specialized nonlinear finite element piping program. The resulting piping stresses were interpreted in accordance of ASME B31.3 (Ref. 1) and ASCE 7-10 (Ref. 2), for structural adequacy. The target housing and heat exchanger interface connection will be idealized with anchors at the flange points.

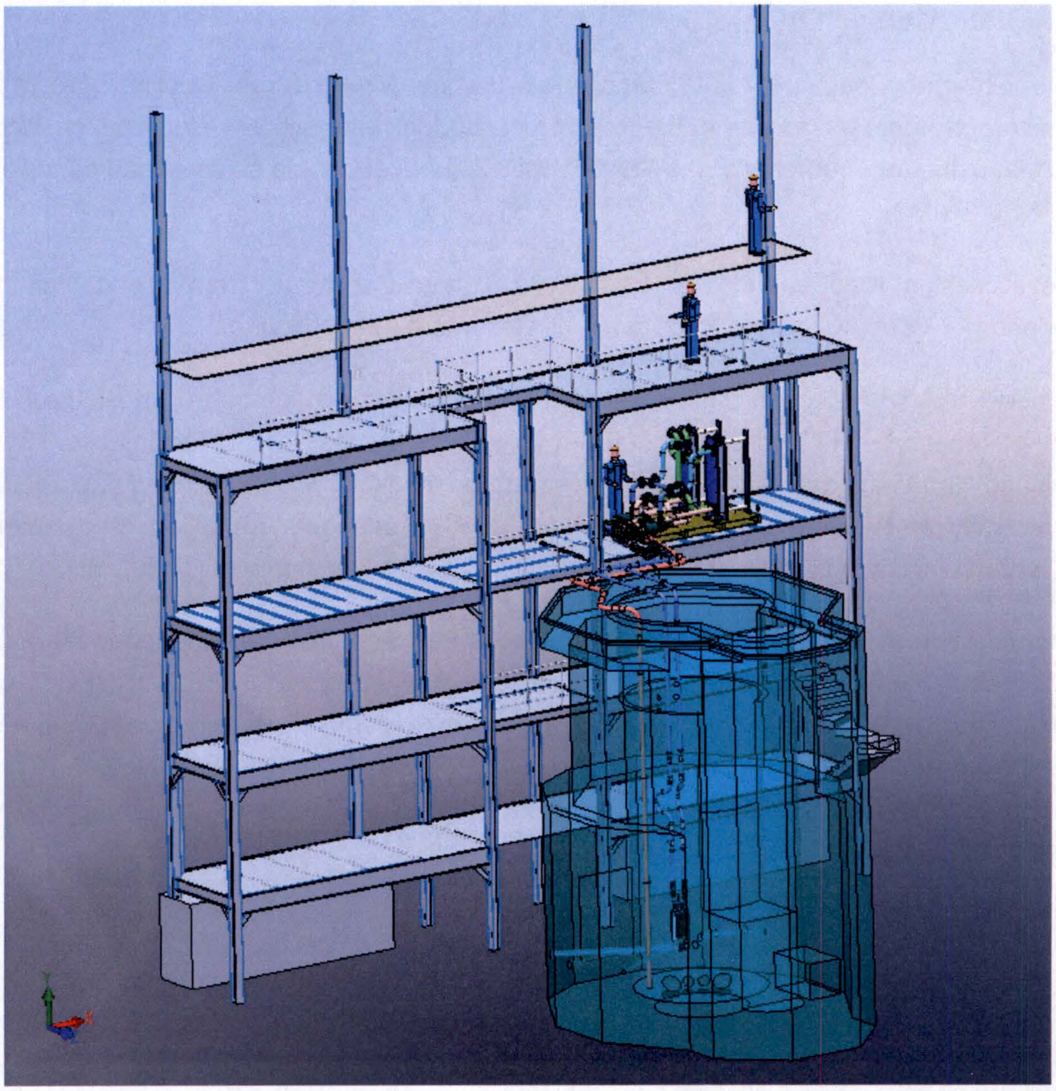


Figure 1. Moly 99 Solidworks model

2 APPLICABLE DOCUMENTS

Document Number	Document Title
30441S00001	Molybdenum-99 Supply System Requirements Document

3 INPUTS

3.1 General

The following inputs were used for the calculations presented herein:

- Piping arrangements as depicted in Figure 2; "MURR Master Model.SLDASM", SolidWorks.

- Pipe sizes and material selection per "MURR Master Model.SLDASM" and as described in Section 5.3

- Component weights per "MURR Master Model.SLDASM" for pipe sizes and material selection.

3.2 Loads

Operating and Seismic loads are based on the "Molybdenum-99 Supply System Requirements Document" (30441S00001), ASME B31.3 (Ref. 1) and ASCE 7-10 (Ref. 2) and are as described in Section 6.

4 ASSUMPTIONS

The following assumptions are made for the structural evaluation of the piping of the target cooling system.

- All pumps, heat exchangers, and external connections will be modeled as anchors at interface connection points. This is an accurate depiction as the mechanical components can be considered rigid, with indefinite stiffness.

- All piping supports, vibration damping type, are modeled as line supports with no gaps and connected to rigid ground. This is an accurate depiction of this type of supports.

- Bio-Shield, CoStarTower and Bridge are rigid structures. This is an accurate depiction of said structures due to low seismic loading, maximum deflections of structures within areas of interest are estimated to be < 1/16th inch.

- Maximum seismic differential movement between CoStarTower/Bridge and Bio-Shield is < 2.0 inches. This is a conservative number, as lateral movement of the CoStarTower is estimated to be less than 1/8th inch at bridge elevation.

5 METHOD

Seismic loading conditions will be defined per ASCE 7-10, and evaluated against ASME B31.3 2014.

Two types of analysis were performed:

1. Rigid Support Structure:

- Assumes that piping support structures, Bio-shield/pool, CoStarTower and bridge are rigid structures. No differential lateral displacements occurs between the individual structures during a seismic event.

- Pipe analysis is performed in accordance with ASME B31.3 and ASCE 7-10.

2. Flexible Support Structure

   - Assumes that the Bioshield/pool and CoStarTower combined with the Bridge will laterally displace during a seismic event.

   - Pipe analysis is performed to evaluate stresses and adequacy of flexible piping. A forced displacement of 2 inches is applied to the piping located on the CoStarTower and Bridge side relative to the piping located and mounted on the Bio-Shield side to simulate differential movement between the two main structures during a seismic event. Analysis is performed in accordance with ASME B31.3 and ASCE 7-10.

Further description and results can be found in Section 7.

6 AUTOPIPE MODEL

AutoPIPE model is generated from Solidworks 3-D model, "MURR Master Model.SLDASM", October 12, 2016, with an update on December 5, 2016 to remove a subset of piping.

Figure 2 to Figure 7 show the Solidworks/AutoPIPE details of the piping system with the pool and frame hidden. Green symbols on AutoPIPE mode figures represent constraints on the piping.

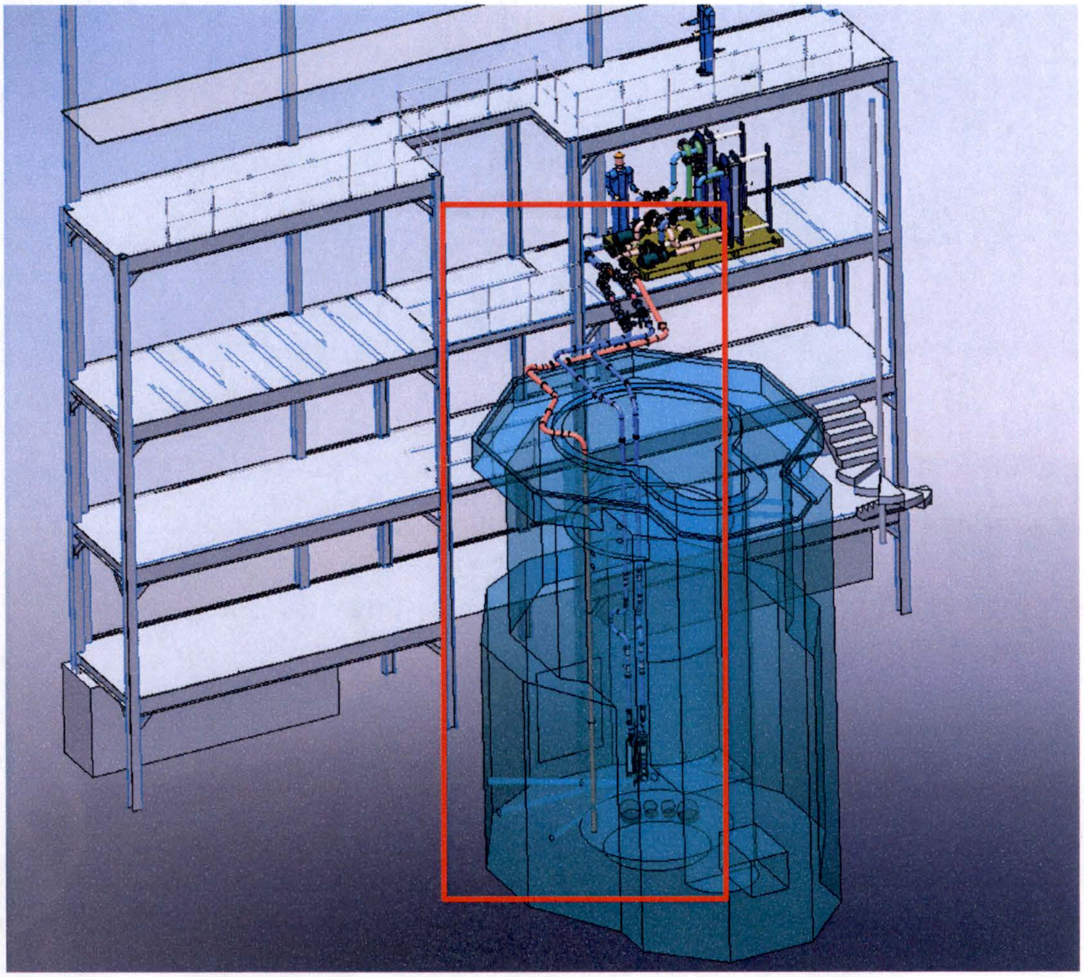


Figure 2. Solidworks Assembly (Red Box is the piping of interest)

