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February 19, 2014

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U. S. Nuclear Regulatory Commission
ATTN: Document Control Desk
Washington, D. C. 20555-0001

Edwin I. Hatch Nuclear Plant – Unit 2
Response to Request for Additional Information from Mechanical and Civil
Branch Regarding High Density Polyethylene (HDPE) Piping Replacement

Ladies and Gentlemen:

By letter dated September 19, 2014, and as supplemented by letters dated November 14, 2014, November 24, 2014, and January 23, 2015, Southern Nuclear Operating Company (SNC), submitted request for relief HNP-ISI-ALT-HDPE-01, Version 2.0 which requests authorization to replace buried steel Plant Service Water (PSW) piping with High Density Polyethylene (HDPE) piping for the duration of the license at Hatch Nuclear Plant, Unit 2.

By letter dated February 5, 2015, the Nuclear Regulatory Commission (NRC) sent a Request for Information (RAI) letter from the Mechanical and Civil Engineering Branch. Enclosure 1 provides the SNC response to the NRC RAI questions. Enclosure 2 provides a revised Summary Report on Stress Analysis for PSW Buried HDPE Piping. This revised report replaces Enclosure 5 to the November 24, 2014 letter (NL-14-1876) in its entirety. The revised Summary Report on Stress Analysis for PSW Buried HDPE Piping contains revision bars to mark changes made from Enclosure 5 to NL-14-1876.

This letter contains no NRC commitments. If you have any questions, please contact Ken McElroy at (205) 992-7369.

Respectfully submitted,

C. R. Pierce

C. R. Pierce
Regulatory Affairs Director

CRP/RMJ

Enclosures:
1. SNC Response to NRC RAIs
2. Revised Summary Report on Stress Analysis for PSW Buried HDPE Piping

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Mr. D. G. Bost, Executive Vice President & Chief Nuclear Officer
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Edwin I. Hatch Nuclear Plant – Unit 2
Response to Request for Additional Information from Mechanical and Civil Branch Regarding High Density Polyethylene (HDPE) Piping Replacement

Enclosure 1

SNC Response to NRC RAIs

RAI-1

Section 1.0, Calculation SMNH-14-013, Enclosure 3 (Calculation of Minimum Wall Thickness for PSW HDPE Piping) to NL-14-1876 (Conceptual Design information Package, Reference 3):

It was noted that minimum wall thickness calculation does not apply to fittings and components. However, the PSW replacement by HDPE includes some fittings, e.g. 90 degree mitered elbows, 45 degree mitered elbows, and flange adaptors. The licensee is requested to address minimum required wall thickness for these components.

Response:

The required minimum wall thickness, t_{Design}, is calculated for straight pipe such that a pipe size with sufficient wall thickness can be specified to provide adequate pressure retaining capabilities for system design conditions.

The pressure design requirements for flange adapters and mitered elbows are identified in Paragraph 3132 of Enclosure 2 to the September 19, 2014 letter to the NRC (NL-14-1250). For the design of flange adapters, a dimension ratio (DR) is selected in accordance with the requirements of Paragraph 3132 of Enclosure 2 to NL-14-1250 to ensure that the pressure rating is greater than or equal to the system design pressure, P_D. The pressure ratings of the flange adapters are confirmed by testing in accordance with ASTM F2206 as required by Paragraph 2232 of Enclosure 2 to NL-14-1250. A required minimum wall thickness is not explicitly calculated for flange adapters but rather is inherent in the specification of the required DR.

For the design of mitered elbows, the required wall thickness for the mitered elbow segments, t_{elbow}, is determined in accordance with the requirements of subparagraph 3132.1 of Enclosure 2 to NL-14-1250 to ensure that the pressure rating is greater than or equal to the system design pressure, P_D.

RAI-2

Section 1.0, Enclosure 5 (Summary Report on Stress Analysis for PSW Buried HDPE Piping) to NL-14-1876 (Conceptual Design information Package, Reference 3):

Section 3.1 of Enclosure 3 of Reference 3 includes design pressure and design temperature for PSW Header HDPE pipe but does not provide normal and maximum operating pressures and temperatures. It was not identified whether the design values are for PSW supply or PSW return system. The licensee is requested to provide a table showing normal operating, and maximum operating pressures and temperatures for the HDPE piping (PSW Supply, and PSW Return portions as applicable).

Response:

The portion of piping to be replaced by HDPE is PSW supply only. PSW return is not within the scope of this piping replacement. Below is a table showing normal operating and maximum operating pressures and temperatures for the HDPE piping.

Condition	Temperature, °F	Pressure, PSIG
Normal Operation	95	140
Maximum Operating	97	190

The information in the table above is also provided in Section 1100 of Enclosure 2 to NL-14-1250.

RAI-3

(a) In section 6220 of Enclosure 2 to NL-14-1250 (Reference 1), it was stated that the system will be hydrostatically tested at not less than 1.5 times the design pressure + 10 psi.

In section 2.0 of Enclosure 5 (Summary Report on Stress Analysis for PSW Buried HDPE) to NL-14-1876 (Conceptual Design information Package, Reference 3), please include stresses in HDPE piping for initial hydrotest based on 1.5 times design pressure + 10 psi, along with allowable stress limit.

Response:

The hydrostatic test is required to ensure the integrity of the system. Similar to ASME Code requirements for metallic piping, it is intentionally performed above design pressure to test the system at a pressure higher than it should experience during normal operation. Also similar to design with metallic piping, it is permissible for the normal allowable stress, *S*, to be exceeded during this test. Section 6220 of Enclosure 2 to NL-14-1250 conservatively imposes a requirement that the hydrostatic design basis (HDB), which is a measure of long term strength of the HDPE rather than short term strength, not be exceeded during this test. As the values for allowable stress, *S*, are based on HDB multiplied by a design factor of 0.5 (i.e. HDB = 2 x *S*), there is an inherent 2 to 1 margin versus HDB in the system design such that testing of the system at 1.5 times design pressure (where the design pressure will not result in a stress exceeding *S*) plus 10 psi will not result in the material exceeding the HDB (i.e. 2 x *S*).

(b) In Supplement 5 (Section XI In-service Inspection) of Enclosure 2 to NL-14-1250 (Reference 1), it was mentioned that the periodic pressure test will be performed using a test pressure of maximum normal operating pressure. Please provide the value for maximum normal operating pressure.

Response:

The annual maximum normal operating pressure for Hatch PSW Train B for the past eight years (2007-2014) was between 147 psig and 156 psig, with an average maximum of 149 psig. This is approximately what would be expected as the maximum normal operating pressure in the future.

RAI-4

In section 2.0 of Enclosure 5 (Summary Report on Stress Analysis for PSW Buried HDPE) to NL-14-1876 (Conceptual Design information Package, Reference 3),

(a) include excerpts from the stress analysis computer program (i) input, and (ii) output corresponding to the maximum reported stress locations.

Response:

The critical input and output is now summarized in the Longitudinal Stresses, Seismic-Induced Stresses, Alternative Thermal Expansion and Contraction Evaluation, and Non-Repeating Anchor Movements Sections of the revised Summary Report on Stress Analysis (Enclosure 2, pages 2 - 6). Tables showing the controlling loads that were used to calculate the stress values have been added along with a discussion about these controlling loads.

(b) provide a description of the stress analysis model termination boundaries; how much of the piping and supports beyond the buried HDPE piping is included.

Response:

The conceptual design stress analysis model was terminated at the vault wall where it was considered to be an anchor. This provides conservative results for the buried piping because modeling the portion of pipe extending beyond the vault wall and out of the ground would add flexibility to the pipe resulting in lower stresses. Discussion of the model termination has been added to the revised Summary Report on Stress Analysis (Enclosure 2, page 8).

As part of the detailed design, the buried piping model will be extended to the HDPE to metallic transition flange and the above ground (i.e. inside the vault) piping model will include a portion of the buried piping to provide overlapping analyses. The piping will then be evaluated using bounding loads from the overlapping models.

(c) include a summary of stresses, and loadings (forces and moments) at the interface (metallic pipe to HDPE pipe) adapter flange from all applicable load cases, and discuss the acceptability of these loadings.

Response:

As noted in (b) above, the conceptual design stress analysis model was terminated at the vault wall. Therefore, the interface between the metallic and HDPE pipe was not included as part of the model. The stresses and loadings at the metallic pipe to HDPE pipe interface will be evaluated in the detailed design.

RAI-5

On page 1 of 2 of Enclosure 1 (Conceptual Design Scope description) to NL-14-1876 (Conceptual Design information Package, Reference 3), it was mentioned that Valve 2P41-F380B and its operator are relocated in the existing Unit 2 Division II vault, and new stainless steel piping is added. Additional pipe supports will be added to the metallic piping. The licensee is requested to:

(a) provide loads on metallic piping supports included in the buried HDPE piping model

Response:

Based on the conceptual design, there are no metallic pipe supports included in the buried HDPE piping model. The loads on metallic piping supports in the above ground piping stress analysis model are not presently available and will be determined as part of the detailed design.

(b) also include valve accelerations for any valves included in the stress analysis model along with their acceptance limits.

Response:

The valve accelerations for Valve 2P41-380B being relocated as well as any other valve accelerations impacted by the change will be determined during detailed design.

(c) Address the impact of these changes on above ground piping stress analysis models, and the qualification of valves and pipe supports in the vicinity of the metallic and HDPE piping interface.

Response:

Impacts of this change on the above ground piping stress analysis model(s) and the qualification of valves and pipe supports in the vicinity of the metallic and HDPE piping interface will be evaluated as part of the detailed design.

RAI-6

Page E2-22, Section 3312 of Enclosure 2 to NL-14-1250 (Reference 1) provides allowable stress limit as 2S for computed stresses from non-repeated anchor movements, where S is Long-Term Allowable Stress for Polyethylene listed in Table 3131-1 (Page E2-22).

