Streamlined Pipeline Seismic Design Geotechnical and Pipeline Modeling for an Essential Pipeline Project

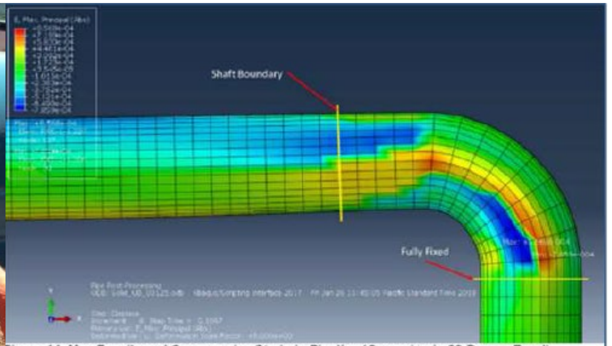

Figure 14: Max Tensile and Compressive Strain in Pipeline (Occurring in 90-Degree Bend).

4/29/2022

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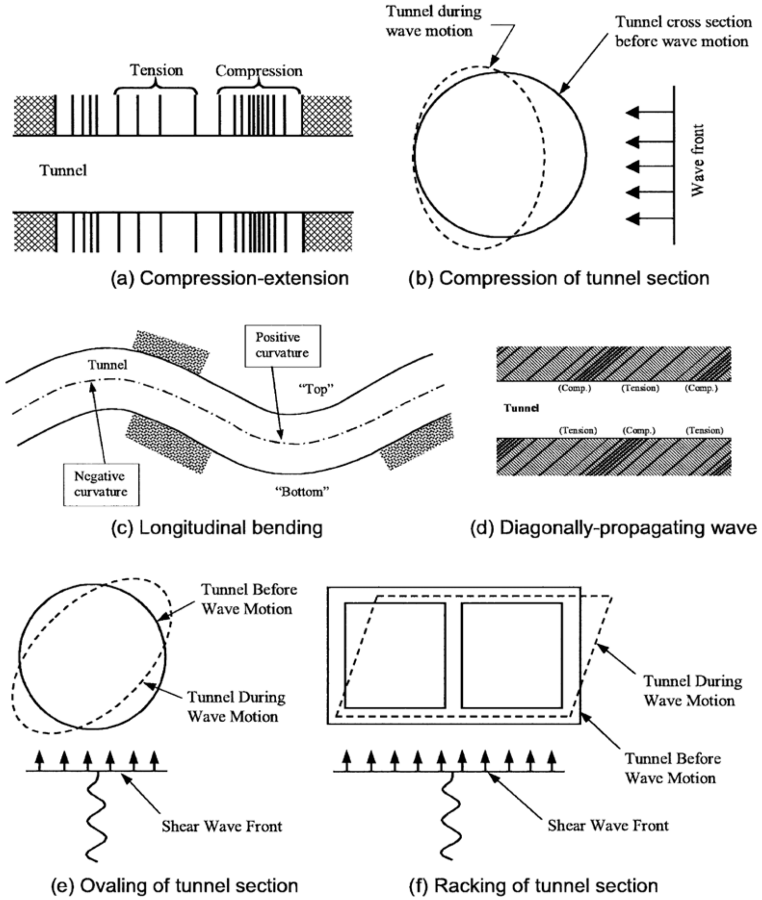
Topic

- Project Overview
- Seismic Analysis Approach
- Site Conditions
- Seismic Hazards and Ground Deformation Analysis
- Steel Pipe Seismic Performance Criteria
- Soil-Pipe Interaction analysis/modeling
- Pipeline Seismic Design Approach