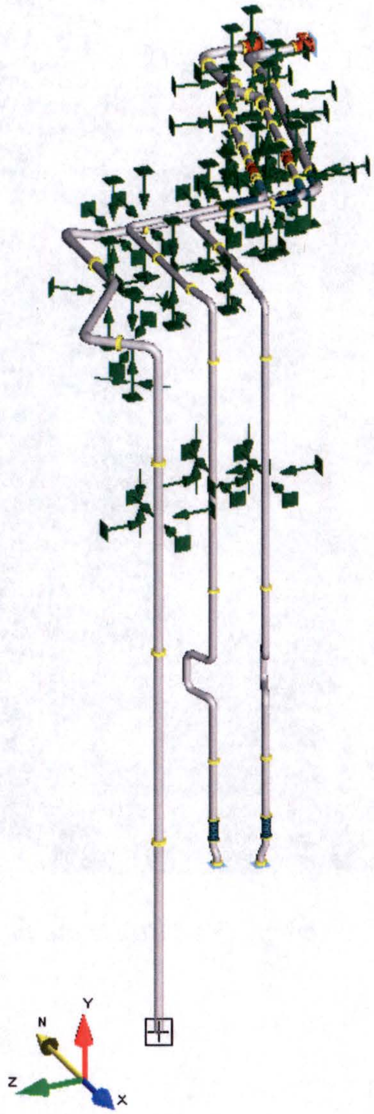


Figure 3. AutoPIPE's model of the piping of interest

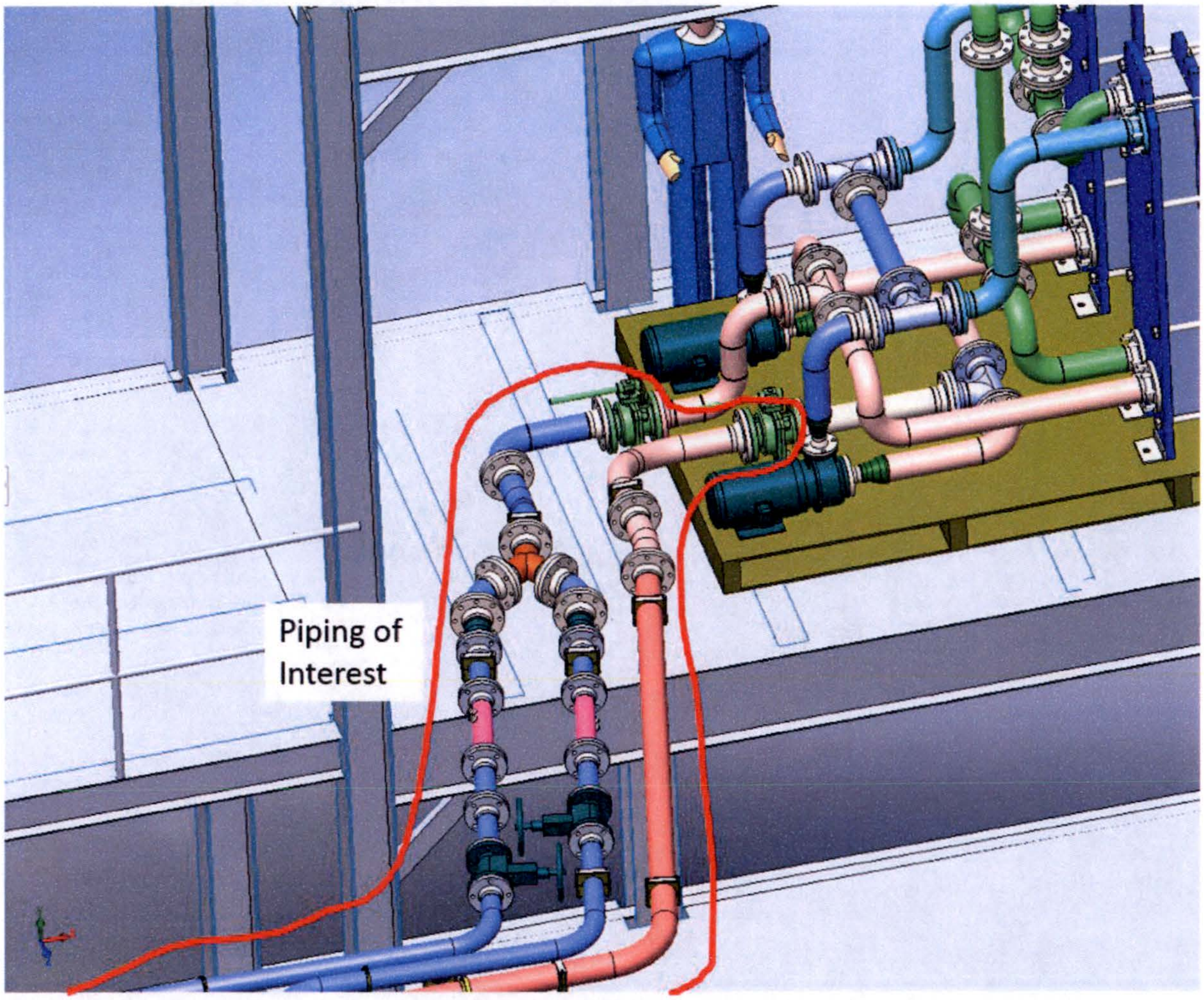


Figure 4. Solidworks Level 3-4 up-close view

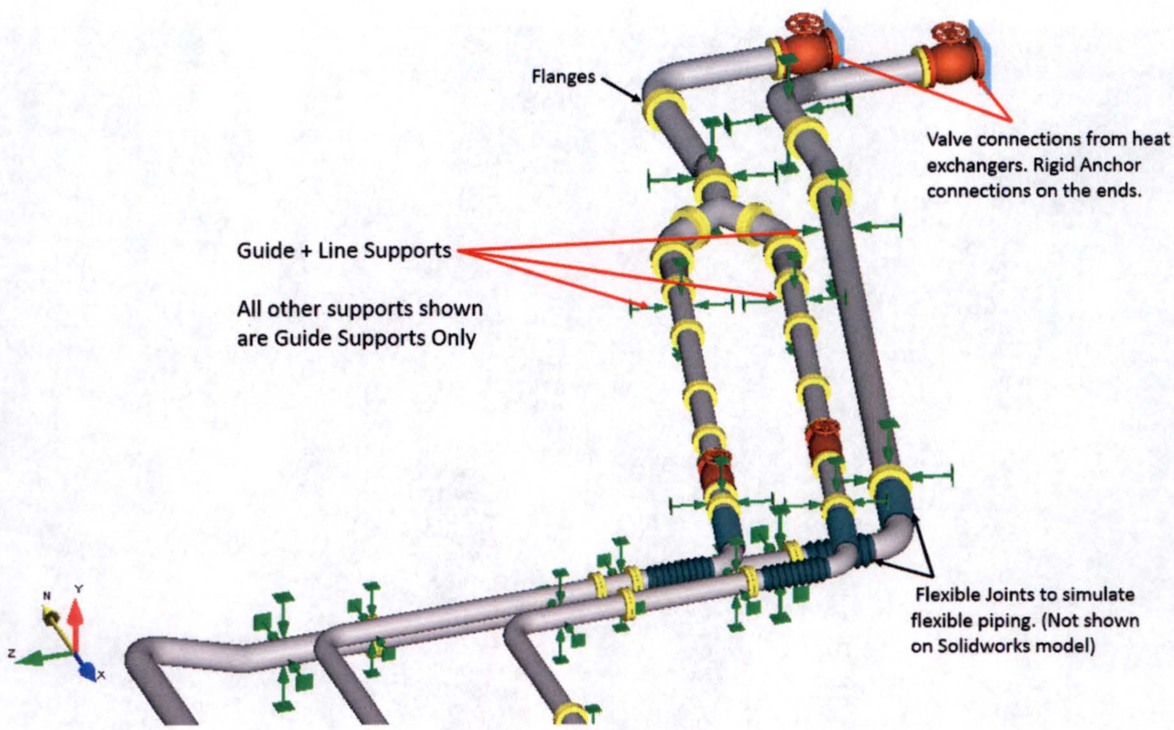


Figure 5. AutoPIPE Level 3-4 up-close view

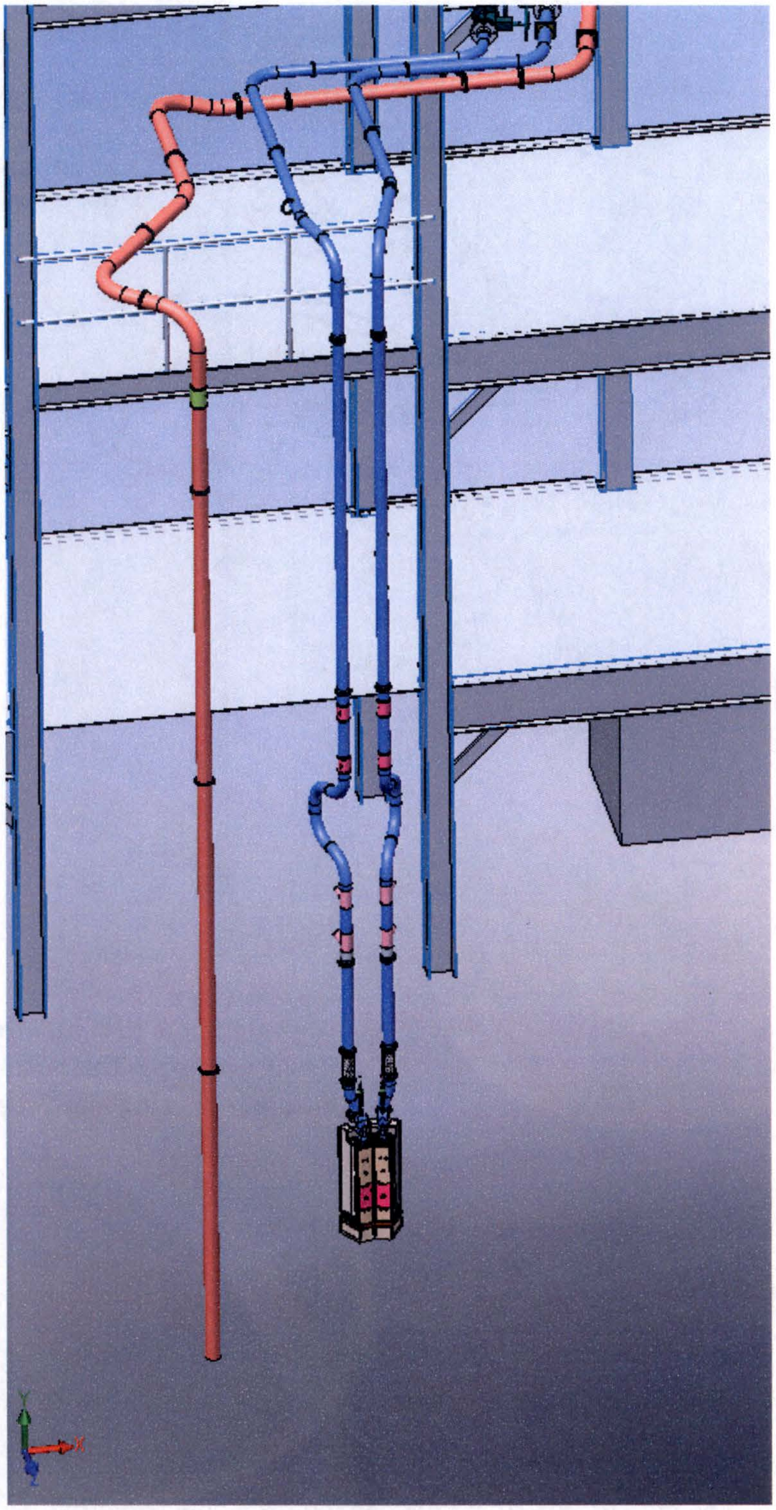


Figure 6. Solidworks model with pool hidden

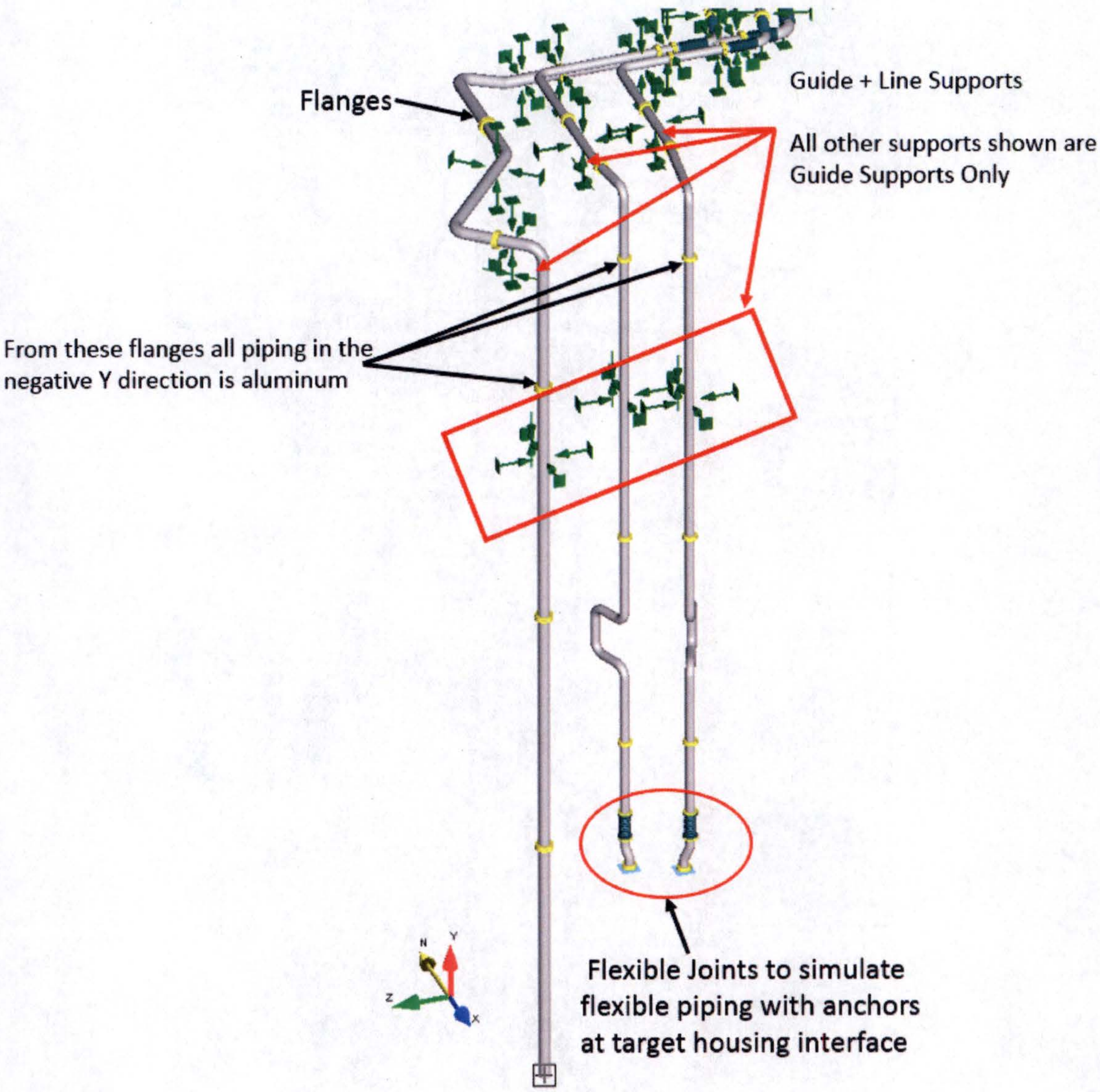


Figure 7. AutoPIPE model with pool hidden

6.1 Support Details

As discussed in the assumptions, Rail Mount Vibration Damping Clamps will be modeled as guide supports with no gaps. An example is shown in Figure 8. Guide supports restrict the radial movement of the piping at that point.

Figure 9 shows the line stop value with no gaps in the axial direction of the piping. The line stop location is shown in the previous section. Line Stop supports restrict the axial movement of the piping at that point. Location of line stops are shown in the previous section.