Page 3 of Section 2.0 of Enclosure 5 (Summary Report on Stress Analysis for PSW Buried HDPE Piping) to NL-14-1876 (Reference 3) computed non-repeated anchor movement stress based on ¼ inch assumed building settlement and used allowable stress limit of 1S only in margin factor calculation. Please provide the following information.

(a) Technical basis or a justification for ¼ inch settlement used in conceptual design.

Response:

The ¼ inch settlement was an assumed value that was considered to be very conservative. This is noted in Section 6.0 of the revised Summary Report on Stress Analysis. The actual settlement will be more accurately predicted with a technical basis in the detailed design.

(b) Explain if 1S limit instead of 2S limit is used for conservatism only.

Response:

The allowable stress for non-repeated anchor movements reported in the table of the Non- Repeating Anchor Movements Section of Enclosure 5 to NL-14-1876 was inadvertently entered as 1S instead of 2S (See the attached Enclosure, Pages 5 and 6). The reported margin factors however, were correctly based on 2S. The values in the table have been corrected in Enclosure 2. Note that the erroneous allowable stress value based on 1S was specific to the stress summary report and that the correct allowable value of 2S was used in the actual analysis.

RAI-7

Page 2 of Section 2.0 of Enclosure 5 (Summary Report on Stress Analysis for PSW Buried HDPE Piping) to NL-14-1876 (Reference 3) provides a table containing computed longitudinal stresses for service levels A, B, and D. Please include the load cases and load combinations used for the above three service levels.

Response:

The Longitudinal Stresses Section of the revised Summary Report on Stress Analysis has been revised to include the requested information (See Enclosure 2, Pages 2 through 4).

RAI-8

Page 3 of Section 2.0 of Enclosure 5 (Summary Report on Stress Analysis for PSW Buried HDPE Piping) to NL-14-1876 (Reference 3) provides a table containing seismically induced stresses for straight pipe and miter elbow. Please include the seismic input values used such as soil strains caused by seismic wave passage, seismic soil movement, and seismic anchor motion. Briefly describe the applicable load cases and load combinations used.

Response:

The Longitudinal Stresses & Seismic-Induced Stresses Sections have been updated to include the requested information (See Enclosure 2, Pages 2 through 4).

RAI-9

Page 3 of Section 2.0 of Enclosure 5 (Summary Report on Stress Analysis for PSW Buried HDPE Piping) to NL-14-1876 (Reference 3) provides a table containing stresses from thermal expansion and thermal contraction and combined stress. Please include the corresponding temperatures for all of the thermal modes applicable to the PSW system.

Response:

The Design for Combined Thermal Expansion and Contraction Section has been updated to include discussion on the various temperatures considered and how they were used to calculate the combined thermal stress (See Enclosure 2, Page 4 and 5).

RAI-10

Page 3 of Section 2.0 of Enclosure 5 (Summary Report on Stress Analysis for PSW Buried HDPE Piping) to NL-14-1876 (Reference 3) provides a table containing stresses from alternative thermal expansion and contraction evaluation. Please describe if these stresses are thermal range stresses and include the corresponding temperatures for the applicable thermal cases used in this evaluation.

Response:

The Alternative Thermal Expansion and Contraction Evaluation Section has been updated to include the requested information (See Enclosure 2, Page 5). A description of the thermal load cases was added along with a discussion of how they were modeled and how the resulting loads were combined to calculate stress values. A tabulation of the resulting controlling loads was also added.

RAI-11

Item (e) Page E2-34, Section 4520 of Enclosure 2 to NL-14-1250 (Reference 1) discusses Flanged Joints at the transition flange. It is mentioned here that in assembling flanged joints, the gaskets, if used, will be uniformly compressed to the proper design loading.

The licensee is requested to clarify whether the transition flanged joints in Hatch unit 2 existing service water sub-grade vault 2B and in new service water sub-grade vault (page 1 of 2 of Enclosure 1 to NL-1876 (Reference 3) contain gaskets or not. Please discuss if leak tight joint can be achieved without a gasket citing any precedents or operating experience. If gaskets will be used, please provide applicable gasket details (Gasket Material, Gasket Factor, Seating Stress, and Seating Width).

Response:

The intention is to use gaskets for both the transition flanged joint in the Hatch Unit 2 existing service water sub-grade vault 2B and in the new service water sub-grade vault. Gasket details such as material, gasket factor, seating stress, and seating width will be determined during the detailed design phase of this project.

Operating experience on the use of gaskets in the HDPE to metallic transition flanged joints in the Callaway ESW system has been favorable. Garlock Gylon 3545 gaskets were selected for the Callaway ESW system based on system design pressure considerations and seating stress considerations to achieve a leak tight joint and provide added protection for the face of the HDPE transition flange.

RAI-12

As discussed in Enclosure 1 to NL-14-1876 (Reference 3), the majority of the HDPE piping is buried with some non-buried portions in an existing vault and in a new vault, which contain transition flanged joints and some valves. The licensee's submittal does not address moderate energy crack postulation assessments for non-buried sections of HDPE piping. The licensee is requested to address the Moderate Energy Crack postulation assessments for non-buried sections of moderate energy piping and any impact on safety related commodities in the vicinity. The evaluations should include computed stresses and crack postulation threshold limits to determine if moderate energy cracks need to be postulated or can be excluded.

Response:

The Hatch Unit 2 FSAR, Table 15A-1 defines moderate-energy piping systems as having either a service pressure of greater than 275 psig or a service temperature of greater than 200°F. Piping systems outside containment whose service pressure is less than 275 psig and whose service temperature is less than 200°F are excluded from moderate energy crack postulation. The maximum operating and design pressures of the PSW system are below 275 psig and the maximum operating and design temperatures are below 200°F and therefore are excluded from moderate energy crack postulation. Therefore, the PSW piping related to this change is not identified or evaluated as a moderate-energy piping.

RAI-13

Provide a brief discussion related to the fire hazard of the non-buried sections of the HDPE piping located in the existing service water vault 2B and the new service water vault and the impact on any safety related commodities in the vicinity from the fire hazard. Please also address fire resistance characteristics of the insulation and any wrapping used on the HDPE piping.

Response:

The current design basis fire for Unit 2 Service Water Valve Pit 2B is considered to be due to transient combustibles. A fire involving transient combustibles within this area will result in no unacceptable consequences, since loss of the redundant safe shutdown circuits in the area may be compensated for by manual actions by using path 1 shutdown procedures. The safe shutdown equipment located in this fire area is credited for safe shutdown paths 2 and 3. There is no safe shutdown equipment located in this fire area for safe shutdown path 1. Safe shutdown path 1 is credited for safe shutdown in the event of a fire in this area.

The only fires of concern are external exposure fires involving both this area and the Unit 1 Service Water Valve Pit 2A which contains path 1 safe shutdown equipment. There are two cable raceways connecting plant service water valve pits 2A and 2B. However these are not considered to be fire propagation paths due to their small size and long length. An asphalt road runs between the two pits and is not considered a propagation pathway due to a lack of ignition sources or combustibles sufficient to transfer enough heat to the asphalt to raise it to its ignition temperature.

The new service water pit located in the yard will only contain Division II components and will not be credited for safe shutdown path 1. Based on the conceptual design approach, there is significant distance (approximately 20 to 30 feet) between the new pit and any other fire areas and there are no fire propagation pathways to other fire areas such that a fire within the pit would interact with any other fire areas. Therefore, a fire within the service water pit will not impact safe shutdown.

Based on the current Fire Hazard Analysis and the above information, the boundaries of these fire areas are adequate to ensure that a fire within either fire area will not damage redundant systems from both shutdown paths and that a fire that originates outside these areas will not spread into them and damage vulnerable shutdown systems. This analysis is based on the conceptual design approach and will be finalized and verified during detailed design.

The additional combustibles in the Unit 2 Service Water Valve Pit 2B and the new service water pit as a result of the addition of the HDPE piping will be tracked in the station combustible loading program.

It is not part of the current design approach to insulate or wrap the exposed HDPE piping.

Edwin I. Hatch Nuclear Plant – Unit 2
Response to Request for Additional Information from Mechanical and Civil Branch
Regarding High Density Polyethylene (HDPE) Piping Replacement

Enclosure 2

Revised Summary Report on Stress Analysis for PSW Buried HDPE Piping

Summary Report

on

Stress Analysis for PSW Buried HDPE Piping

Hatch Nuclear Plant – Unit 2

1.0 Purpose of Summary Report

This report summarizes the stress analysis calculation that has been prepared to support SNC's Inservice Inspection (ISI) Alternative Request HNP-ISI-ALT-HDPE-01, Version 2.0 (ATR). This ISI Alternative is needed to support the planned replacement of buried steel piping in Hatch Nuclear Plant Unit 2, Plant Service Water (PSW) system with High Density Polyethylene (HDPE) piping.

The stress analysis calculation evaluates the conceptual design for the replacement piping to the design requirements in the ATR. The piping to be replaced is the supply piping from the Unit 2 Service Water Valve Pit 2B to a new subgrade vault located outside of the Unit 2 Reactor Building.

All computations from the calculation are not included in the summary. Calculation results and conclusions are shown in Section 2.0.

2.0 Results and Conclusions

The replacement HDPE piping meets all of the acceptance criteria outlined in the Inservice Inspection (ISI) Alternative Request HNP-ISI-ALT-HDPE-01, Version 2.0.

Detailed results are shown in this section. All margin factor values are greater than 1.0 and are therefore acceptable. The controlling margin factor that was dependent on pipe loading was 1.26 which was for longitudinal stress for Service Level D using upper bound spring values (straight pipe). The stress analysis calculation also evaluated pipe floatation and concluded that the unanchored pipe will not float.

The piping has been analyzed to the following conditions per Section 1100 of Design Input 3.1.