Seismic Hazards on Pipeline

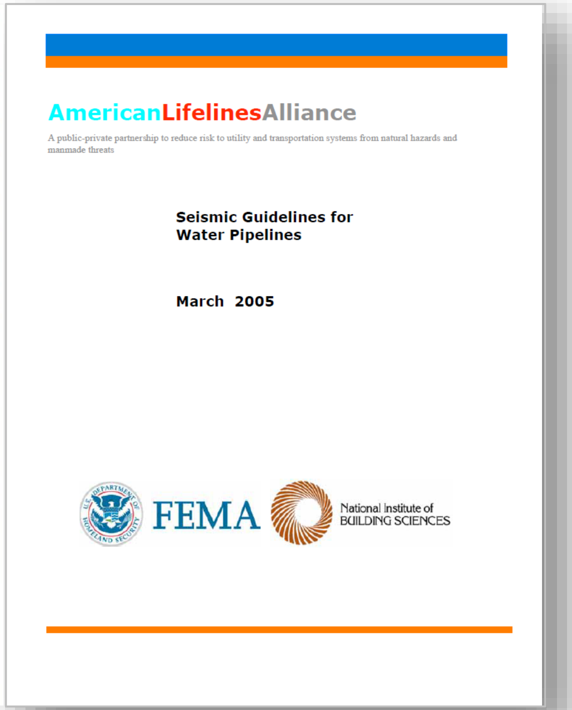
Seismic Wave Propagation
Transient deformations



Permanent deformations from Fault Offset/Liquefaction/Lateral Spreading/Slope Failure

Seismic Design Criteria


www.OurReliableWater.org
Willamette Water Supply
Our Reliable Water
Willamette Water Supply Program
Seismic Guidelines and Minimum Design Requirements
June 08, 2018


AmericanLifelinesAlliance
A public-private partnership to reduce risk to utility and transportation systems from natural hazards and manmade threats
Seismic Guidelines for Water Pipelines
March 2005
FEMA
National Institute of BUILDING SCIENCES

Seismic Guidelines for Water Pipelines R80.01.01 Rev. 0

Pipe Function Class	Seismic Importance	Description
I	Very low to None	Pipelines that represent very low hazard to human life in the event of failure. Not needed for post earthquake system performance, response, or recovery. Widespread damage resulting in long restoration times (weeks or longer) will not materially harm the economic well being of the community.
II	Ordinary, normal	Normal and ordinary pipeline use, common pipelines in most water systems. All pipes not identified as Function I, III, or IV.
III	Critical	Critical pipelines serving large numbers of customers and present significant economic impact to the community or a substantial hazard to human life and property in the event of failure.
IV	Essential	Essential pipelines required for post-earthquake response and recovery and intended to remain functional and operational during and following a design earthquake.

Table 3-1. Pipe Function Classes

- WWSP Seismic Design Criteria
- Pipe Function Class: Class IV
- Design Earthquake Event: 1/2475 years return period
- Level of Service: functionality requirements during and after design earthquake, and for post earthquake response and recovery.