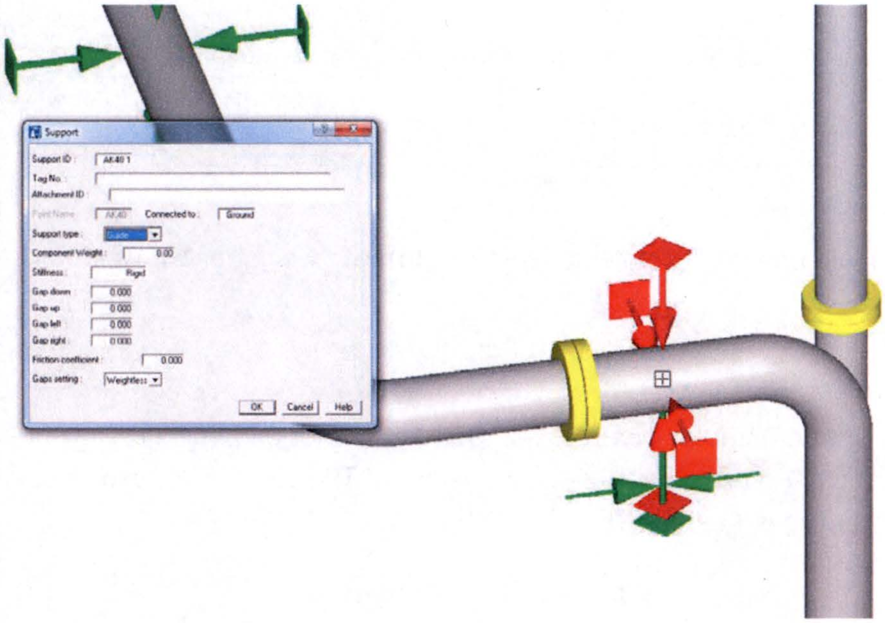


Figure 8. AutoPIPE Model Guide Support Value

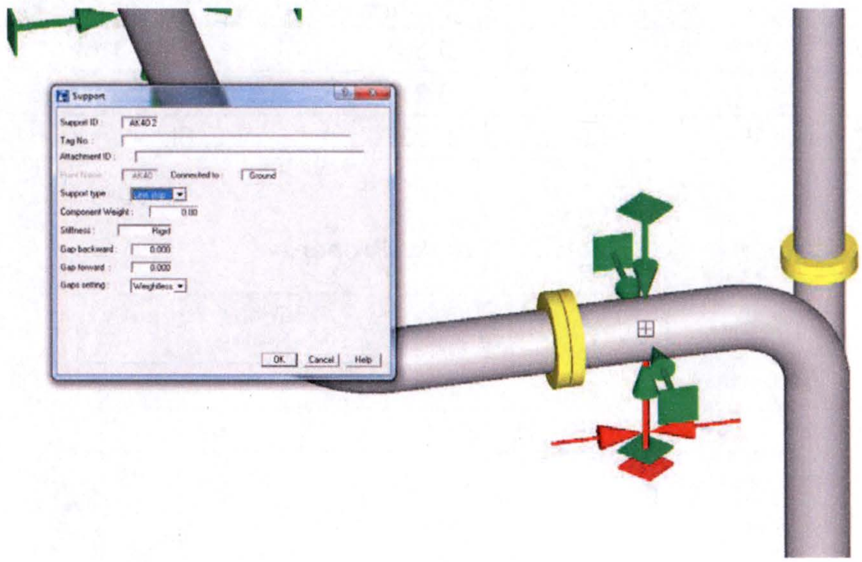


Figure 9. AutoPIPE Model Line Stop Value

6.2 Valves and Flanges

The valves in this model are flanged and rated at 150 lb with 3", and 4" sizing. See Table 1 for weights.

Table 1. Flanged Valve Weight

Size (inch)	Ball Valve (lbf)	Globe (lbf)
3	N/A	82
4	144	N/A

Flanges are modeled as point elements (zero length) with weight and a weld neck connection specified.

6.3 Piping

The system consists of three standard sizes. See Table 2 for properties and Figure 10 for pipe size. The entire model is assigned material properties of TP316L with the exception of the piping in the pool. Pool piping is AL-6061 T6.

Table 2. Pipe Properties

Nominal Size (inch)	Schedule	Outer Diameter (inch)	Wall Thickness (inch)	Material
2	40	2.375	0.154	TP316L
3	40	3.5	0.216	TP316L or AL-6061 T6
4	40	4.5	0.237	TP316L or AL-6061 T6

Table 3. Material Properties

Material	Yield Strength (ksi)	Ultimate Strength (ksi)
TP316L	25	70
AL-6061 T6	35	42

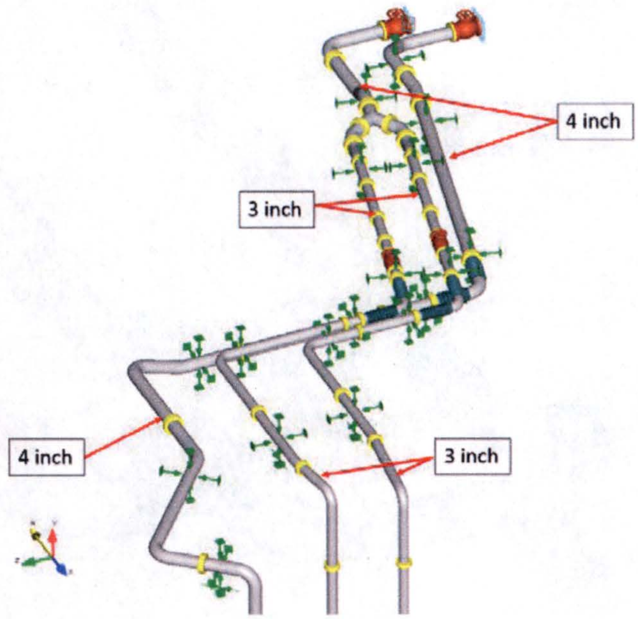


Figure 10. Pipe sizes

6.4 Flexible Joints

To account for independent seismic movement of the building relative to the pool, flexible piping is added to the piping connection at the bridge level. All flexible piping is 11 inches in length and flanged. A guide support is added with the flange connections on the non-flexible piping side. Flexible piping stiffness values were based on GA test data. The following stiffness is applied

- Axial – 182 lb/in
- Shear – 14 lb/in (both directions)
- Torsional – Rigid
- Bending – Rigid (both directions)

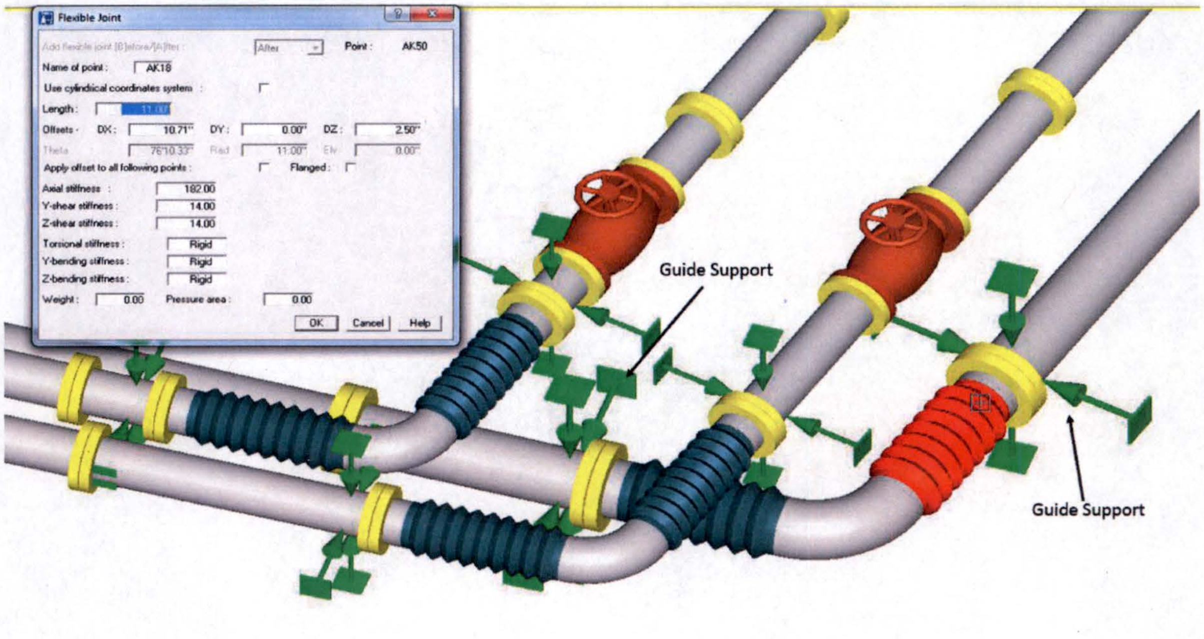


Figure 11. Flexible joint input values

7 CALCUATION BODY

7.1 Operational Loading

The system was analyzed subject to the following loading in Table 4. In addition to the temperature and pressure loads the piping system was also subjected to gravitational load. The liquid in the piping is assumed to be water.

Table 4. Loading Inputs

Gravity	Temperature	Pressure	Notes
1g	78.8°F	30 psig	Ambient is 68°F

7.2 Seismic Loads

ASCE 7-10, Reference 2, shall serve as the seismic design guide for the installed and operated target cooling system at MURR.

7.2.1 Site Specific Criteria

Location is Latitude 38.93166 and Longitude -92.3418 is based on Columbia, MO 65211

- Ip = 1.0 (attached to an occupancy II building/structure)
- Rp = 12 (ASCE 7-10 table 13.6-1; welded piping)
- a_p = 2.5 (ASCE 7-10 table 13.6-1)

- S_{DS} = 0.112g (Refs. 4 and 5- USGS APPENDIX A and APPENDIX B respectively)
- Site Class B (Rock, based on FEMA maps see Ref. 6 - APPENDIX C)
- z = 62.5 ft (Based on the Solidworks model the bottom of the building to top of the piping system)
- h = 70ft (Based on the Solidworks model from the bottom to the top of the building)

7.2.2 Seismic Forces

Seismic forces, F_P, will be determined in accordance with Section 13.3 (Ref. 2) as follows:

$$F_P = \frac{0.4 a_P S_{DS} W_D (1+2z/h)}{(R_P/I_P)}$$ (Eqn. 13.3-1, Ref. 2)

However, F_P will not be greater than: $F_P = 1.6 S_{DS} I_P W_D$ (Eqn. 13.3-2, Ref. 2)

and, F_P will not be less than: $F_P = 0.3 S_{DS} I_P W_D$ (Eqn. 13.3-3, Ref. 2)

where:

F_P = Seismic design force
a_P = Amplification factor
S_{DS}= Design spectral response acceleration, short period
W_D = Dead load
z = Attachment Height, relative to finished grade
h = Roof Height, height of structure, relative to adjacent finished grade
R_P = Response modification factor
I_P = Importance factor

Seismic Load per Section 12.4.2 (Ref. 2):

$E_h = \rho Q_E$ (Eqn. 12.4-3, Ref. 2)
$E_v = 0.2 S_{DS} D$ (Eqn. 12.4-4, Ref. 2)*

where:

E_h = Horizontal seismic load effect
E_v = Vertical seismic load effect
ρ = 1.0 (Redundancy Factor)
Q_E = F_P (Effect of horizontal seismic force)
S_{DS}= Design spectral response acceleration at short period
D = Dead Load (piping operating weight)

*Note: In addition of applying the two shear forces simultaneously, a conservative AutoPIPE default vertical factor of 0.5 was used. Vertical force can be calculated using ASCE 7-10 12.4-4 but is much smaller than 0.5 x shear direction. The higher value is used.

- E_h = 0.035g (Shear)

- E_v = 0.0175g (Vertical)

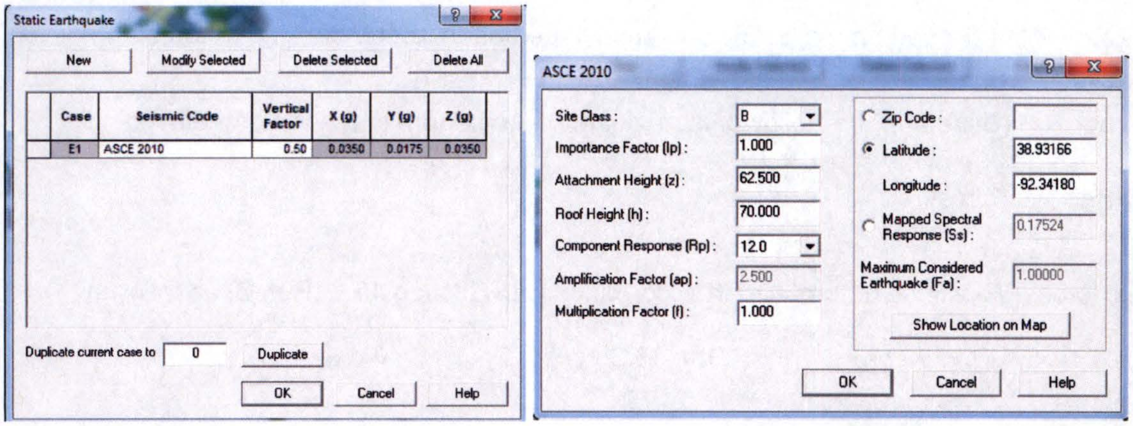


Figure 12. AutoPIPE Seismic Inputs and corresponding G levels

8 RESULTS

8.1 ASME B31.3 Code Stress Results

The ASME B31.3 code combinations results are documented in this section. Results in Table 5 show combinations with numbers in the name. Loading input is shown in Table 4. Occasional stress category is calculated by combining seismic with sustain load. Figures 13 through 24 show the stress ratio plots. The red circles indicate the general areas of the high stress. Within that circle the square box with crosshairs is the exact point of the high stress.