Condition	Temperature, ^{o}F	Pressure, psig
Normal Operating	95	140
Maximum Operating	97	190
Design	123	180

<u>Allowable Service Level Spikes Due to Transient Pressures</u>

Per Assumption 6.2, fluid transients, if any, are considered to be negligible.

<u>Pressure Design of Joints and Fittings (Based on GSRs)</u>

Component	Pressure Rating (psi)	Design Pressure (psi)	Margin Factor
Flange Adapters	187	180	1.04
Miter Elbows	207	180	1.15

The margin factors are greater than 1.0 for all components and are therefore acceptable.

<u>Pressure Design of Miter Elbows (Based on Design Equations)</u>

Pressure Rating (psi)	Design Pressure (psi)	Margin Factor
218	180	1.21

The margin factor is greater than 1.0 and is therefore acceptable.

Ring Deflection due to Soil and Surcharge Loads

Ring Deflection (%)	Max. Ring Deflection (%)	Margin Factor
1.61	2.8	1.73

The margin factor is greater than 1.0 at all locations for the design truck and the ISFSI crawler loads and is therefore acceptable.

Compression of Sidewalls Due to Soil and Surcharge Loads

Circumferential Compressive Stress (psi)	Allowable Compression Stress (psi)	Margin Factor
110	630	5.73

The margin factor is greater than 1.0 at all locations for the design truck and the ISFSI crawler loads and is therefore acceptable.

Buckling Due to External Pressure

Total Pressure on Pipe (psi)	Pressure Limit for Buckling (psi)	Margin Factor
31.44	173.6	5.52

The margin factor is greater than 1.0 at all locations for the design truck and the ISFSI crawler loads and is therefore acceptable.

Effects of Negative Internal Pressure

Per Section 3.10.1 of Enclosure 8 of design input 3.1, there are no negative internal pipe pressures anticipated.

Flotation

Downward Resultant Force Acting on Pipe (plf)	Upward Buoyant Force Acting on Pipe (plf)
557	67

Since the downward force acting on the pipe is greater than the upward force, the unanchored pipe will not float.

Longitudinal Stresses

The seismic-induced stresses due to seismic wave passage were determined by following the methodology outlined in Section 4.5 of Ref. 7.3. The methodology involves calculating the controlling strain induced in the pipe due to seismic wave passage. The seismic wave induced strain is limited by breakaway between the pipe and soil. The controlling strain is converted into an equivalent differential temperature which is input into the SAP2000 Finite Element Models (FEM) for the seismic load cases. The axial soil strains caused by soil curvature were calculated as 1.357x10^-8 and 2.544x10^-8 for OBE and DBE seismic responses, respectively. The axial soil strains caused by wave passage were calculated as 1.6x10^-4 and 3x10^-4 for OBE and DBE seismic responses, respectively. Therefore, the controlling axial soil strains due to wave passage are input into the FEM as equivalent differential temperatures.

The piping is terminated at the valve vaults for the conceptual design model. Seismic anchor movements between the soil and the valve vaults are negligible as the vault motion is considered to be the same as the ground motion. The HDPE piping is connected to the existing steel piping inside the new subgrade vault located outside of the Reactor Building. The existing steel piping continues into the Reactor Building. Since a portion of the Reactor Building seismic anchor movements could be distributed to the portion of the HDPE piping, the full Reactor Building seismic anchor movements were conservatively applied at the model termination point. The Reactor Building DBE seismic anchor movements were taken from Table 1 of Design Input 3.10 at Elevation 130' as 0.078-in and 0.064-in for the horizontal and vertical directions respectively. One-half of these values were considered for the OBE load case which is consistent with Design Input 3.11.

The loads resulting from applying the seismic anchor movements in each direction were combined by square root sum of the squares (SRSS). The resulting seismic anchor movement loads were then combined with the other seismic loads by SRSS (per Design Input 3.1, Section 3410).

Loads due to seismic soil movement are considered zero since the soil is not susceptible to liquefaction (per Design Input 3.6, Sections 2A.4.8 & 2A.5.2).

The longitudinal stresses tabulated on the following page consider the worst case axial loads in combination with the worst case bending moments. This is conservative since the worst case axial load is likely to not occur at the same location as the worst case bending moment. The table below summarizes the maximum loading that is used in developing the bounding stresses. These loads include seismic wave passage and seismic anchor movements which were extracted from the analysis computer program output.

Using Upper Bound Springs	Straight Pipe	Max. Axial Load, OBE	2840.74 lbf
		Max. Moment, OBE	18254.87 in-lbf
		Max. Axial Load, DBE	5676.91 lbf
		Max. Moment, DBE	36493.83 in-lbf
	Elbows	Max. Axial Load, OBE	1927.52 lbf
		Max. Moment, OBE	10204.46 in-lbf
		Max. Axial Load, DBE	3849.82 lbf
		Max. Moment, DBE	20188.62 in-lbf
Using Lower Bound Springs	Straight Pipe	Max. Axial Load, OBE	989.06 lbf
		Max. Moment, OBE	11849.02 in-lbf
		Max. Axial Load, DBE	1854.48 lbf
		Max. Moment, DBE	23639.72 in-lbf
	Elbows	Max. Axial Load, OBE	468.81 lbf
		Max. Moment, OBE	6195.10 in-lbf
		Max. Axial Load, DBE	879.02 lbf
		Max. Moment, DBE	12323.56 in-lbf

The allowable stress value was conservatively based on a temperature of 125°F instead of the design temperature of 123°F.

Service Level	Component	Spring Load Case	Pipe Stress (psi)	Stress Factor	Stress Factor x Allowable Stress (psi)	Margin Factor
A	Straight Pipe	N/A	315	1	561	1.78
	Miter Elbow	N/A	331	1	561	1.69
B	Straight Pipe	Upper Bound	462	1.1	617	1.34
		Lower Bound	405	1.1	617	1.52
	Miter Elbow	Upper Bound	409	1.1	617	1.51
		Lower Bound	378	1.1	617	1.63
D	Straight Pipe	Upper Bound	591	1.33	746	1.26
		Lower Bound	476	1.33	746	1.57
	Miter Elbow	Upper Bound	467	1.33	746	1.60
		Lower Bound	405	1.33	746	1.84

The loads included in each Service Level are defined in Section 3.10 of Enclosure 8 of Design Input 3.1. Service Level A includes stresses due to the design pressure. Service Level B includes stresses due to the maximum operating pressure and forces and moments due to the effects of OBE seismic wave passage, OBE seismic soil movement, and OBE seismic anchor movements. Service Level D includes stresses due to the maximum operating pressure and forces and moments due to the effects of DBE seismic wave passage, DBE seismic soil movement, and DBE seismic anchor movements. As previously noted, loads due to seismic soil movement are considered zero since the soil is not susceptible to liquefaction. All margin factors are greater than 1.0 and are therefore acceptable.

Seismic-Induced Stresses

See the Longitudinal Stresses Section for discussion on the development of the seismic load cases.

Similar to the longitudinal stresses evaluations, the seismic-induced stresses consider the worst case axial loads in combination with the worst case bending moments. The same forces and moments previously tabulated in the longitudinal stress section for the DBE case were used to calculate the stress values in the table below.

Component	Spring Load Case	Pipe Stress (psi)	Allowable Stress Range (psi)	Margin Factor
Straight Pipe	Upper Bound	517	2032	3.93
	Lower Bound	286	2032	7.09
Miter Elbow	Upper Bound	225	2032	9.05
	Lower Bound	113	2032	17.98

All margin factors are greater than 1.0 and are therefore acceptable.

Short Duration Longitudinal Applied Mechanical Loads

There are no short duration longitudinal applied mechanical loads for this piping.

Design for Combined Thermal Expansion and Contraction

The thermal stresses due to thermal contraction are based on a minimum water temperature of 32°F. The thermal stresses due to thermal expansion are based on the design temperature of 123°F. This is conservative since the normal operating temperature and maximum operating temperature are only 95°F and 97°F respectively. Both cases utilize a ground temperature of 70°F. Additionally, the allowable stress value was based on a temperature of 125°F instead of the design temperature of 123°F which is conservative. The stress due to thermal contraction is added to the stress due to thermal expansion, which results in a thermal range stress.

Stress Due to Thermal Contraction (psi)	Stress Due to Thermal Expansion (psi)	Combined Stress (psi)	Allowable Stress Range (psi)	Margin Factor
439	195	634	2032	3.20

The margin factor is greater than 1.0 and is therefore acceptable.

<u>Alternative Thermal Expansion and Contraction Evaluation</u>

The temperature values of 32°F and 123°F discussed in the Design for Combined Thermal Expansion and Contraction Section were modeled in the FEM as two separate load cases. These were input into the FEM as changes in temperature of -38°F (= 32°F - 70°F) and +53°F (= 123°F - 70°F). The resulting loads for the two thermal load cases were then combined by absolute sum to obtain the thermal range response.

Similar to the longitudinal stresses evaluations, the thermal stresses consider the worst case axial loads in combination with the worst case bending moments. The table below summarizes the maximum loading that is used in developing the bounding stresses for the thermal expansion and contraction load cases. The loads in this table are for the thermal range and were extracted from the analysis computer output.

Using Upper Bound Springs	Straight Pipe	Max. Axial Load	25249.36 lbf
		Max. Moment	29409.47 in-lbf
	Elbows	Max. Axial Load	23214.51 lbf
		Max. Moment	125988.29 in-lbf
Using Lower Bound Springs	Straight Pipe	Max. Axial Load	25249.04 lbf
		Max. Moment	66307.80 in-lbf
	Elbows	Max. Axial Load	12753.50 lbf
		Max. Moment	144777.92 in-lbf

These loads were used to calculate the pipe stresses reported in the table below.