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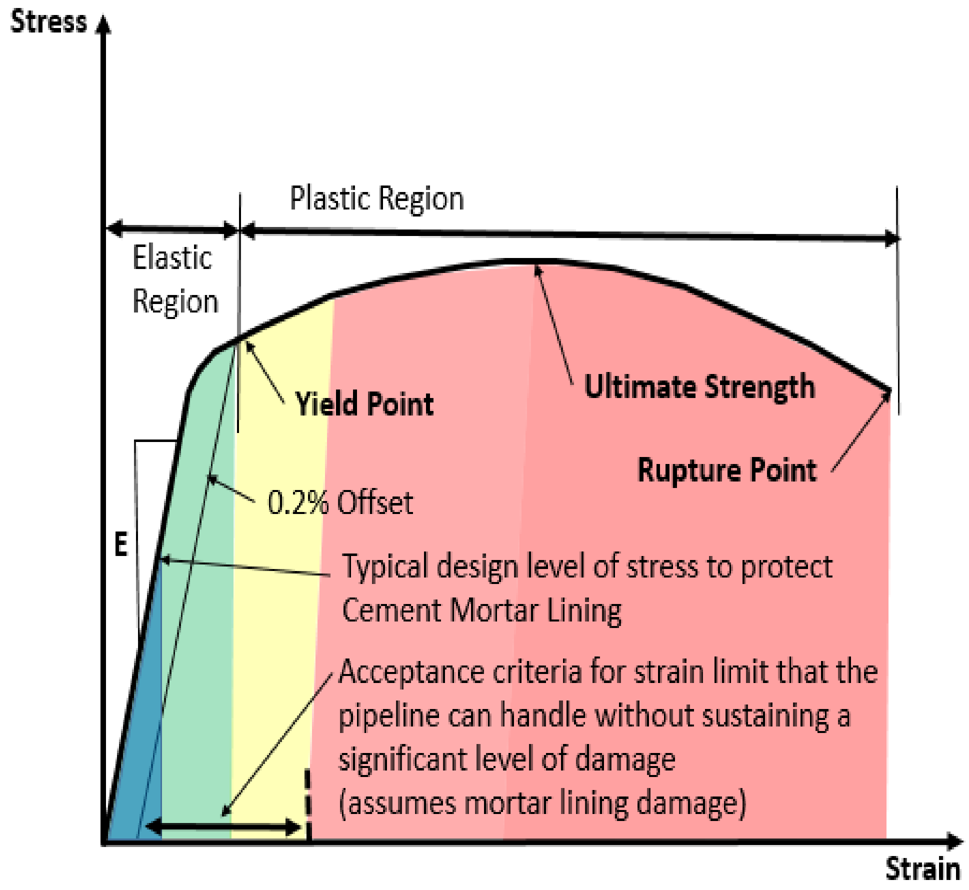
Seismic Design Approach

- Approach 1: Remain in service without need for repair (normal stress based design – no damage)
- Approach 2: Limit pipeline load demands to a tolerable level (strain based)
  - Strain limits that allow some controlled level of pipe yield
    - *May require repair to linings*
  - Permit the pipe to deform plastically to a high state of deformation without rupture
    - *May require repair to pipe*

What is the cost difference between "accepting some damage" and "no damage"? Is "no damage" even feasible?



FUNCTIONAL

NOT ACCEPTABLE

Seismic Design Considerations

- The benefit of strain based design is the ability to target specific points of failure, rather than overdesigning with unnecessary pipe thickness and/or ground improvements.
- When is strain-based design most appropriate?
  - Essential pipeline required for post-earthquake response and recovery
  - Pipeline with complex alignment, subject to ovality and mainly axial forces effects
  - Preventing a fracture accident