- GR – Gravity
- Amb to T1 – Ambient to Operating Temperature
- Max P – Max Pressure
- Sus – GR + Max P
- E – Seismic Load

Table 5. ASME B31.3 Code Max Stress Result Summary

Combination	Category	Material	Stress (ksi)	Stress Allowable (ksi)	Stress/Stress Allowable Ratio	Node Number	Location	Figure
GR + Max P{1}	Sustain	316L	0.7	16.7	0.04	AL13	Y-Pipe, before flexible piping	Figure 14
GR + Max P{1}	Sustain	6061-T6	1.0	12.7	0.08	AL36F -	Inside Pool, on expansion loop	Figure 15

Combination	Category	Material	Stress (ksi)	Stress Allowable (ksi)	Stress/Stress Allowable Ratio	Node Number	Location	Figure
Amb to T1{1}	Expansion	316L	3.2	25	0.13	AK03	At Heat Exchanger Interface	Figure 17
Amb to T1{1}	Expansion	6061-T6	0.2	19	0.01	AH51	At SS to Al pipe interface	Figure 18
Max P{1}	Hoop	316L	0.3	16.7	0.02	AL06	3" to 2" y pipe	Figure 20
Max P{1}	Hoop	6061-T6	0.3	12.7	0.02	AK46	All Al piping	Figure 21
Sus. + E1{1}	Occasion	316L	0.9	22.2	0.04	AL09-	Y-piping support	Figure 23
Sus. + E1{1}	Occasion	6061-T6	1.0	16.9	0.06	AH61N+	Inside Pool, on expansion loop	Figure 24