Component	Spring Load Case	Pipe Stress (psi)	Allowable Stress Range (psi)	Margin Factor
Straight Pipe	Upper Bound	482	2032	4.21
	Lower Bound	668	2032	3.04
Miter Elbow	Upper Bound	694	2032	2.93
	Lower Bound	684	2032	2.97

All margin factors are greater than 1.0 and are therefore acceptable.

<u>Non-Repeating Anchor Movements</u>

The assumed building settlement of 1/4" (Assumption 6.5) was modeled in all of the SAP2000 finite element models (lower and upper bound springs for thermal and seismic load cases). Even though the thermal analyses (long-term load condition) provide the most realistic values, the worst case values from all of the models have been considered.

Similar to the longitudinal stresses evaluations, the non-repeating anchor movement stress evaluations consider the worst case axial loads in combination with the worst case bending moments. The following table summarizes the maximum loading that is used in developing the bounding stresses. The loads in this table were extracted from the analysis computer output.

Straight Pipe	Max. Axial Load	11.36 lbf
	Max. Moment	102252.40 in-lbf
Elbows	Max. Axial Load	14.44 lbf
	Max. Moment	21330.21 in-lbf

These loads were used to calculate the pipe stresses reported in the table below.

Component	Pipe Stress (psi)	Long Term Allowable Stress (psi)	Margin Factor
Straight Pipe	513	1122	2.19
Miter Elbow	86	1122	13.12

Both margin factors are greater than 1.0 and are therefore acceptable.

<u>Other Design Considerations</u>

As noted in Enclosure 2 of Design Input 3.1, other design considerations will be addressed under SNC design procedures in accordance with the existing design and license basis for HNP.

3.0 Design Inputs

3.1 Edwin I. Hatch Nuclear Plant - Unit 2, Proposed Inservice Inspection Alternative HNP-ISI-ALT-HDPE-01, Version 2.0.

The acceptance criteria and general methodology was taken from this design input document.

3.2 Drawing SK-001, Version A, "SNC591628 Unit 2 Service Water Division II Underground Piping Isometric."

The routing of the piping is detailed in this design input document.

3.3 Drawing SK-002, Version A, "SNC591628 Unit 2 Service Water Division II SS/HDPE Transition Vault Piping Plan."

The routing of the piping is detailed in this design input document.

3.4 Drawing SK-003, Version A, "SNC591628 Unit 2 Service Water Division II SS/HDPE Transition Vault Piping Sections & Details."

The routing of the piping is detailed in this design input document.

3.5 Drawing SK-004, Version A, "SNC591628 Unit 2 Service Water Division II SS/HDPE Transition Vault Detail "C"."

The routing of the piping is detailed in this design input document.

3.6 HNP-2-FSAR-2, Rev. 26 (9/08)

Site specific details were taken from this design input document. Specifically, seismic wave velocity values, peak horizontal ground accelerations and site soil conditions.

3.7 ISCO Product Catalog, Version 4.1, 2013.

The HDPE pipe section dimensional properties and weight are taken from this design input document.

3.8 Flowable Fill Website, http://flowablefill.org/performance.html

The typical maximum and minimum densities for flowable fill are taken from this design input document.

3.9 DCR00-35, "Addition of RR Pad and New Track, and Evaluation of Crawler Path," Rev. 1.

The crawler track dimensions for the ISFSI cask transporter and the total weight for the cask and crawler are taken from this design input document.

3.10 Calculation BH0-C-S08-V001-0003, Version 1, Edwin I. Hatch Nuclear Plant, Units 1 and 2, "The Stress Analysis of Underground Piping and Electric Ducts."

The DBE seismic anchor movements for the Reactor Building are taken from this design input document.

3.11 Calculation SMSH-12-020, Version 1.0, "Stress Analysis of Unit 1 Div II Buried Service Water Pipe", with MC-H-13-0129, Version 1.0.

The OBE seismic anchor movements for the Reactor Building are taken as half of the value of the DBE anchor movements. This is consistent with this design input document.

3.12 BH2-C-S23-V012-0001, "Final Seismic Analysis Reactor Building and Internals", April 15, 1975, Volume 1.

The DBE & OBE seismic anchor movements were compared to the values reported in this design input document and were found to be of negligible difference.

3.13 BH2-C-S23-V013-0001, "Final Seismic Analysis Reactor Building and Internals", April 15, 1975, Volume 2.

The DBE & OBE seismic anchor movements were compared to the values reported in this design input document and were found to be of negligible difference.

4.0 Acceptance Criteria

The stress analysis calculation followed the acceptance criteria outlined in the Inservice Inspection (ISI) Alternative Request HNP-ISI-ALT-HDPE-01, Version 2.0.

5.0 Methodology

The stress analysis calculation followed the methodology outlined in the Inservice Inspection (ISI) Alternative Request HNP-ISI-ALT-HDPE-01, Version 2.0 (ATR). In addition to the design truck in the ATR, surcharge loads for an ISFSI cask transporter were also considered.

In order to obtain the pipe axial forces and resultant moments for Sections 3223.1, 3311.4, 3312, & 3410 of the ATR, several SAP2000 Finite Element Models (FEM) were produced. The piping is supported at the model termination points, which were conservatively considered rigid anchor points, and at discrete node points that were modeled using springs. The springs in the FEM consist of pipe ovaling springs and soil springs, which are dependent on the modulus of elasticity of the pipe and soil properties in series. Detailed calculations and resulting values for the springs are shown in Attachment A.

The modulus of elasticity of the pipe is different for the thermal and seismic load cases. The exact soil parameters are not fully defined during the conceptual design phase. Therefore, lower bound and upper bound spring values were determined for both the thermal and seismic load cases for a range of potential soil and pipe properties. Then, best estimate spring values were determined by taking the average of the calculated lower and upper bound spring values. These best estimate values were adjusted downward and upward by a coefficient of variation (COV) to calculate best estimate lower and upper bound springs. A COV of 1 was conservatively used in accordance with Ref. 7.7, Section II.4.c.iii. This resulted in factors of 0.5 and 2.0 for the lower and upper bound best estimate cases respectively. The pipe was qualified for the bounding range of calculated upper and lower cases and best estimate upper and lower cases.

The spring values and node point spacing for the FEM were determined by following the methodology outlined in Appendix B & Appendix E of Ref. 7.3.

After the initial run of the SAP2000 models, displacements at all node points were compared to the displacement range that was valid for each of the applied springs. There were several nodes that exceeded the breakaway displacement in the axial direction for the thermal load cases. Replacing the springs that exceed the displacement range with the breakaway force would be an acceptable, but iterative, solution. As an alternative, links were used in place of all of the axial springs for the thermal models. The links were modeled with a linear force-displacement relationship up to the breakaway displacement. The breakaway force was considered for pipe displacements beyond the breakaway displacement. Similar to the spring values, the breakaway force for each link is dependent on the effective length.

The piping in the FEM was terminated at the vault wall where it was considered to be an anchor. This provides conservative results for the buried piping because modeling the portion of pipe extending beyond the vault wall and out of the ground would add flexibility to the pipe resulting in lower stresses.

6.0 Assumptions

6.1 Assumption:

Miter elbows have the same inside diameter as the straight pipe, an average outside diameter of 16", a bend radius of 24", and a one-half angle between adjacent miter axes of 11.25 degrees.

Justification:

This assumption does not require verification as it will be worked into the detailed design.

6.2 Assumption:

Fluid transients, if any, are considered to be negligible.

Justification:

There have been no identified relief valves or other valves that would create a significant pressure spike due to transient pressures for the replacement piping. Verification of this assumption needs to be completed for the detailed design.

6.3 Assumption:

Native soil is considered to be loose.

Justification:

The native soil properties will need to be verified for the detailed design.

6.4 Assumption:

Flowable fill is considered to have a minimum modulus of soil reaction of 3000-psi.

Justification:

This assumption does not require verification as it will be worked into the detailed design.

6.5 Assumption:

A settlement of 1/4" is applied at both of the model termination points.

Justification:

The assumed settlement of 1/4" is considered to be a very conservative value for the settlement at the model termination points. However, justification will need to be provided for the value used in the detailed design.

6.6 Assumption:

A smaller trench width produces larger and less favorable ring deflection. A trench width of 3-ft is considered to be a lower bound value which is used as a worst case.

Justification:

This assumption does not require verification as it will be worked into the detailed design.

6.7 Assumption:

The flowable fill is conservatively considered to be used for all of the backfill (all the way to grade).

Justification:

This assumption does not require verification as it will be worked into the detailed design.

7.0 References

7.1 PPI, "Handbook of Polyethylene Pipe", 2nd Ed. with 6/6/12 Errata.

7.2 Marohl, M. P., "Comparison of Numerical Methods for Calculation of Vertical Soil Pressures on Buried Piping Due to Truck Loading," Proceedings of the ASME 2014 Pressure Vessels & Piping Conference, PVP2014-28467, July 20-24, 2014.

7.3 EPRI Report 1013549, "Nondestructive Evaluation: Seismic Design Criteria for Polyethylene Pipe Replacement Code Case," Technical Update, September 2006.

7.4 Das, Braja M., "Principles of Foundation Engineering," 6th Ed.

7.5 American Lifelines Alliance, "Guidelines for the Design of Buried Steel Pipe," July 2001 with Addenda through February 2005.

7.6 McGrath, T. J. and Hoopes, R. J., " 'Bedding Factors and E' Values for Buried Pipe Installations Backfilled with Air-Modified CLSM," The Design and Application of Controlled Low-Strength Materials (Flowable Fill), ASTM STP 1331, A. K. Howard and J. L. Hitch, Eds., American Society for Testing and Materials, 1998.

7.7 NUREG-0800, Section 3.7.2, "Seismic System Analysis."

This attachment develops the spring and breakaway force values that are input into the SAP2000 models.

See Design Input 3.2, 3.3, 3.4, and 3.5 for the replacement piping layout. Per Design Input 3.2 through 3.5, the ground surface elevation (grade elevation) for this piping is 129', the highest elevation to the pipe centerline is 122' and the deepest elevation to the pipe centerline is 119'-6". The deepest pipe location (smallest elevation) is used as a worst case for calculating soil overburden loads except for lower bound spring evaluations. The shallowest pipe location (largest elevation) is used as a worst case for calculating all surcharge loads.

$EL_{ground} := 129 \cdot ft$	Grade Elevation (See 3.4 & 3.5)
$EL_{max} := 122 \cdot ft$	Pipe Centerline Maximum Elevation (See 3.2)
$EL_{min} := 119.5 \cdot ft$	Pipe Centerline Minimum Elevation (See 3.2)
$E_{pipe.th} := 46000 \cdot psi$	Modulus of Elasticity of Pipe for Thermal Evaluations (1000-hrs & 73°F, From Table 3210-3 of Design Input 3.1)
$E_{pipe.seis} := 82000 \cdot psi$	Modulus of Elasticity of Pipe for Seismic Evaluations (0.5-hrs & 73°F, From Table 3210-3 of Design Input 3.1)

The modulus of soil reaction for the backfill (flowable fill) is taken from Table 4 of Ref. 7.6 considering a minimum age of 28 days. Note that this value is similar to that of Table 3-8 of Chapter 6 of Ref. 7.1 for coarse-grain soil at a depth of cover ranging from 5 to 10 feet. The pipe has a cover of at least 5 feet for the entire routing.

$E' := 3000 psi$	Modulus of Soil Reaction for Backfill

The straight pipe portions consist of IPS 14 HDPE piping produced with PE4710 material of cell classification 445574C per Section 1100 of Design Input 3.1.

$D := 14.00 in$	Average Outside Diameter of Pipe (See 3.7)
$DR := 7$	Dimension Ratio of Pipe
$t_{fabmin} := 2 \cdot in$	Minimum Fabricated Pipe Wall Thickness (See 3.7)
$D_i := D - 2 \cdot t_{fabmin} = 10 \cdot in$	Inside Diameter of Pipe
$D_{elbow} := 16 \cdot in$	Miter Elbow Outside Diameter (See 6.1)

Inside diameter for the miter elbows is set to match the inside diameter of the straight pipe (See 6.1).

$D_{i.elbow} := D - 2 \cdot t_{fabmin} = 10 \cdot in$	Miter Elbow Inside Diameter
$t_{elbow} := \dfrac{D_{elbow} - D_{i.elbow}}{2} = 3 \cdot in$	Miter Elbow Wall Thickness
$DR_{elbow} := \dfrac{D_{elbow}}{t_{elbow}} = 5.333$	Dimension Ratio of Miter Elbow
$I_P := \pi \cdot \dfrac{D^4 - D_i^4}{64} = 1394.867 in^4$	Moment of Inertia of Pipe

The maximum and minimum soil densities are taken as the upper and lower bound values for the typical range of weight for flowable fill (See 3.8). The upper bound value used is considered to include any soil saturation affects. The flowable fill is conservatively considered to be used for all of the backfill (all the way to grade) (See 6.7).

$\rho_{max} := 145 \cdot pcf$ Maximum Density of Soil Above Pipe

$\rho_{min} := 70 \cdot pcf$ Minimum Density of Soil Above Pipe

$K := 0.1$ Bedding Factor (See 3.1, Section 3210)

The methodology outlined in Appendix B & Appendix E of Ref. 7.3 is followed for developing pipe ovaling spring values, soil spring values, and spring spacing.

The soil properties range from a lower bound to an upper bound (soil density for example). Therefore, each load condition will have a lower bound evaluation and an upper bound evaluation. This results in four sets of spring values: seismic load condition lower bound, seismic load condition upper bound, thermal load condition lower bound, and thermal load condition upper bound.

The pipe ovaling springs are dependent on the pipe inside and outside diameter. Therefore, spring values for both the straight pipe and the miter elbows are calculated.

<u>Lower Bound Pipe Ovaling Springs</u>:

The lower bound modulus of soil reaction value is used for the lower bound springs.

$E' = 3000 \cdot psi$ Modulus of Soil Reaction for Backfill (Previously Defined)

Per Ref. 7.3, Section 5.10, a lag factor of 1.0 is recommended for short-term loads and 1.5 for long-term loads. Therefore, 1.0 is used for seismic load condition and 1.5 is used for thermal load condition.

$L_{f.s} := 1.0$ $L_{f.th} := 1.5$ Lag Factor (Ref. 7.3, Section 5.10)

Stiffness due to Pipe Ovaling for Straight Pipe (Seismic Load Condition)

$$K_{po.s.ls} := \frac{2}{D_i} \cdot \frac{\frac{2 \cdot E_{pipe.seis}}{3} \cdot \left(\frac{1}{DR - 1}\right)^3 + 0.061 \cdot E'}{K \cdot L_{f.s}} \cdot D = 12210.42 \cdot psi$$ (Ref. 7.3, Eq. B-1a)

Stiffness due to Pipe Ovaling for Straight Pipe (Thermal Load Condition)

$$K_{po.th.ls} := \frac{2}{D_i} \cdot \frac{\frac{2 \cdot E_{pipe.th}}{3} \cdot \left(\frac{1}{DR - 1}\right)^3 + 0.061 \cdot E'}{K \cdot L_{f.th}} \cdot D = 6066.206 \cdot psi$$ (Ref. 7.3, Eq. B-1a)

Stiffness due to Pipe Ovaling for Miter Elbows (Seismic Load Condition)

$$K_{po.s.le} := \frac{2}{D_{i.elbow}} \cdot \frac{\frac{2 \cdot E_{pipe.seis}}{3} \cdot \left(\frac{1}{DR_{elbow} - 1}\right)^3 + 0.061 \cdot E'}{K \cdot L_{f.s}} \cdot D_{elbow} = 27354.407 \cdot psi$$ (Ref. 7.3, Eq. B-1a)

Stiffness due to Pipe Ovaling for Miter Elbows (Thermal Load Condition)

$$K_{po.th.le} := \frac{2}{D_{i.elbow}} \cdot \frac{\frac{2 \cdot E_{pipe.th}}{3} \cdot \left(\frac{1}{DR_{elbow} - 1}\right)^3 + 0.061 \cdot E'}{K \cdot L_{f.th}} \cdot D_{elbow} = 11944.055 \cdot psi$$ (Ref. 7.3, Eq. B-1a)

Lower Bound Transverse Soil Spring:

The flowable fill is considered to behave like dense sand for determination of soil springs.

The minimum ground cover is used which, as a worst case, produces the smallest stiffness.

$EL_p := EL_{max} = 122 \cdot ft$ Pipe Elevation (To Pipe Centerline)

$H := EL_{ground} - EL_p = 7 \cdot ft$ Height of Ground Cover (Depth to Pipe Centerline)

$\phi := 40 \cdot deg$ Best Estimate Angle of Internal Friction (Ref. 7.4, Table 1.8)

Calculations for Straight Pipe Springs:

The Horizontal Bearing Capacity Factor, N_{qh}, can be determined by using Figures B-1 and B-2(a) of Ref. 7.3. These same figures are developed in Ref. 7.5. In-lieu of using the figures, the equation in Section B.2 of Ref. 7.5 is used which will provide a more accurate value.

Horizontal Bearing Capacity Factor (Ref. 7.5, Section B.2) for ϕ=40°:

$$N_{qh} := 10.959 + 1.783 \cdot \left(\frac{H}{D}\right) + 0.045 \cdot \left(\frac{H}{D}\right)^2 - 0.005425 \cdot \left(\frac{H}{D}\right)^3 - 0.0001153 \cdot \left(\frac{H}{D}\right)^4 = 21.956$$

The minimum soil density is used for all of the lower bound spring calculations since this produces the smallest spring values.

$f_t := D \cdot \rho_{min} \cdot H \cdot N_{qh} = 1045.949 \cdot \frac{lbf}{in}$ Breakaway Force (Per Table B-1 of Ref. 7.3, Sand)

The transverse displacement ranges between 2% and 10% of (H+D/2) per Table B-1 of Ref. 7.3. The larger the displacement, the smaller the spring value. Therefore, the largest displacement values from Table B-1 of Ref. 7.3 are considered for all of the lower bound spring values.