8.1.1 ASME B31.3 Sustain Stress Ratio Plots

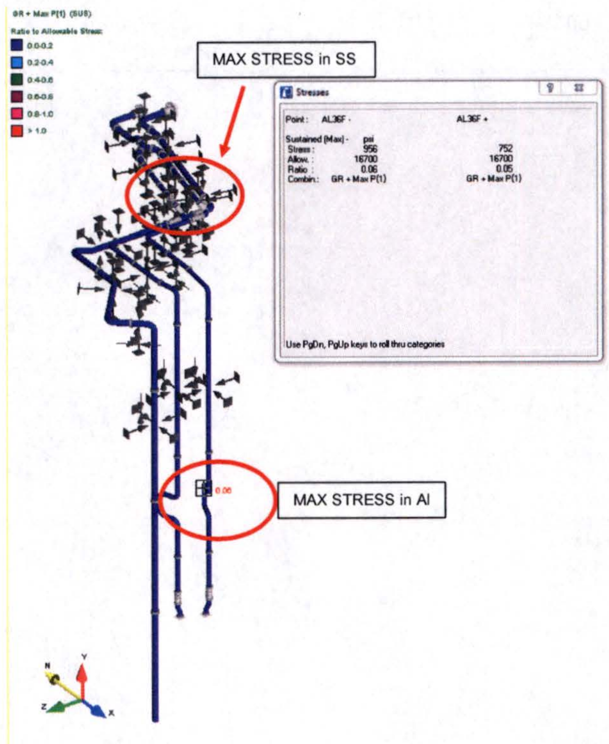


Figure 13. GR + MaxP{1} Stress Ratio Plot

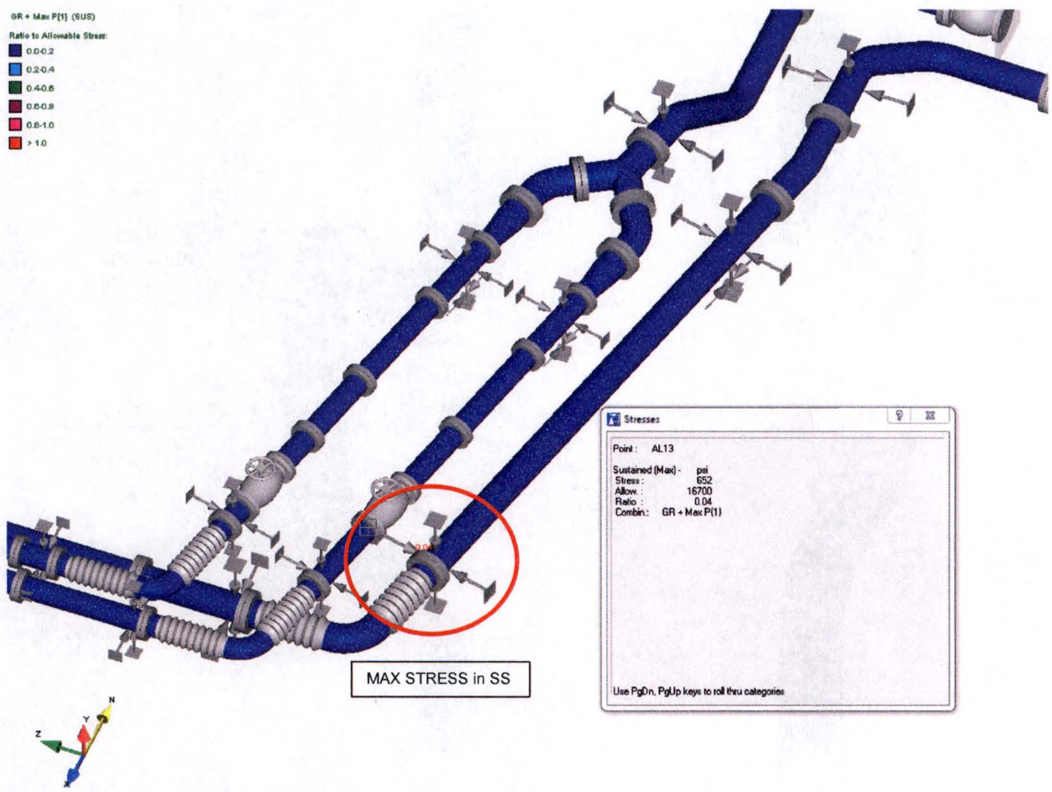


Figure 14. GR + MaxP{1} Stress Ratio Plot Close Up, Stainless Steel Pipes

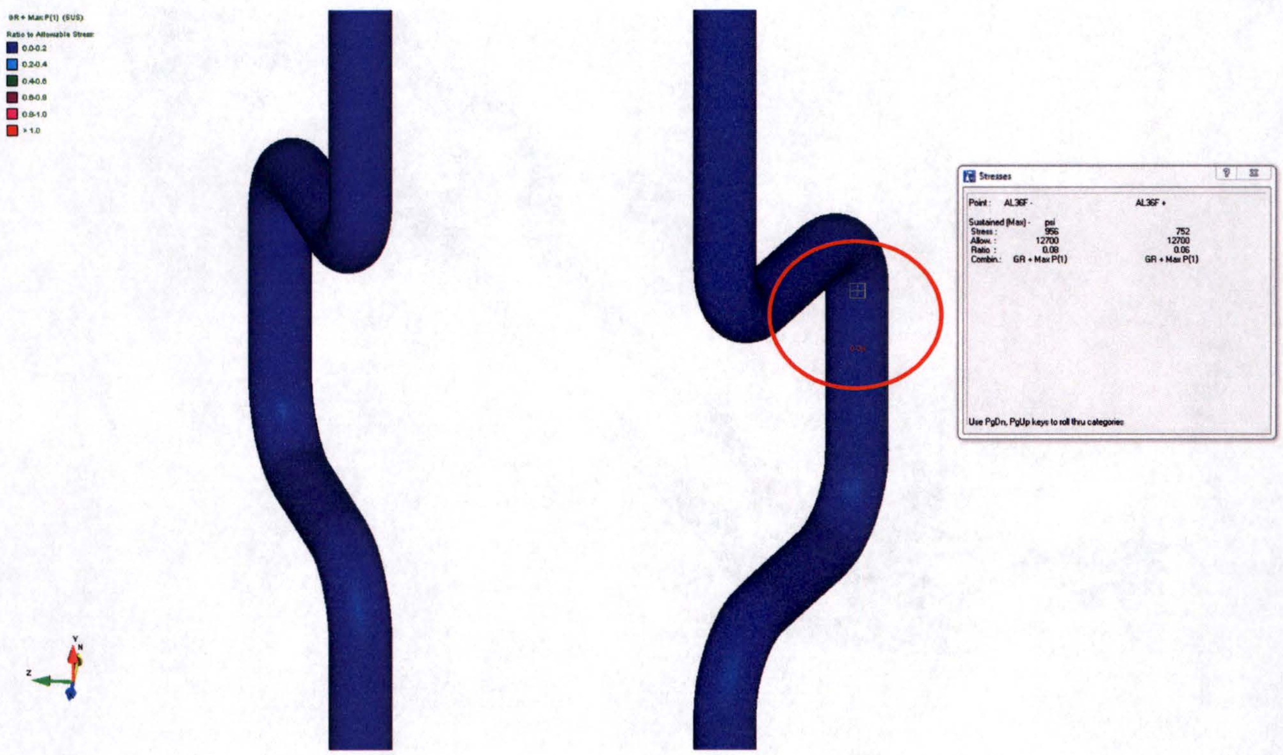


Figure 15. GR + MaxP{1} Stress Ratio Plot Close Up, Aluminum Pipes

8.1.2 ASME B31.3 Expansion Stress Ratio Plots

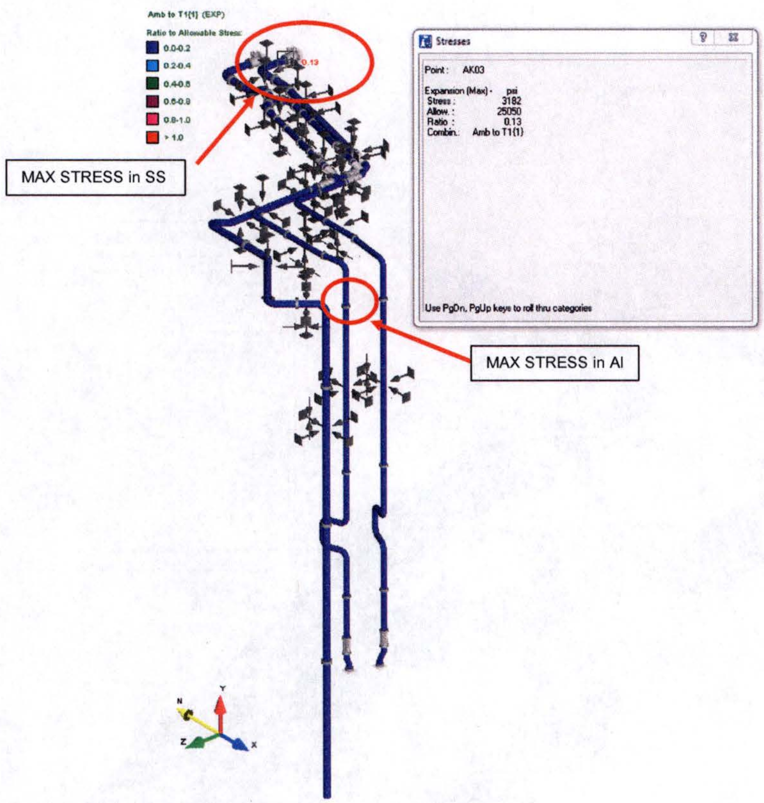


Figure 16. Amb to T1{1} Stress Ratio Plot

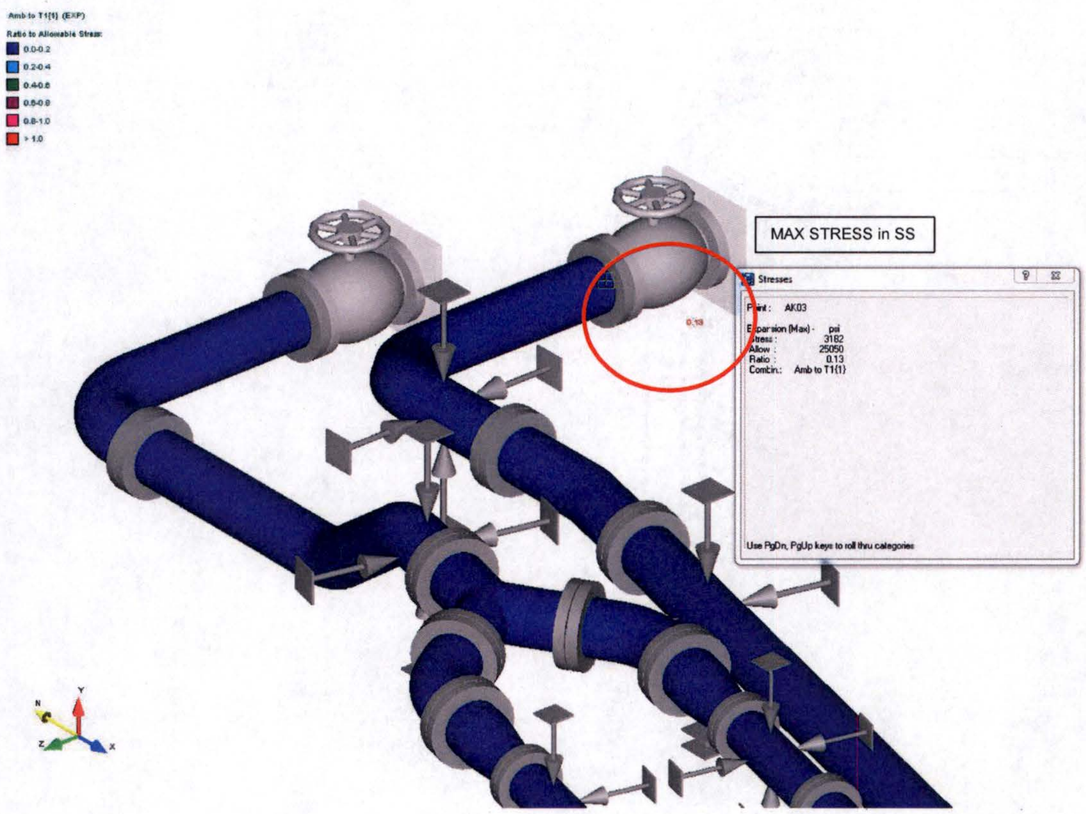


Figure 17. Amb to T1{1} Stress Ratio Plot Close Up, Stainless Steel Pipes

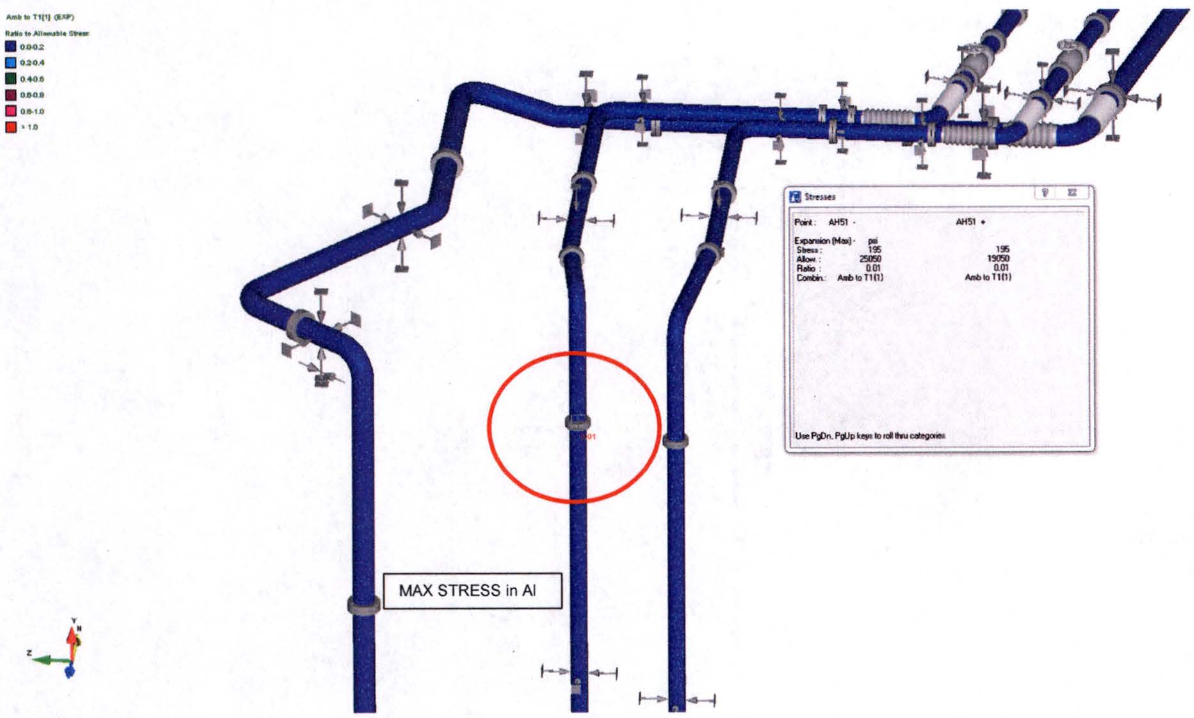


Figure 18. Amb to T1{1} Stress Ratio Plot Close Up, Aluminum Pipes

8.1.3 ASME B31.3 Hoop Stress Ratio Plots

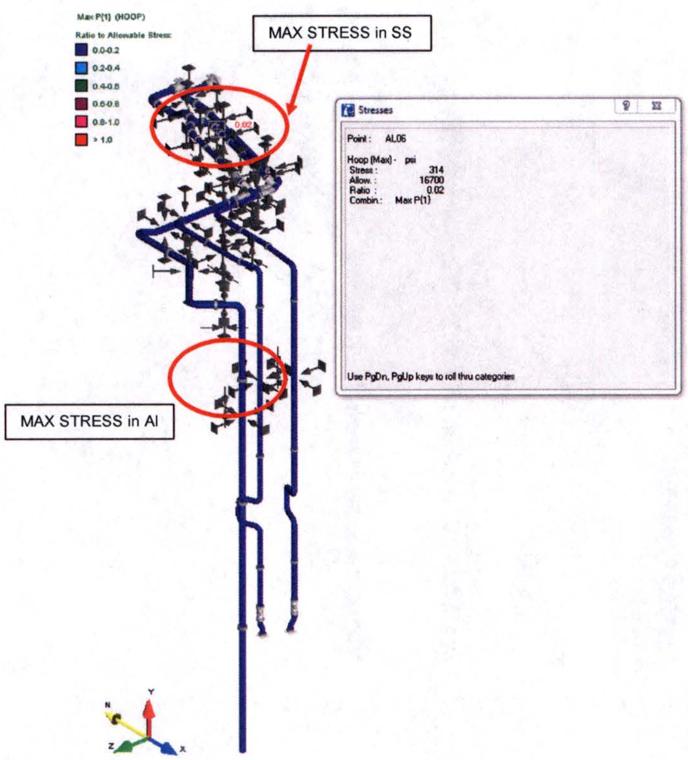


Figure 19. MaxP{1} Stress Ratio Plot

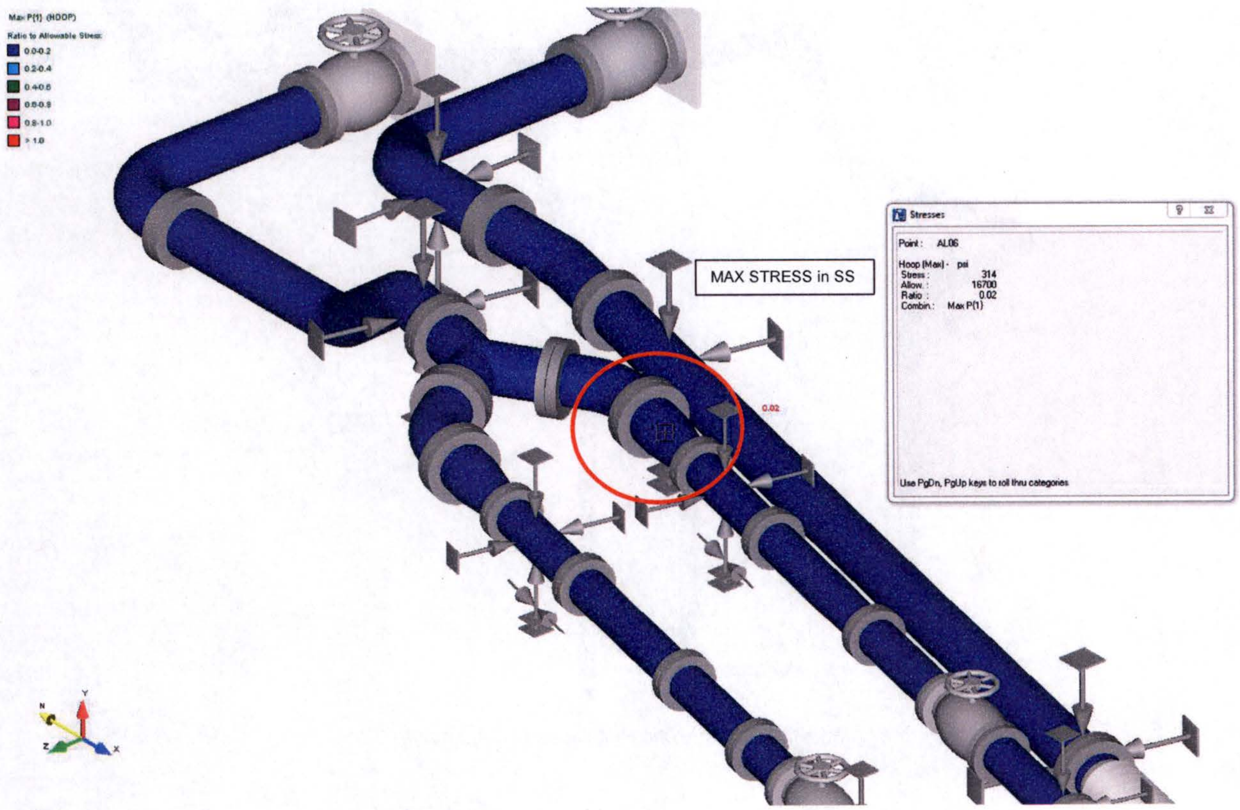


Figure 20. MaxP{1} Stress Ratio Plot Close Up, Stainless Steel Pipes

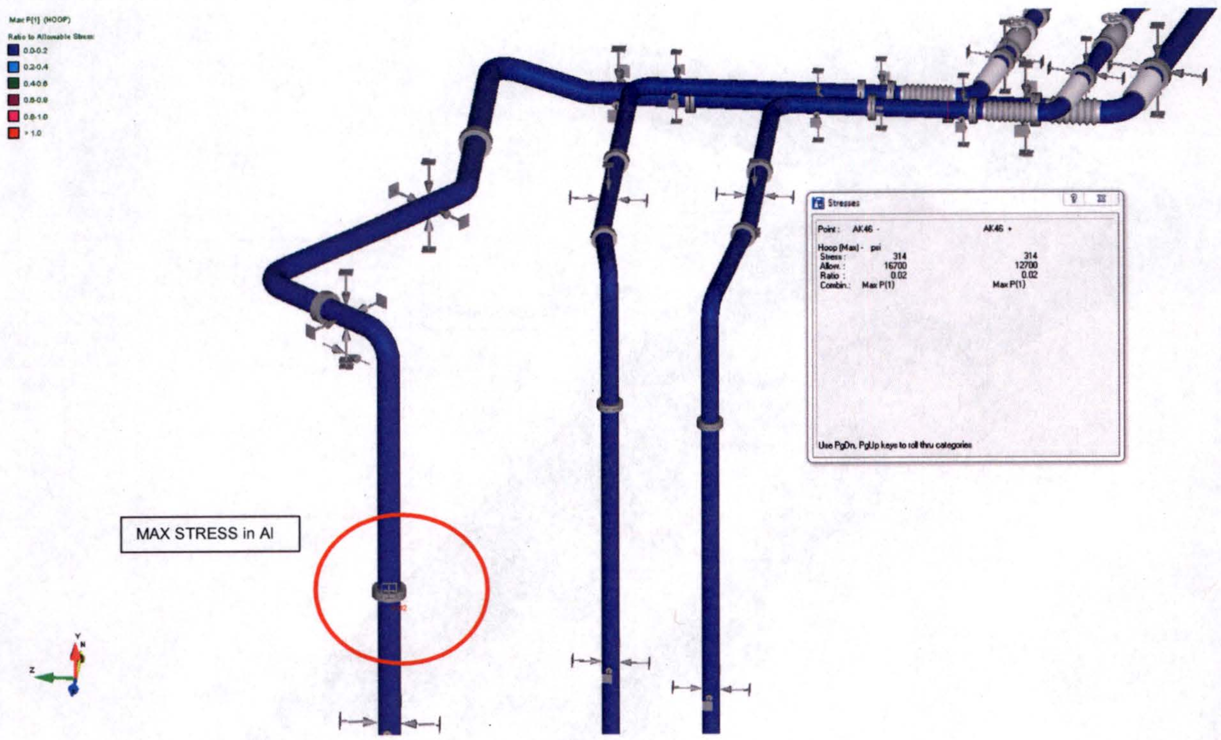


Figure 21. MaxP{1} Stress Ratio Plot Close Up, Aluminum Pipes

8.1.4 ASME B31.3 Occasional Stress Ratio Plots

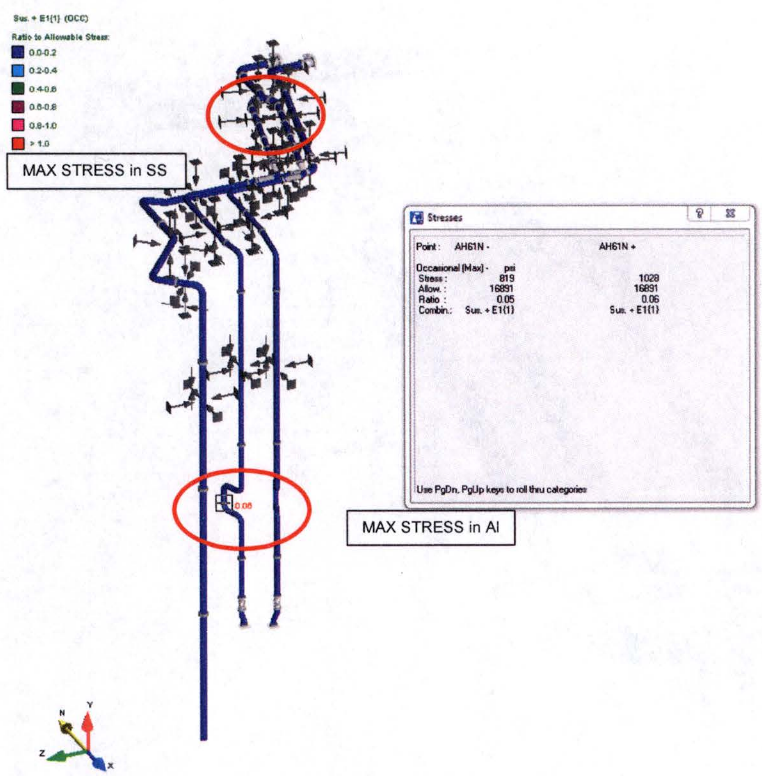


Figure 22. Sus + E{1} Stress Ratio Plot (Seismic)