$d_t := 10\% \cdot \left(H + \frac{D}{2}\right) = 9.1 \cdot in$ Displacement (Per Table B-1 of Ref. 7.3, Sand)

$K_{t.ls} := \frac{f_t}{d_t} = 114.939 \cdot psi$ Transverse Soil Spring for Straight Pipe (Per Table B-1 of Ref. 7.3)

Calculations for Miter Elbow Springs:

Horizontal Bearing Capacity Factor (Ref. 7.5, Section B.2) for ϕ=40°:

$$N_{qh} := 10.959 + 1.783\cdot\left(\frac{H}{D_{elbow}}\right) + 0.045\cdot\left(\frac{H}{D_{elbow}}\right)^2 - 0.005425\cdot\left(\frac{H}{D_{elbow}}\right)^3 - 0.0001153\cdot\left(\frac{H}{D_{elbow}}\right)^4$$

$$N_{qh} = 20.687$$

$$f_t := D_{elbow}\cdot\rho_{min}\cdot H\cdot N_{qh} = 1126.317\cdot\frac{lbf}{in}$$ Breakaway Force (Per Table B-1 of Ref. 7.3, Sand)

$$d_t := 10\%\cdot\left(H + \frac{D_{elbow}}{2}\right) = 9.2\cdot in$$ Displacement (Per Table B-1 of Ref. 7.3, Sand)

$$K_{t.le} := \frac{f_t}{d_t} = 122.426\cdot psi$$ Transverse Soil Spring for Miter Elbows (Per Table B-1 of Ref. 7.3)

<u>Lower Bound Axial Soil Spring</u>:

The coefficient of soil pressure at rest is calculated using Jaky's simplified equation from Section 7.2 of Ref. 7.4. This provides a reasonable empirical approximation of the true value.

$$K_o := 1 - \sin(\phi) = 0.357$$ Coefficient of Soil Pressure at Rest (Ref. 7.4, Section 7.2)

Per Ref. 7.3, page B-4, the friction angle pipe-soil, δ, ranges between 0.5 and 0.8 times the internal angle of friction. The smaller the friction angle pipe-soil, the smaller the spring value. Therefore, 0.5 times the internal angle of friction is considered for the lower bound spring values

$$\delta := 0.5\cdot\phi = 0.349$$

Calculations for Straight Pipe Springs:

$$f_{a.ls} := \left(\pi\cdot\frac{D}{2}\right)\cdot\rho_{min}\cdot H\cdot\left(1 + K_o\right)\cdot\tan(\delta) = 36.965\cdot\frac{lbf}{in}$$ Breakaway Force (Per Table B-1 of Ref. 7.3, Sand)

$$d_a := 0.2\cdot in$$ Displacement (Per Table B-1 of Ref. 7.3, Sand)

$$K_{a.ls} := \frac{f_{a.ls}}{d_a} = 184.827\cdot psi$$ Axial Soil Spring for Straight Pipe (Per Table B-1 of Ref. 7.3)

Calculations for Miter Elbow Springs:

$$f_{a.le} := \left(\pi\cdot\frac{D_{elbow}}{2}\right)\cdot\rho_{min}\cdot H\cdot\left(1 + K_o\right)\cdot\tan(\delta) = 42.246\cdot\frac{lbf}{in}$$ Breakaway Force (Per Table B-1 of Ref. 7.3, Sand)

$$d_a := 0.2\cdot in$$ Displacement (Per Table B-1 of Ref. 7.3, Sand)

$$K_{a.le} := \frac{f_{a.le}}{d_a} = 211.231\cdot psi$$ Axial Soil Spring for Miter Elbows (Per Table B-1 of Ref. 7.3)

Lower Bound Vertical Soil Spring:

The Downward Bearing Capacity Factors 1 and 2, N_q & N_γ respectively, can be determined by using Figure B-3 of Ref. 7.3. In-lieu of using this figure, the equations in Section B.4 of Ref. 7.5 are used to obtain more accurate values.

$$N_q := \exp(\pi \cdot \tan(\phi)) \cdot \tan\left(45 \cdot deg + \frac{\phi}{2}\right)^2 = 64.195$$

Downward Bearing Capacity Factor 1 (Ref. 7.5, Section B.4)

$$N_\gamma := \exp\left(0.18 \cdot \frac{\phi}{deg} - 2.5\right) = 109.947$$

Downward Bearing Capacity Factor 2 (Ref. 7.5, Section B.4)

Calculations for Straight Pipe Springs:

$$f_d := \rho_{min} \cdot H \cdot N_q \cdot D + \rho_{min} \cdot D^2 \cdot \frac{N_\gamma}{2} = 3494.668 \cdot \frac{lbf}{in}$$

Vertical Down Breakaway Force (Per Table B-1 of Ref. 7.3, Sand)

$$d_d := 15\% \cdot D = 2.1 \cdot in$$

Displacement (Per Table B-1 of Ref. 7.3, Sand)

$$K_{d.ls} := \frac{f_d}{d_d} = 1664.128 \cdot psi$$

Vertical Down Soil Spring for Straight Pipe (Per Table B-1 of Ref. 7.3)

The Vertical Uplift Factor, N_{qv}, can be determined by using Figure B-4 of Ref. 7.3. These same figures are developed in Ref. 7.5. In-lieu of using the figures, the equation in Section B.3 of Ref. 7.5 is used, which provides a more accurate value.

$$N_{qv} := \min\left(\frac{\phi \cdot H}{44 \cdot deg \cdot D}, N_q\right) = 5.455$$

Vertical Uplift Factor (Ref. 7.5, Section B.3)

$$f_u := D \cdot \rho_{min} \cdot H \cdot N_{qv} = 259.848 \cdot \frac{lbf}{in}$$

Vertical Upward Breakaway Force (Per Table B-1 of Ref. 7.3, Sand)

$$d_u := 1.5\% \cdot H = 1.26 \cdot in$$

Displacement (Per Table B-1 of Ref. 7.3, Sand)

$$K_{u.ls} := \frac{f_u}{d_u} = 206.229 \cdot psi$$

Vertical Up Soil Spring for Straight Pipe (Per Table B-1 of Ref. 7.3)

As recommended in Ref. 7.3, Appendix B, the total vertical soil spring is taken as the average of the vertical up and down.

$$K_{v.ls} := \frac{K_{u.ls} + K_{d.ls}}{2} = 935.178 \cdot psi$$

Vertical Soil Spring for Straight Pipe

Calculations for Miter Elbow Springs:

$$f_d := \rho_{min} \cdot H \cdot N_q \cdot D_{elbow} + \rho_{min} \cdot D_{elbow}^2 \cdot \frac{N_\gamma}{2} = 4065.169 \cdot \frac{lbf}{in}$$ Vertical Down Breakaway Force (Per Table B-1 of Ref. 7.3, Sand)

$$d_d := 15\% \cdot D_{elbow} = 2.4 \cdot in$$ Displacement (Per Table B-1 of Ref. 7.3, Sand)

$$K_{d.le} := \frac{f_d}{d_d} = 1693.82 \cdot psi$$ Vertical Down Soil Spring for Miter Elbows (Per Table B-1 of Ref. 7.3)

$$N_{qv} := \min\left(\frac{\phi \cdot H}{44 \cdot deg \cdot D_{elbow}}, N_q\right) = 4.773$$ Vertical Uplift Factor (Ref. 7.5, Section B.3)

$$f_u := D_{elbow} \cdot \rho_{min} \cdot H \cdot N_{qv} = 259.848 \cdot \frac{lbf}{in}$$ Vertical Upward Breakaway Force (Per Table B-1 of Ref. 7.3, Sand)

$$d_u := 1.5\% \cdot H = 1.26 \cdot in$$ Displacement (Per Table B-1 of Ref. 7.3, Sand)

$$K_{u.le} := \frac{f_u}{d_u} = 206.229 \cdot psi$$ Vertical Up Soil Spring for Miter Elbows (Per Table B-1 of Ref. 7.3)

$$K_{v.le} := \frac{K_{u.le} + K_{d.le}}{2} = 950.025 \cdot psi$$ Vertical Soil Spring for Miter Elbows

Lower Bound Influence Length:

Since the influence lengths affect the straight pipe portions, only the straight pipe properties are used to determine the influence length. The soil modulus (K_o) is taken as the pipe ovalization spring stiffness following the example in Ref. 7.3, Appendix E.

$$K_{po.s.ls} = 12210.42 \cdot psi$$

$$\beta_s := \left(\frac{K_{po.s.ls}}{4 \cdot E_{pipe.seis} \cdot I_P}\right)^{\frac{1}{4}} = 0.072 \cdot \frac{1}{in}$$ Characteristic of the System (Ref. 7.3, Eq. B-6)

$$L_{\beta.s} := \frac{3 \cdot \pi}{4 \cdot \beta_s} = 32.782 \cdot in$$ Influence Length (Seismic Load Condition) (Ref. 7.3, Eq. B-5)

$$K_{po.th.ls} = 6066.206 \cdot psi$$

$$\beta_{th} := \left(\frac{K_{po.th.ls}}{4 \cdot E_{pipe.th} \cdot I_P}\right)^{\frac{1}{4}} = 0.07 \cdot \frac{1}{in}$$ Characteristic of the System (Ref. 7.3, Eq. B-6)

$$L_{\beta.th} := \frac{3 \cdot \pi}{4 \cdot \beta_{th}} = 33.792 \cdot in$$ Influence Length (Thermal Load Condition) (Ref. 7.3, Eq. B-5)

$$L_{\beta.l} := \max(L_{\beta.s}, L_{\beta.th}) = 33.792 \cdot in$$ Controlling Influence Length

Upper Bound Pipe Ovaling Springs:

The larger the modulus of elasticity of the soil, the larger the spring value. Therefore, the modulus of elasticity for the backfill is taken from Table 3-9 of Chapter 6 of Ref. 7.1 as 20000-psi, which is the largest tabulated, realistic value.

$E' := 20000 \cdot psi$ Upper Bound Modulus of Elasticity for Backfill

Stiffness due to Pipe Ovaling for Straight Pipe (Seismic Load Condition)

$$K_{po.s.us} := \frac{2}{D_i} \cdot \frac{\frac{2 \cdot E_{pipe.seis}}{3} \cdot \left(\frac{1}{DR - 1}\right)^3 + 0.061 \cdot E'}{K \cdot L_{f.s}} \cdot D = 41246.42 \cdot psi$$ (Ref. 7.3, Eq. B-1a)

Stiffness due to Pipe Ovaling for Straight Pipe (Thermal Load Condition)

$$K_{po.th.us} := \frac{2}{D_i} \cdot \frac{\frac{2 \cdot E_{pipe.th}}{3} \cdot \left(\frac{1}{DR - 1}\right)^3 + 0.061 \cdot E'}{K \cdot L_{f.th}} \cdot D = 25423.539 \cdot psi$$ (Ref. 7.3, Eq. B-1a)

Stiffness due to Pipe Ovaling for Miter Elbows (Seismic Load Condition)

$$K_{po.s.ue} := \frac{2}{D_{i.elbow}} \cdot \frac{\frac{2 \cdot E_{pipe.seis}}{3} \cdot \left(\frac{1}{DR_{elbow} - 1}\right)^3 + 0.061 \cdot E'}{K \cdot L_{f.s}} \cdot D_{elbow}$$ (Ref. 7.3, Eq. B-1a)

$K_{po.s.ue} = 60538.407 \cdot psi$

Stiffness due to Pipe Ovaling for Miter Elbows (Thermal Load Condition)

$$K_{po.th.ue} := \frac{2}{D_{i.elbow}} \cdot \frac{\frac{2 \cdot E_{pipe.th}}{3} \cdot \left(\frac{1}{DR_{elbow} - 1}\right)^3 + 0.061 \cdot E'}{K \cdot L_{f.th}} \cdot D_{elbow}$$ (Ref. 7.3, Eq. B-1a)

$K_{po.th.ue} = 34066.721 \cdot psi$

Upper Bound Transverse Soil Spring:

The maximum ground cover is used which, as a worst case, produces the largest stiffness.

$EL_p := EL_{min} = 119.5 \cdot ft$ Pipe Elevation (To Pipe Centerline)

$H := EL_{ground} - EL_p = 9.5 \cdot ft$ Height of Ground Cover (Depth to Pipe Centerline)

The angle of internal friction, ϕ,is dependent upon the relative density of the soil. The flowable fill is considered to be a dense soil and the value for ϕ ranges between 40 and 45 degrees per Table 1.8 of Ref. 7.4. 40 degrees is considered as a best estimate for the actual value.

$\phi := 40 \cdot deg$ Angle of Internal Friction (Ref. 7.4, Table 1.8)

Calculations for Straight Pipe Springs:

The Horizontal Bearing Capacity Factor, N_{qh}, can be determined by using Figures B-1 and B-2(a) of Ref. 7.3. These same figures are developed in Ref. 7.5. In-lieu of using the figures, the equation in Section B.2 of Ref. 7.5 is used, which provides a more accurate value.

Horizontal Bearing Capacity Factor (Ref. 7.5, Section B.2) for ϕ=40°:

$$N_{qh} := 10.959 + 1.783 \cdot \left(\frac{H}{D}\right) + 0.045 \cdot \left(\frac{H}{D}\right)^2 - 0.005425 \cdot \left(\frac{H}{D}\right)^3 - 0.0001153 \cdot \left(\frac{H}{D}\right)^4 = 25.026$$

The maximum soil density is used for all of the upper bound spring calculations since this produces the largest spring values.

$f_t := D \cdot \rho_{max} \cdot H \cdot N_{qh} = 3351.505 \cdot \frac{lbf}{in}$ Breakaway Force (Per Table B-1 of Ref. 7.3, Sand)

The transverse displacement ranges between 2% and 10% of (H+D/2) per Table B-1 of Ref. 7.3. The smaller the displacement, the larger the spring value. Therefore, the smallest displacement values from Table B-1 of Ref. 7.3 are considered for all of the upper bound spring values.

$d_t := 2\% \cdot \left(H + \frac{D}{2}\right) = 2.42 \cdot in$ Displacement (Per Table B-1 of Ref. 7.3, Sand)

$K_{t.us} := \frac{f_t}{d_t} = 1384.92 \cdot psi$ Transverse Soil Spring for Straight Pipe (Per Table B-1 of Ref. 7.3)

Calculations for Miter Elbow Springs:

Horizontal Bearing Capacity Factor (Ref. 7.5, Section B.2) for ϕ=40°:

$$N_{qh} := 10.959 + 1.783 \cdot \left(\frac{H}{D_{elbow}}\right) + 0.045 \cdot \left(\frac{H}{D_{elbow}}\right)^2 - 0.005425 \cdot \left(\frac{H}{D_{elbow}}\right)^3 - 0.0001153 \cdot \left(\frac{H}{D_{elbow}}\right)^4$$

$$N_{qh} = 23.688$$

$f_t := D_{elbow} \cdot \rho_{max} \cdot H \cdot N_{qh} = 3625.57 \cdot \frac{lbf}{in}$ Breakaway Force (Per Table B-1 of Ref. 7.3, Sand)

$d_t := 2\% \cdot \left(H + \frac{D_{elbow}}{2}\right) = 2.44 \cdot in$ Displacement (Per Table B-1 of Ref. 7.3, Sand)

$K_{t.ue} := \frac{f_t}{d_t} = 1485.889 \cdot psi$ Transverse Soil Spring for Miter Elbows (Per Table B-1 of Ref. 7.3)

Upper Bound Axial Soil Spring:

The coefficient of soil pressure at rest is calculated using Jaky's simplified equation from Section 7.2 of Ref. 7.4. This provides a reasonable empirical approximation of the true value.

$K_o := 1 - \sin(\phi) = 0.357$ Coefficient of Soil Pressure at Rest (Ref. 7.4, Section 7.2)

Per Ref. 7.3, page B-4, the friction angle pipe-soil, δ, ranges between 0.5 and 0.8 times the internal angle of friction. The larger the friction angle pipe-soil, the larger the spring value. Therefore, 0.8 times the internal angle of friction is considered for the upper bound spring values

$$\delta := 0.8 \cdot \phi = 0.559$$

Calculations for Straight Pipe Springs:

$f_{a.us} := \left(\pi \cdot \frac{D}{2}\right) \cdot \rho_{max} \cdot H \cdot \left(1 + K_o\right) \cdot \tan(\delta) = 178.408 \cdot \frac{lbf}{in}$ Breakaway Force (Per Table B-1 of Ref. 7.3, Sand)

$d_a := 0.1 \cdot in$ Displacement (Per Table B-1 of Ref. 7.3, Sand)

$K_{a.us} := \frac{f_{a.us}}{d_a} = 1784.079 \cdot psi$ Axial Soil Spring for Straight Pipe (Per Table B-1 of Ref. 7.3)

Calculations for Miter Elbow Springs:

$f_{a.ue} := \left(\pi \cdot \frac{D_{elbow}}{2}\right) \cdot \rho_{max} \cdot H \cdot \left(1 + K_o\right) \cdot \tan(\delta) = 203.895 \cdot \frac{lbf}{in}$ Breakaway Force (Per Table B-1 of Ref. 7.3, Sand)

$d_a := 0.1 \cdot in$ Displacement (Per Table B-1 of Ref. 7.3, Sand)

$K_{a.ue} := \frac{f_{a.ue}}{d_a} = 2038.947 \cdot psi$ Axial Soil Spring for Miter Elbows (Per Table B-1 of Ref. 7.3)

Upper Bound Vertical Soil Spring:

The Downward Bearing Capacity Factors 1 and 2, N_q and N_γ respectively, can be determined by using Figure B-3 of Ref. 7.3. In-lieu of using this figure, the equations in Section B.4 of Ref. 7.5 are used to obtain more accurate values.

$$N_q := \exp(\pi \cdot \tan(\phi)) \cdot \tan\left(45 \cdot deg + \frac{\phi}{2}\right)^2 = 64.195$$

Downward Bearing Capacity Factor 1 (Ref. 7.5, Section B.4)

$$N_\gamma := \exp\left(0.18 \cdot \frac{\phi}{deg} - 2.5\right) = 109.947$$

Downward Bearing Capacity Factor 2 (Ref. 7.5, Section B.4)

Calculations for Straight Pipe Springs:

$$f_d := \rho_{max} \cdot H \cdot N_q \cdot D + \rho_{max} \cdot D^2 \cdot \frac{N_\gamma}{2} = 9501.391 \cdot \frac{lbf}{in}$$

Vertical Down Breakaway Force (Per Table B-1 of Ref. 7.3, Sand)

$$d_d := 10\% \cdot D = 1.4 \cdot in$$

Displacement (Per Table B-1 of Ref. 7.3, Sand)

$$K_{d.us} := \frac{f_d}{d_d} = 6786.708 \cdot psi$$

Vertical Down Soil Spring for Straight Pipe (Per Table B-1 of Ref. 7.3)

The vertical uplift factor can be determined by using Figure B-4 of Ref. 7.3. These same figures are developed in Ref. 7.5. In-lieu of using the figures, the equation in Section B.3 of Ref. 7.5 is used which provides a more accurate value.

$$N_{qv} := \min\left(\frac{\phi \cdot H}{44 \cdot deg \cdot D}, N_q\right) = 7.403$$

Vertical Uplift Factor (Ref. 7.5, Section B.3)

$$f_u := D \cdot \rho_{max} \cdot H \cdot N_{qv} = 991.383 \cdot \frac{lbf}{in}$$

Vertical Upward Breakaway Force (Per Table B-1 of Ref. 7.3, Sand)

$$d_u := 0.5\% \cdot H = 0.57 \cdot in$$

Displacement (Per Table B-1 of Ref. 7.3, Sand)

$$K_{u.us} := \frac{f_u}{d_u} = 1739.268 \cdot psi$$

Vertical Up Soil Spring for Straight Pipe (Per Table B-1 of Ref. 7.3)

As recommended in Ref. 7.3, Appendix B, the total vertical soil spring is taken as the average of the vertical up and down.

$$K_{v.us} := \frac{K_{u.us} + K_{d.us}}{2} = 4262.988 \cdot psi$$

Vertical Soil Spring for Straight Pipe

Calculations for Miter Elbow Springs:

$$f_d := \rho_{max} \cdot H \cdot N_q \cdot D_{elbow} + \rho_{max} \cdot D_{elbow}^2 \cdot \frac{N_\gamma}{2}$$

Vertical Down Breakaway Force (Per Table B-1 of Ref. 7.3, Sand)

$$f_d = 11006.347 \cdot \frac{lbf}{in}$$

$$d_d := 10\% \cdot D_{elbow} = 1.6 \cdot in$$

Displacement (Per Table B-1 of Ref. 7.3, Sand)

$$K_{d.ue} := \frac{f_d}{d_d} = 6878.967 \cdot psi$$

Vertical Down Soil Spring for Miter Elbows (Per Table B-1 of Ref. 7.3)

$$N_{qv} := \min\left(\frac{\phi \cdot H}{44 \cdot deg \cdot D_{elbow}}, N_q\right) = 6.477$$

Vertical Uplift Factor (Ref. 7.5, Section B.3)

$$f_u := D_{elbow} \cdot \rho_{max} \cdot H \cdot N_{qv} = 991.383 \cdot \frac{lbf}{in}$$

Vertical Upward Breakaway Force (Per Table B-1 of Ref. 7.3, Sand)

$$d_u := 0.5\% \cdot H = 0.57 \cdot in$$

Displacement (Per Table B-1 of Ref. 7.3, Sand)

$$K_{u.ue} := \frac{f_u}{d_u} = 1739.268 \cdot psi$$

Vertical Up Soil Spring for Miter Elbows (Per Table B-1 of Ref. 7.3)

$$K_{v.ue} := \frac{K_{u.ue} + K_{d.ue}}{2} = 4309.117 \cdot psi$$

Vertical Soil Spring for Miter Elbows

Upper Bound Influence Length:

Since the influence lengths affect the straight pipe portions, only the straight pipe properties are used to determine the influence length. The soil modulus (K_o) is taken as the pipe ovalization spring stiffness following the example in Ref. 7.3, Appendix E.