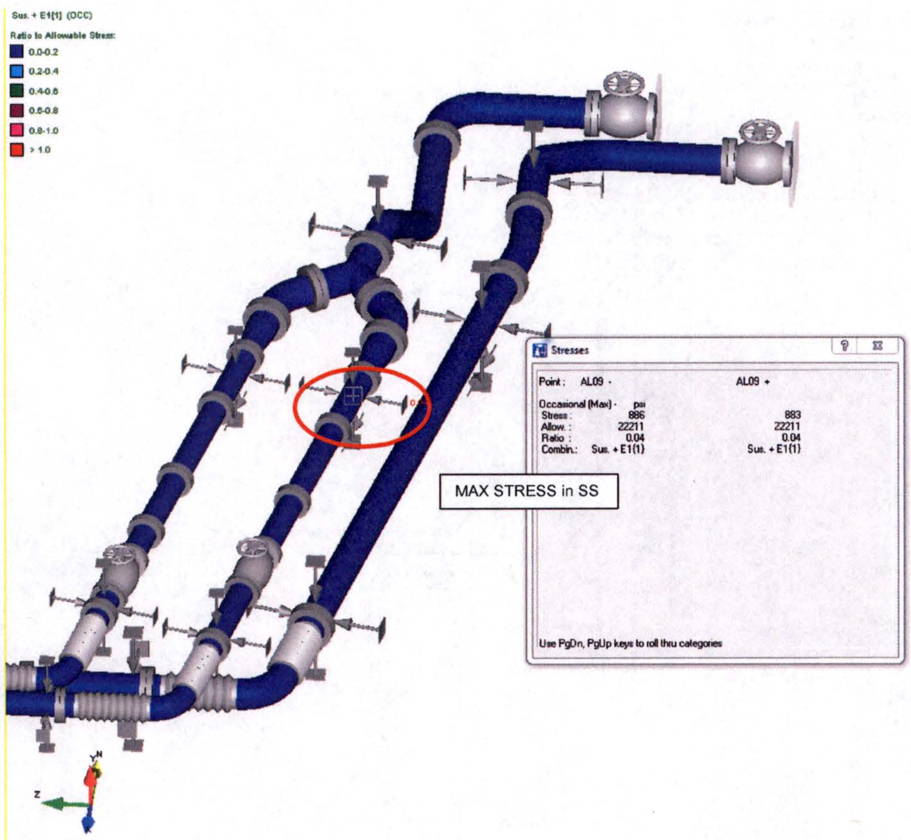


Figure 23. Sus + E{1} Stress Ratio Plot Close Up (Seismic), in Stainless Steel Piping

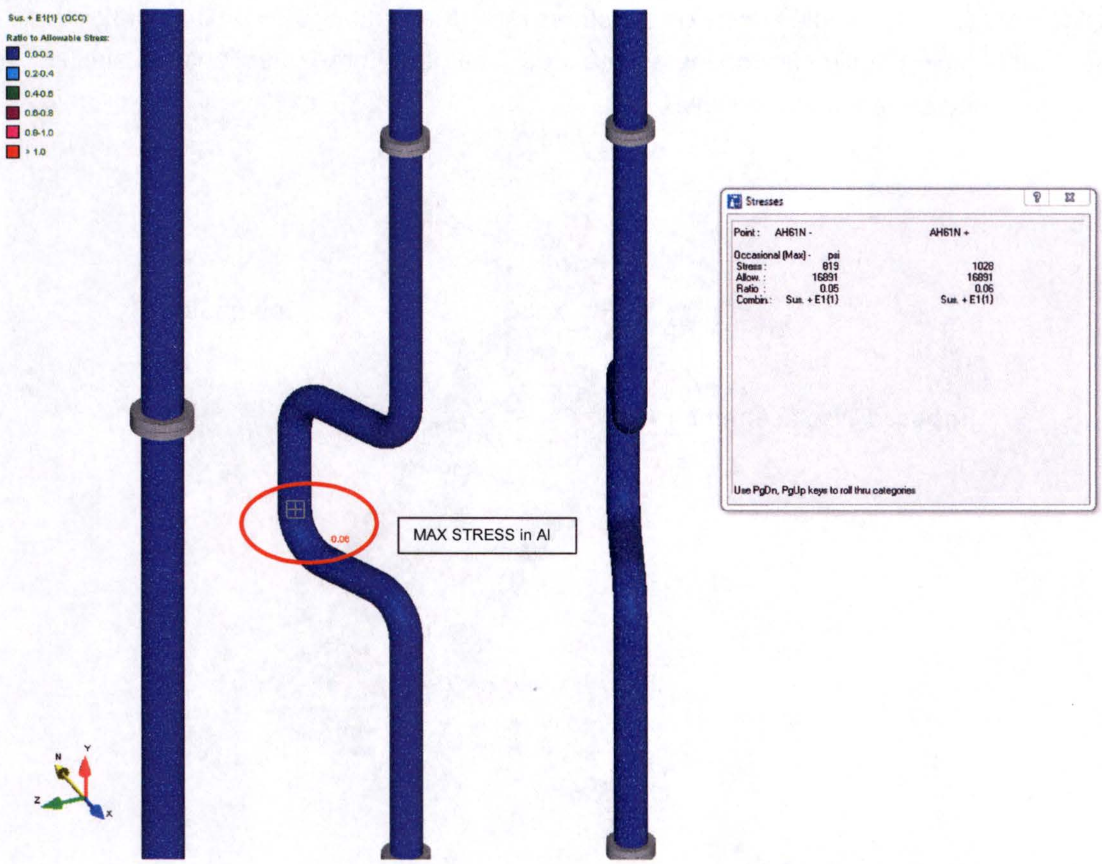


Figure 24. Sus + E{1} Stress Ratio Plot Close Up (Seismic), in Aluminum Piping

8.2 Seismic Displacement

The design of the system shows that the tower and the pool are two independent structures. During a seismic event these structures will displace independently. To alleviate stress caused from independent movement, flexible piping was added at the pool/tower interface (towards the pool side). To verify the flexible piping doesn't induce stresses, an analysis with an imposed displacement was done. A two inch imposed displacement was applied independently on the Tower side of the flexible piping in +/- x and +/- z direction. Figure 25 and Figure 26 show the AutoPIPE model and the Seismic results. As shown in the results box in Figure 26, the two inch imposed displacement has negligible effects on the stress ratio (Max ratio is 0.05 on the AH42F+). Therefore the flexible piping design is working as intended. The other three directions are similar and are not shown since stress ratios are low.

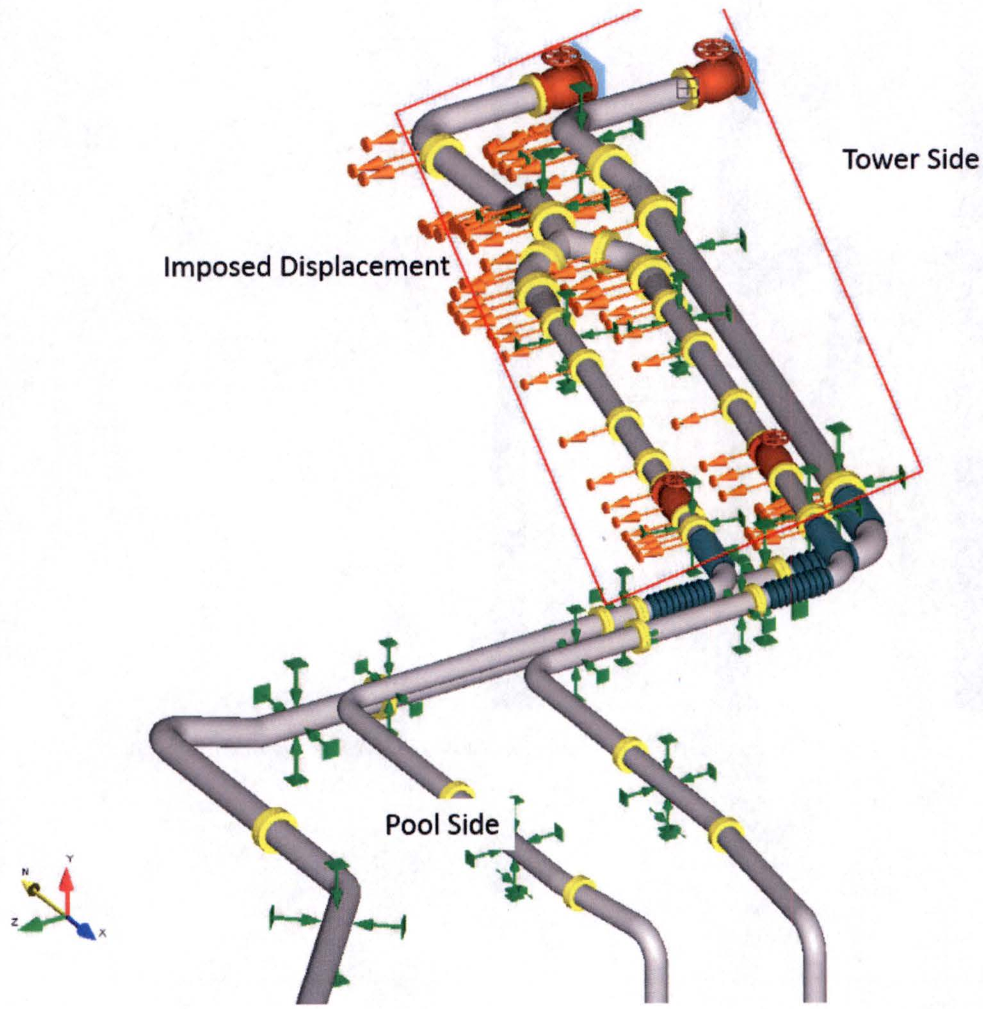


Figure 25. Imposed displacement on the Tower Side AutoPIPE model +z direction

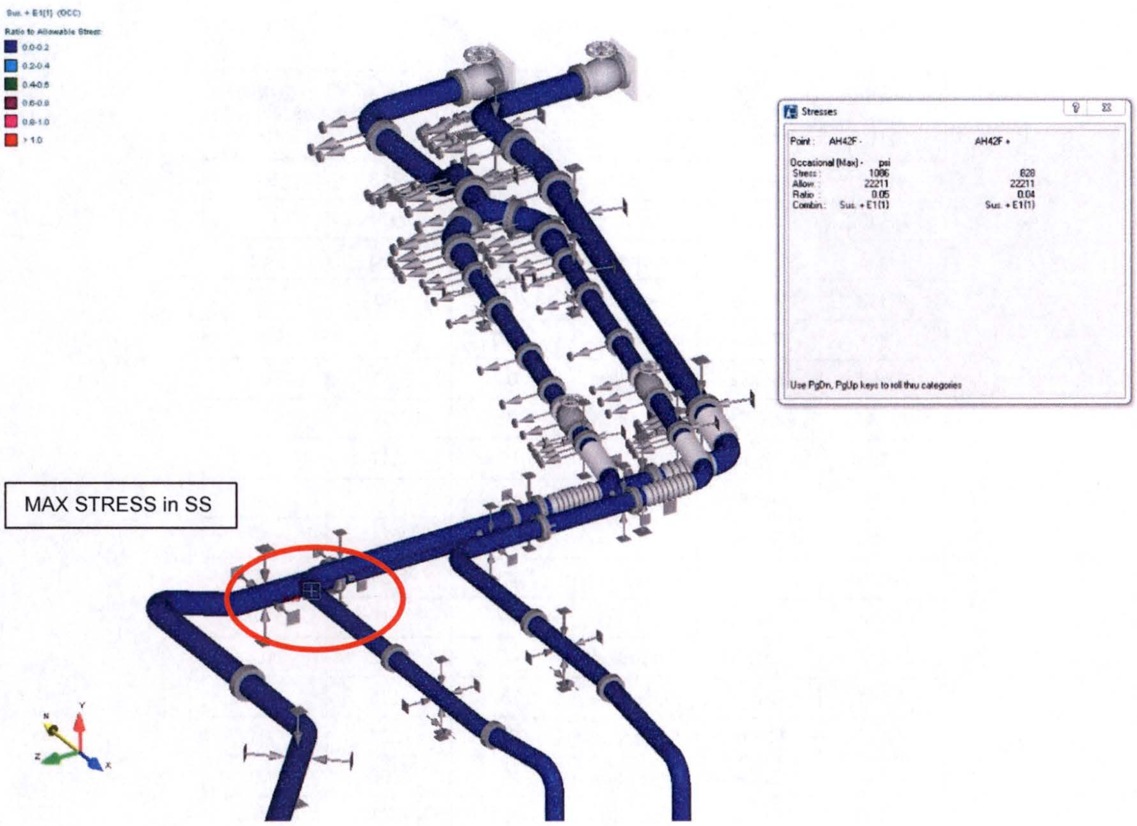


Figure 26. Imposed displacement on the Tower Side Sus + E{1} Stress Ratio Plot +z direction

9 SUPPORT AND ANCHOR LOADS

The following section shows the support force during operation and operation plus seismic calculations. Operation is Gravity + Temperature + Pressure (Gravity, Expansion, and Hoop). Table 6 and Table 7 show a summary of the forces of the two cases. Figures 27 through 29 show the point numbers associated with the support. Please note these cases are not the same as the combination code stress.