$K_{po.s.us} = 41246.42 \cdot psi$

$$\beta_s := \left(\frac{K_{po.s.us}}{4 \cdot E_{pipe.seis} \cdot I_P}\right)^{\frac{1}{4}} = 0.097 \cdot \frac{1}{in}$$ Characteristic of the System (Ref. 7.3, Eq. B-6)

$$L_{\beta.s} := \frac{3 \cdot \pi}{4 \cdot \beta_s} = 24.181 \cdot in$$ Influence Length (Seismic Load Condition) (Ref. 7.3, Eq. B-5)

$K_{po.th.us} = 25423.539 \cdot psi$

$$\beta_{th} := \left(\frac{K_{po.th.us}}{4 \cdot E_{pipe.th} \cdot I_P}\right)^{\frac{1}{4}} = 0.1 \cdot \frac{1}{in}$$ Characteristic of the System (Ref. 7.3, Eq. B-6)

$$L_{\beta.th} := \frac{3 \cdot \pi}{4 \cdot \beta_{th}} = 23.618 \cdot in$$ Influence Length (Thermal Load Condition) (Ref. 7.3, Eq. B-5)

$$L_{\beta.u} := \max\left(L_{\beta.s}, L_{\beta.th}\right) = 24.181 \cdot in$$ Controlling Influence Length

To simplify the modeling process, the enveloping spring for either the straight pipe properties or the miter bend properties is used.

$K_{po.s.l} := \min(K_{po.s.ls}, K_{po.s.le}) = 12210.42 \cdot psi$ — Lower Bound Pipe Ovaling Spring for Seismic

$K_{po.th.l} := \min(K_{po.th.ls}, K_{po.th.le}) = 6066.206 \cdot psi$ — Lower Bound Pipe Ovaling Spring for Thermal

$K_{t.l} := \min(K_{t.ls}, K_{t.le}) = 114.939 \cdot psi$ — Lower Bound Transverse Soil Spring

$K_{a.l} := \min(K_{a.ls}, K_{a.le}) = 184.827 \cdot psi$ — Lower Bound Axial Soil Spring

$K_{v.l} := \min(K_{v.ls}, K_{v.le}) = 935.178 \cdot psi$ — Lower Bound Vertical Soil Spring

$K_{po.s.u} := \max(K_{po.s.us}, K_{po.s.ue}) = 60538.407 \cdot psi$ — Upper Bound Pipe Ovaling Spring for Seismic

$K_{po.th.u} := \max(K_{po.th.us}, K_{po.th.ue}) = 34066.721 \cdot psi$ — Upper Bound Pipe Ovaling Spring for Thermal

$K_{t.u} := \max(K_{t.us}, K_{t.ue}) = 1485.889 \cdot psi$ — Upper Bound Transverse Soil Spring

$K_{a.u} := \max(K_{a.us}, K_{a.ue}) = 2038.947 \cdot psi$ — Upper Bound Axial Soil Spring

$K_{v.u} := \max(K_{v.us}, K_{v.ue}) = 4309.117 \cdot psi$ — Upper Bound Vertical Soil Spring

<u>Average of Lower and Upper Spring Values & Lower and Upper Axial Breakaway Forces</u>:

$K_{po.s.a} := 0.5 \cdot (K_{po.s.l} + K_{po.s.u}) = 36374.413 \cdot psi$

$K_{po.th.a} := 0.5 \cdot (K_{po.th.l} + K_{po.th.u}) = 20066.464 \cdot psi$

$K_{t.a} := 0.5 \cdot (K_{t.l} + K_{t.u}) = 800.414 \cdot psi$

$K_{a.a} := 0.5 \cdot (K_{a.l} + K_{a.u}) = 1111.887 \cdot psi$

$K_{v.a} := 0.5 \cdot (K_{v.l} + K_{v.u}) = 2622.148 \cdot psi$

$f_{a.ae} := 0.5 \cdot (f_{a.le} + f_{a.ue}) = 123.07 \cdot \frac{lbf}{in}$

$f_{a.as} := 0.5 \cdot (f_{a.ls} + f_{a.us}) = 107.687 \cdot \frac{lbf}{in}$

<u>1/2 x Average Spring Values:</u>

$K_{po.s.al} := 0.5 \cdot K_{po.s.a} = 18187.207 \cdot psi$

$K_{po.th.al} := 0.5 \cdot K_{po.th.a} = 10033.232 \cdot psi$

$K_{t.al} := 0.5 \cdot K_{t.a} = 400.207 \cdot psi$

$K_{a.al} := 0.5 \cdot K_{a.a} = 555.944 \cdot psi$

$K_{v.al} := 0.5 \cdot K_{v.a} = 1311.074 \cdot psi$

<u>2 x Average Spring Values:</u>

$K_{po.s.au} := 2 \cdot K_{po.s.a} = 72748.827 \cdot psi$

$K_{po.th.au} := 2 \cdot K_{po.th.a} = 40132.927 \cdot psi$

$K_{t.au} := 2 \cdot K_{t.a} = 1600.829 \cdot psi$

$K_{a.au} := 2 \cdot K_{a.a} = 2223.774 \cdot psi$

$K_{v.au} := 2 \cdot K_{v.a} = 5244.296 \cdot psi$

1/2 x Average Axial Breakaway Forces:

$f_{a.ale} := 0.5 \cdot f_{a.ae} = 61.535 \cdot \frac{lbf}{in}$

$f_{a.als} := 0.5 \cdot f_{a.as} = 53.843 \cdot \frac{lbf}{in}$

2 x Average Axial Breakaway Forces:

$f_{a.aue} := 2 \cdot f_{a.ae} = 246.141 \cdot \frac{lbf}{in}$

$f_{a.aus} := 2 \cdot f_{a.as} = 215.373 \cdot \frac{lbf}{in}$

Bounding Springs & Axial Breakaway Forces for Models:

$K_{po.s.bl} := \min(K_{po.s.l}, K_{po.s.al}) = 12210.42 \cdot psi$	Lower Bound Pipe Ovaling Spring for Seismic
$K_{po.th.bl} := \min(K_{po.th.l}, K_{po.th.al}) = 6066.206 \cdot psi$	Lower Bound Pipe Ovaling Spring for Thermal
$K_{a.bl} := \min(K_{a.l}, K_{a.al}) = 184.827 \cdot psi$	Lower Bound Axial Soil Spring
$K_{v.bl} := \min(K_{v.l}, K_{v.al}) = 935.178 \cdot psi$	Lower Bound Vertical Soil Spring
$K_{t.bl} := \min(K_{t.l}, K_{t.al}) = 114.939 \cdot psi$	Lower Bound Transverse Soil Spring
$K_{po.s.bu} := \max(K_{po.s.u}, K_{po.s.au}) = 72748.827 \cdot psi$	Upper Bound Pipe Ovaling Spring for Seismic
$K_{po.th.bu} := \max(K_{po.th.u}, K_{po.th.au}) = 40132.927 \cdot psi$	Upper Bound Pipe Ovaling Spring for Thermal
$K_{a.bu} := \max(K_{a.u}, K_{a.au}) = 2223.774 \cdot psi$	Upper Bound Axial Soil Spring
$K_{v.bu} := \max(K_{v.u}, K_{v.au}) = 5244.296 \cdot psi$	Upper Bound Vertical Soil Spring
$K_{t.bu} := \max(K_{t.u}, K_{t.au}) = 1600.829 \cdot psi$	Upper Bound Transverse Soil Spring
$f_{a.bl.s} := \min(f_{a.ls}, f_{a.als}) = 36.965 \cdot \frac{lbf}{in}$	Lower Bound Axial Breakaway Force for Straight Pipe
$f_{a.bl.e} := \min(f_{a.le}, f_{a.ale}) = 42.246 \cdot \frac{lbf}{in}$	Lower Bound Axial Breakaway Force for Elbows
$f_{a.bu.s} := \max(f_{a.us}, f_{a.aus}) = 215.373 \cdot \frac{lbf}{in}$	Upper Bound Axial Breakaway Force for Straight Pipe
$f_{a.bu.e} := \max(f_{a.ue}, f_{a.aue}) = 246.141 \cdot \frac{lbf}{in}$	Upper Bound Axial Breakaway Force for Elbows
$L_{\beta} := \max(L_{\beta.l}, L_{\beta.u}) = 33.792 \cdot in$	Controlling Influence Length

The spring values and breakaway forces above are dependent on their effective lengths. Therefore, the value modeled will vary from node to node.