Table 6. Support Forces Summary for Normal Operation

Location	Support Type	Case	X (lbf)	Y (lbf)	Z (lbf)
AH19	Guide	Operation	-2	-115	7
AH30	Guide	Operation	-13	-218	57
AH30	Line Stp	Operation	279	0	65
AH36	Guide	Operation	2	-193	-10
AH83	Guide	Operation	63	-80	-1
AH41	Guide	Operation	-310	-85	3
AH84	Guide	Operation	0	-33	0
AH84	Line Stp	Operation	235	0	0
AH85	Line Stp	Operation	0	-317	0
AH85	Guide	Operation	11	0	-1
AK08	Guide	Operation	0	199	853
AK16	Guide	Operation	41	-154	-177
AK16	Line Stp	Operation	627	0	146
AK17	Guide	Operation	-2	-102	10
AK21	Guide	Operation	13	-135	0
AK24	Guide	Operation	-60	-207	0
AK47	Guide	Operation	16	-166	-19
AK40	Guide	Operation	35	173	29
AK40	Line Stp	Operation	-16	0	19
AK52	Line Stp	Operation	0	-673	0
AK52	Guide	Operation	13	0	-29
AL09	Guide	Operation	11	-218	-47
AL09	Line Stp	Operation	242	0	57
AL14	Guide	Operation	0	-156	1
AL63	Guide	Operation	86	-59	-1
AL19	Guide	Operation	-355	-88	4
AL64	Guide	Operation	0	-57	-7
AL64	Line Stp	Operation	259	0	0
AL65	Line Stp	Operation	0	-303	0
AL65	Guide	Operation	10	0	4

Table 7. Support Forces Summary for Operation + Seismic

Location	Support Type	Case	X (lbf)	Y (lbf)	Z (lbf)
AH19	Guide	Operation + Seismic	-2	-112	11
AH30	Guide	Operation + Seismic	-15	-213	64
AH30	Line Stp	Operation + Seismic	300	0	70
AH36	Guide	Operation + Seismic	1	-189	-5
AH83	Guide	Operation + Seismic	67	-78	-1
AH41	Guide	Operation + Seismic	-350	-85	4
AH84	Guide	Operation + Seismic	0	-27	6
AH84	Line Stp	Operation + Seismic	277	0	0
AH85	Line Stp	Operation + Seismic	0	-316	0
AH85	Guide	Operation + Seismic	23	0	9
AK08	Guide	Operation + Seismic	0	200	855
AK16	Guide	Operation + Seismic	41	-151	-175
AK16	Line Stp	Operation + Seismic	639	0	149
AK17	Guide	Operation + Seismic	-3	-100	13
AK21	Guide	Operation + Seismic	13	-133	0
AK24	Guide	Operation + Seismic	-45	-203	0
AK47	Guide	Operation + Seismic	-8	-158	10
AK40	Guide	Operation + Seismic	32	158	27
AK40	Line Stp	Operation + Seismic	1	0	-1
AK52	Line Stp	Operation + Seismic	0	-655	0
AK52	Guide	Operation + Seismic	42	0	0
AL09	Guide	Operation + Seismic	10	-214	-41
AL09	Line Stp	Operation + Seismic	262	0	61
AL14	Guide	Operation + Seismic	-1	-153	4
AL63	Guide	Operation + Seismic	90	-57	-1
AL19	Guide	Operation + Seismic	-386	-88	4
AL64	Guide	Operation + Seismic	0	-51	0
AL64	Line Stp	Operation + Seismic	291	0	0
AL65	Line Stp	Operation + Seismic	0	-301	0
AL65	Guide	Operation + Seismic	22	0	14

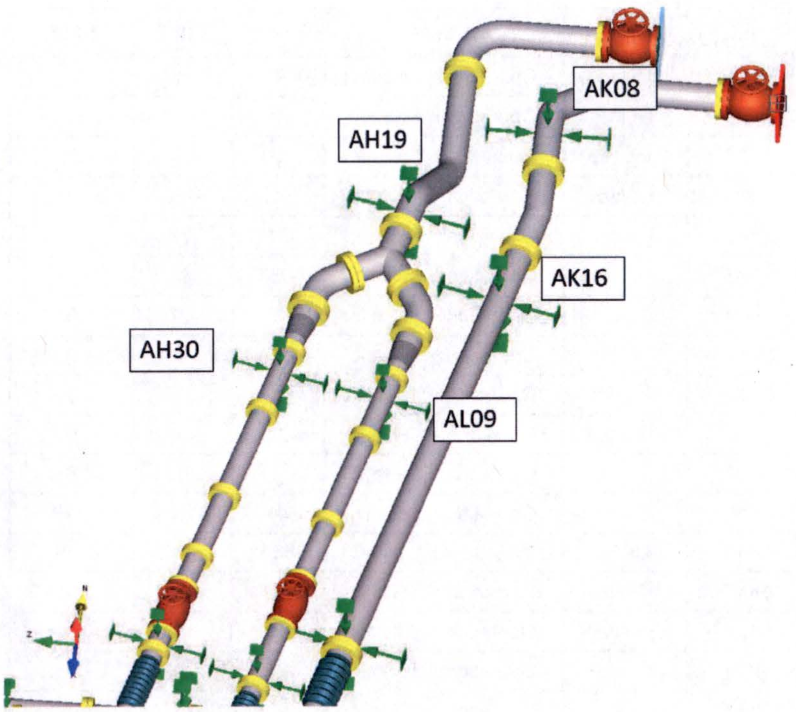


Figure 27. Piping supports point numbers on Tower side

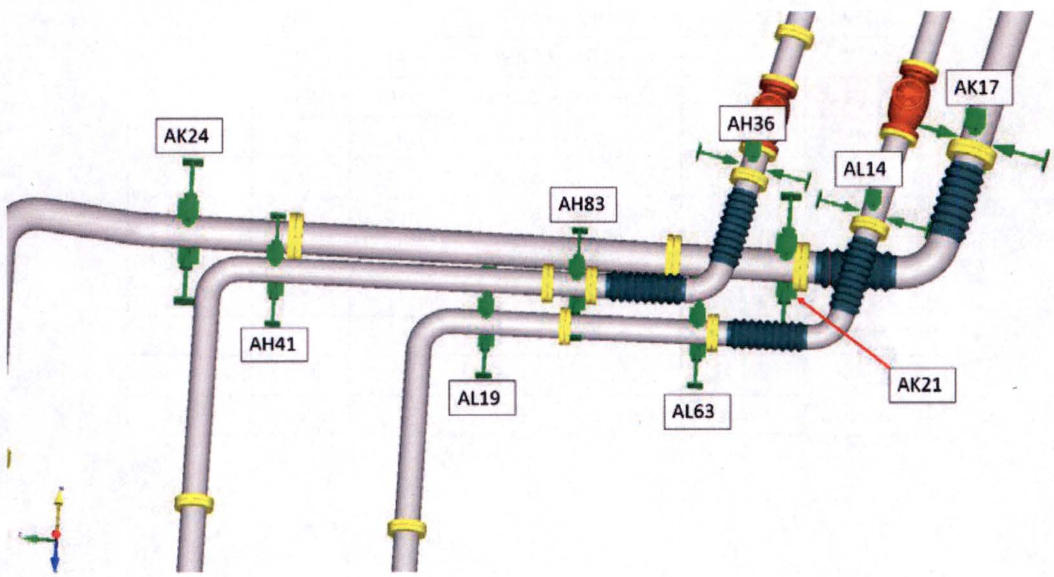


Figure 28. Piping supports point numbers for Flex Joints and along the pool

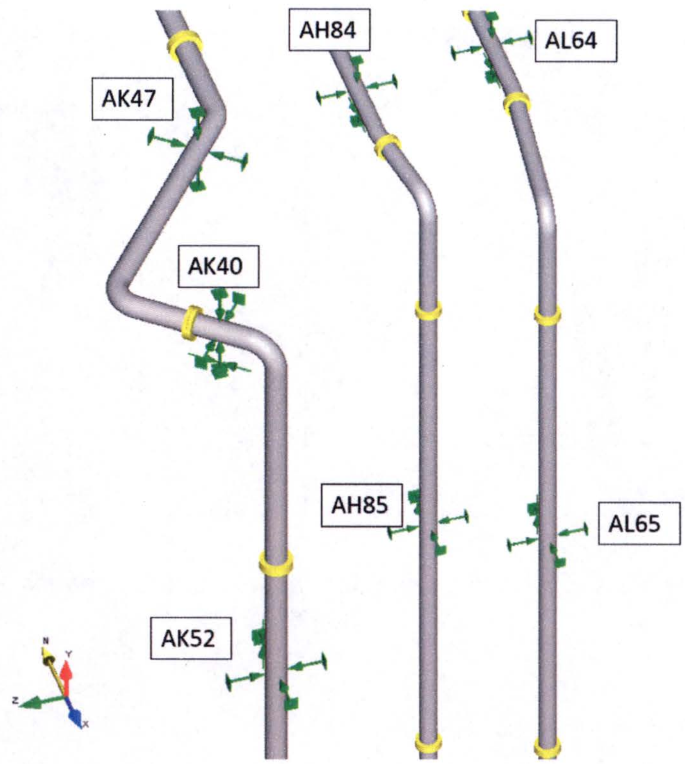


Figure 29. Piping supports point numbers in the pool

As stated in the assumptions, interfaces were modeled as rigid anchors. Table 8 and Figure 30 show the anchor forces and the point numbers.

Table 8. Anchor Forces Summary

Location	Support Type	Case	X- force (lbf)	Y- force (lbf)	Z- force (lbf)	X- moment (ft-lb)	Y- moment (ft-lb)	Z- moment (ft-lb)
AH08	Anchor	Operation	-519	-350	-130	459	-1076	-74
AK02	Anchor	Operation	-666	-437	-833	530	-1253	18
AH80	Anchor	Operation	1	-67	-1	-5	-4	-17
AL60	Anchor	Operation	1	-68	0	3	-2	-24
AH08	Anchor	Operation + Seismic	-511	-346	-122	455	-1070	-74
AK02	Anchor	Operation + Seismic	-660	-434	-826	529	-1250	18
AH80	Anchor	Operation + Seismic	4	-66	3	-13	-2	-8
AL60	Anchor	Operation + Seismic	4	-68	3	-5	-2	-16

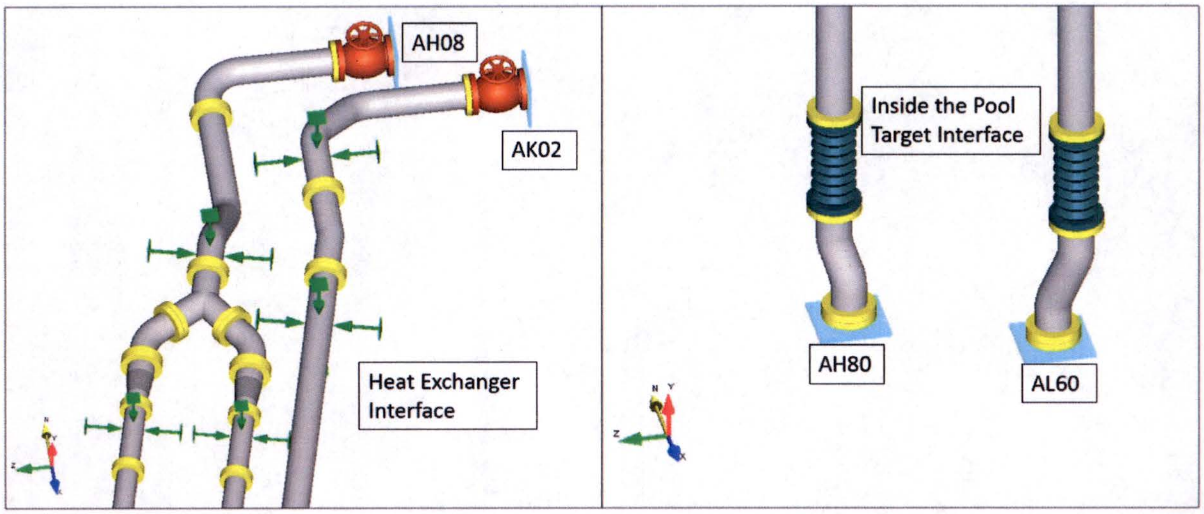


Figure 30. Anchor supports point numbers at the Heat Exchanger and Target interface

10 CONCLUSIONS

The target cooling water system piping was modeled in AutoPIPE with the operational, and ASCE 7-10 seismic loading. The results shows that piping passes ASME B31.3 2014 piping stress code. Additionally, the analysis shows that the flexible piping located at the bridge to Bio-Shield/Pool interface alleviates stress cause from independent movement of the tower and bio-shield during a seismic event and allows for an up to 2 inch movement, which is ample margin. Overall, the piping analysis shows that there is a large margin in the stress allowable, with a Factor of Safety (FoS) > 7.

11 REFERENCES

Reference	Document Number	Description
1	ASCE 7-10	Minimum Design Loads for Buildings and Other Structures
2	ASME B31.3	Process Piping, 2014 Edition
3	30441S00001	*Moved to Applicable Documents Section*
4	USGS	Design Maps Detail Report
5	USGS	Design Maps Summary Report
6	FEMA	FEMA Hazard Maps

APPENDIX A USGS DESIGN MAPS DETAIL REPORT

USGS Design Maps Detailed Report

ASCE 7-10 Standard (38.93166°N, 92.3418°W)

Site Class B – "Rock", Risk Category I/II/III

Section 11.4.1 — Mapped Acceleration Parameters

Note: Ground motion values provided below are for the direction of maximum horizontal spectral response acceleration. They have been converted from corresponding geometric mean ground motions computed by the USGS by applying factors of 1.1 (to obtain S_S) and 1.3 (to obtain S_1). Maps in the 2010 ASCE-7 Standard are provided for Site Class B. Adjustments for other Site Classes are made, as needed, in Section 11.4.3.

From Figure 22-1 [1] $S_S = 0.168$ g

From Figure 22-2 [2] $S_1 = 0.093$ g

Section 11.4.2 — Site Class

The authority having jurisdiction (not the USGS), site-specific geotechnical data, and/or the default has classified the site as Site Class B, based on the site soil properties in accordance with Chapter 20.

Table 20.3–1 Site Classification

Site Class	$\bar{v}_s$	$\bar{N}$ or $\bar{N}_{ch}$	$\bar{s}_u$
A. Hard Rock	>5,000 ft/s	N/A	N/A
B. Rock	2,500 to 5,000 ft/s	N/A	N/A
C. Very dense soil and soft rock	1,200 to 2,500 ft/s	>50	>2,000 psf
D. Stiff Soil	600 to 1,200 ft/s	15 to 50	1,000 to 2,000 psf
E. Soft clay soil	<600 ft/s	<15	<1,000 psf
	Any profile with more than 10 ft of soil having the characteristics: • Plasticity index $PI > 20$, • Moisture content $w \geq 40\%$, and • Undrained shear strength $\bar{s}_u < 500$ psf		
F. Soils requiring site response analysis in accordance with Section 21.1	See Section 20.3.1		

For SI: 1ft/s = 0.3048 m/s 1lb/ft² = 0.0479 kN/m²

Section 11.4.3 — Site Coefficients and Risk-Targeted Maximum Considered Earthquake (MCE_R) Spectral Response Acceleration Parameters

Table 11.4-1: Site Coefficient F_a

Site Class	Mapped MCE $_R$ Spectral Response Acceleration Parameter at Short Period				
	$S_S \le 0.25$	$S_S = 0.50$	$S_S = 0.75$	$S_S = 1.00$	$S_S \ge 1.25$
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.2	1.2	1.1	1.0	1.0
D	1.6	1.4	1.2	1.1	1.0
E	2.5	1.7	1.2	0.9	0.9
F	See Section 11.4.7 of ASCE 7				

Note: Use straight-line interpolation for intermediate values of S_S

For Site Class = B and S_S = 0.168 g, F_a = 1.000

Table 11.4-2: Site Coefficient F_v

Site Class	Mapped MCE $_R$ Spectral Response Acceleration Parameter at 1-s Period				
	$S_1 \le 0.10$	$S_1 = 0.20$	$S_1 = 0.30$	$S_1 = 0.40$	$S_1 \ge 0.50$
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.7	1.6	1.5	1.4	1.3
D	2.4	2.0	1.8	1.6	1.5
E	3.5	3.2	2.8	2.4	2.4
F	See Section 11.4.7 of ASCE 7				

Note: Use straight-line interpolation for intermediate values of S_1

For Site Class = B and S_1 = 0.093 g, F_v = 1.000

Equation (11.4-1): $S_{MS} = F_aS_S = 1.000 \times 0.168 = 0.168$ g

Equation (11.4-2): $S_{M1} = F_vS_1 = 1.000 \times 0.093 = 0.093$ g

Section 11.4.4 — Design Spectral Acceleration Parameters

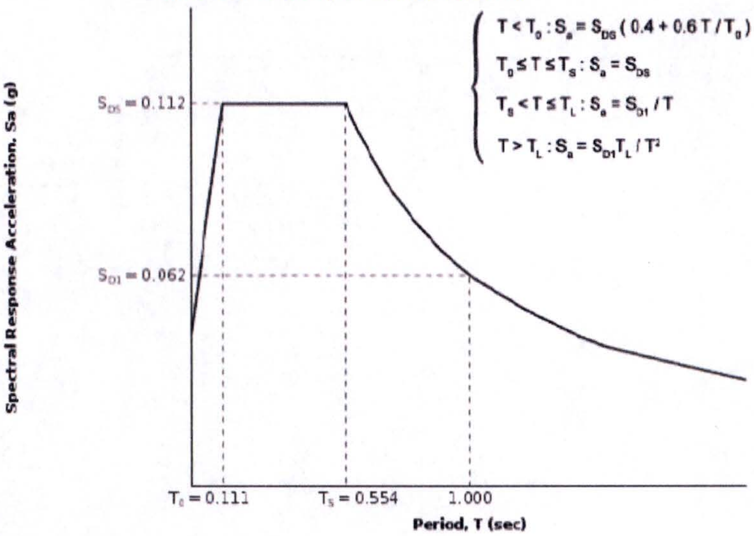
Equation (11.4-3): $S_{DS} = ⅔\ S_{MS} = ⅔ \times 0.168 = 0.112$ g

Equation (11.4-4): $S_{D1} = ⅔\ S_{M1} = ⅔ \times 0.093 = 0.062$ g

Section 11.4.5 — Design Response Spectrum

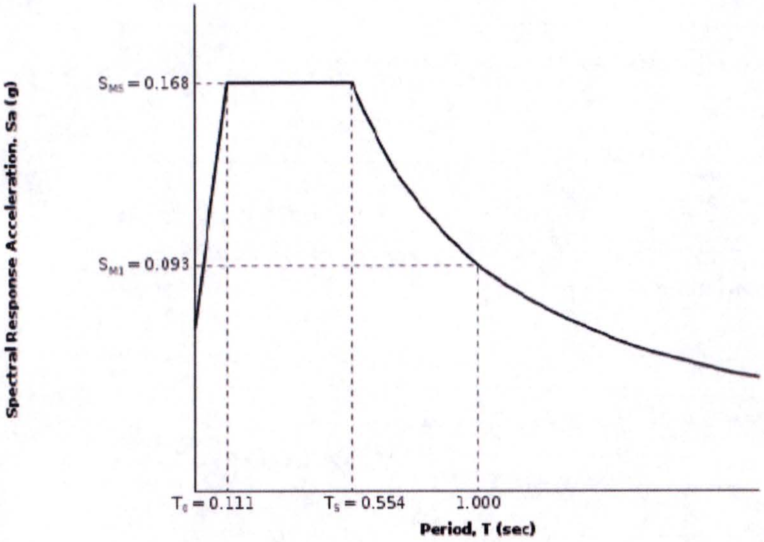
From Figure 22-12 [3] T_L = 12 seconds

Figure 11.4-1: Design Response Spectrum



Section 11.4.6 — Risk-Targeted Maximum Considered Earthquake (MCE_R) Response Spectrum

The MCE_R Response Spectrum is determined by multiplying the design response spectrum above by 1.5.



Section 11.8.3 — Additional Geotechnical Investigation Report Requirements for Seismic Design Categories D through F

From Figure 22-7 [4] PGA = 0.080

Equation (11.8–1): $PGA_M = F_{PGA}PGA = 1.000 \times 0.080 = 0.08$ g

Table 11.8–1: Site Coefficient F_{PGA}

Site Class	Mapped MCE Geometric Mean Peak Ground Acceleration, PGA				
	PGA ≤ 0.10	PGA = 0.20	PGA = 0.30	PGA = 0.40	PGA ≥ 0.50
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.2	1.2	1.1	1.0	1.0
D	1.6	1.4	1.2	1.1	1.0
E	2.5	1.7	1.2	0.9	0.9
F	See Section 11.4.7 of ASCE 7				

Note: Use straight–line interpolation for intermediate values of PGA

For Site Class = B and PGA = 0.080 g, F_{PGA} = 1.000

Section 21.2.1.1 — Method 1 (from Chapter 21 – Site-Specific Ground Motion Procedures for Seismic Design)

From Figure 22-17 [5] C_{RS} = 0.862

From Figure 22-18 [6] C_{R1} = 0.835

Section 11.6 — Seismic Design Category

Table 11.6-1 Seismic Design Category Based on Short Period Response Acceleration Parameter

VALUE OF S_{DS}	RISK CATEGORY		
	I or II	III	IV
$S_{DS} < 0.167g$	A	A	A
$0.167g \le S_{DS} < 0.33g$	B	B	C
$0.33g \le S_{DS} < 0.50g$	C	C	D
$0.50g \le S_{DS}$	D	D	D

For Risk Category = I and S_{DS} = 0.112 g, Seismic Design Category = A

Table 11.6-2 Seismic Design Category Based on 1-S Period Response Acceleration Parameter

VALUE OF S_{D1}	RISK CATEGORY		
	I or II	III	IV
$S_{D1} < 0.067g$	A	A	A
$0.067g \le S_{D1} < 0.133g$	B	B	C
$0.133g \le S_{D1} < 0.20g$	C	C	D
$0.20g \le S_{D1}$	D	D	D

For Risk Category = I and S_{D1} = 0.062 g, Seismic Design Category = A

Note: When S_1 is greater than or equal to 0.75g, the Seismic Design Category is **E** for buildings in Risk Categories I, II, and III, and **F** for those in Risk Category IV, irrespective of the above.

Seismic Design Category ≡ "the more severe design category in accordance with Table 11.6-1 or 11.6-2" = A

Note: See Section 11.6 for alternative approaches to calculating Seismic Design Category.

References

1. *Figure 22-1*: http://earthquake.usgs.gov/hazards/designmaps/downloads/pdfs/2010_ASCE-7_Figure_22-1.pdf
2. *Figure 22-2*: http://earthquake.usgs.gov/hazards/designmaps/downloads/pdfs/2010_ASCE-7_Figure_22-2.pdf
3. *Figure 22-12*: http://earthquake.usgs.gov/hazards/designmaps/downloads/pdfs/2010_ASCE-7_Figure_22-12.pdf
4. *Figure 22-7*: http://earthquake.usgs.gov/hazards/designmaps/downloads/pdfs/2010_ASCE-7_Figure_22-7.pdf
5. *Figure 22-17*: http://earthquake.usgs.gov/hazards/designmaps/downloads/pdfs/2010_ASCE-7_Figure_22-17.pdf
6. *Figure 22-18*: http://earthquake.usgs.gov/hazards/designmaps/downloads/pdfs/2010_ASCE-7_Figure_22-18.pdf

APPENDIX B USGS MAPS SUMMARY REPORT

USGS Design Maps Summary Report

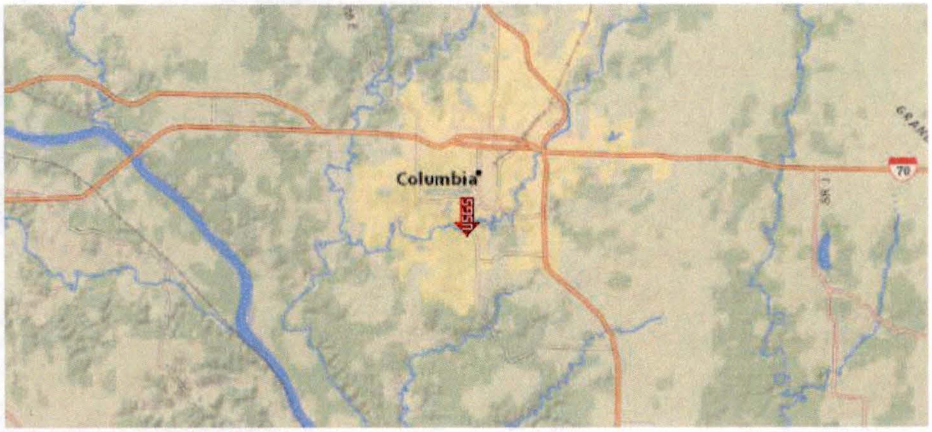
User-Specified Input

Building Code Reference Document ASCE 7-10 Standard
(which utilizes USGS hazard data available in 2008)

Site Coordinates 38.93166°N, 92.3418°W

Site Soil Classification Site Class B – "Rock"

Risk Category I/II/III

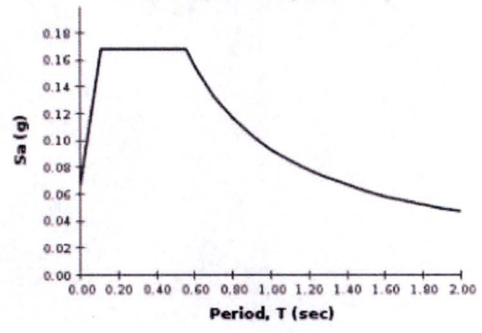


USGS-Provided Output

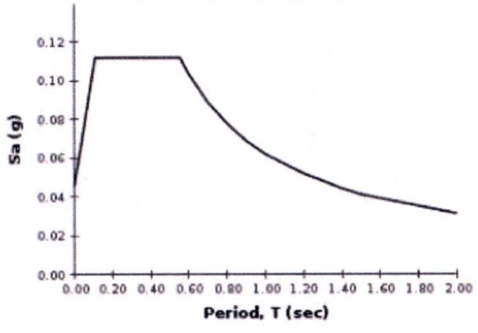
S_S =	0.168 g	S_{MS} =	0.168 g	S_{DS} =	0.112 g
S_1 =	0.093 g	S_{M1} =	0.093 g	S_{D1} =	0.062 g

For information on how the SS and S1 values above have been calculated from probabilistic (risk-targeted) and deterministic ground motions in the direction of maximum horizontal response, please return to the application and select the "2009 NEHRP" building code reference document.

MCE_R Response Spectrum



Design Response Spectrum



For PGA_M, T_L, C_{RS}, and C_{R1} values, please view the detailed report.

APPENDIX C FEMA MAPS

program-managers-toolkit-earthquake-program-managers)

- Information for Individuals (/earthquake-information-individuals-and-families)

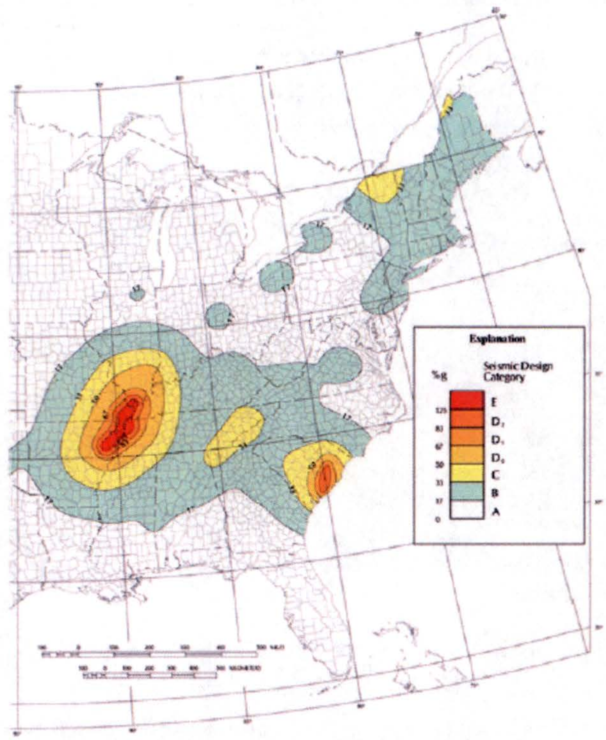
Information for Communities (/earthquake-information-communities)

- Information for Businesses (/earthquake-information-businesses-and-other-organizations)

Information for Building Designers (/earthquake-information-building-designers-managers-and-regulators)

Earthquake Hazard Maps (/earthquake-hazard-maps)

Your Earthquake Risk (/your-earthquake-risk)



SDC map of the Eastern United States for low-rise Occupancy Category I and II structures located on sites with average alluvial soil conditions.