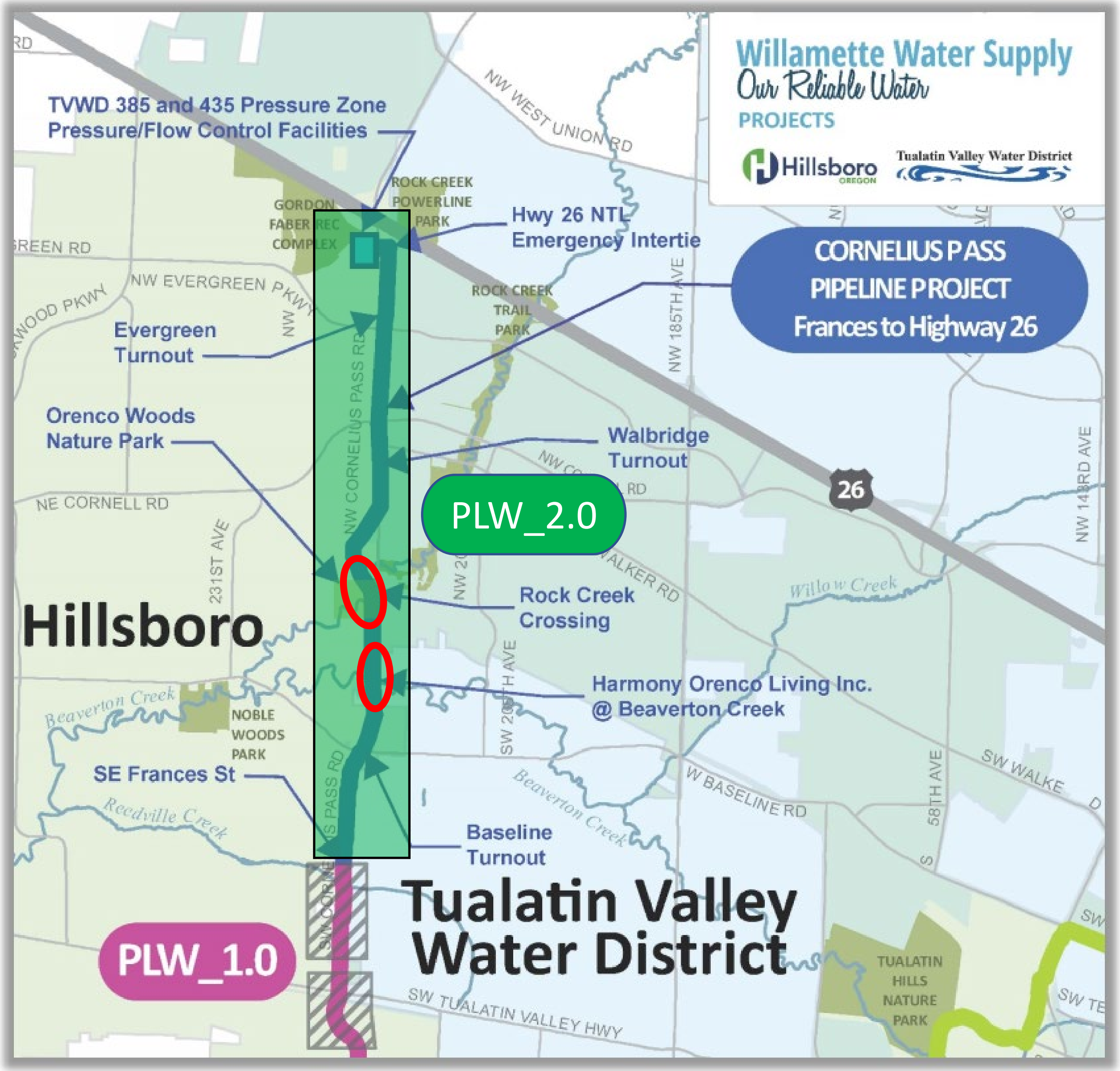
General Seismic Pipeline Design Process

- Identify hazards that apply to the pipeline
- Evaluate the magnitudes of the hazards and loading parameters
- Perform finite element analysis (Soil-Pipe Interaction Modeling)
- Using iterative process to confirm acceptable strain and/or other design criteria are achieved.

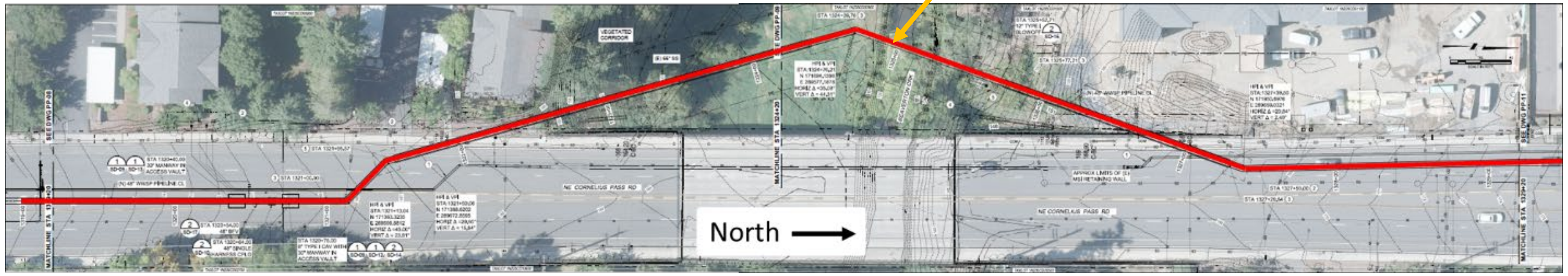
Project Overview

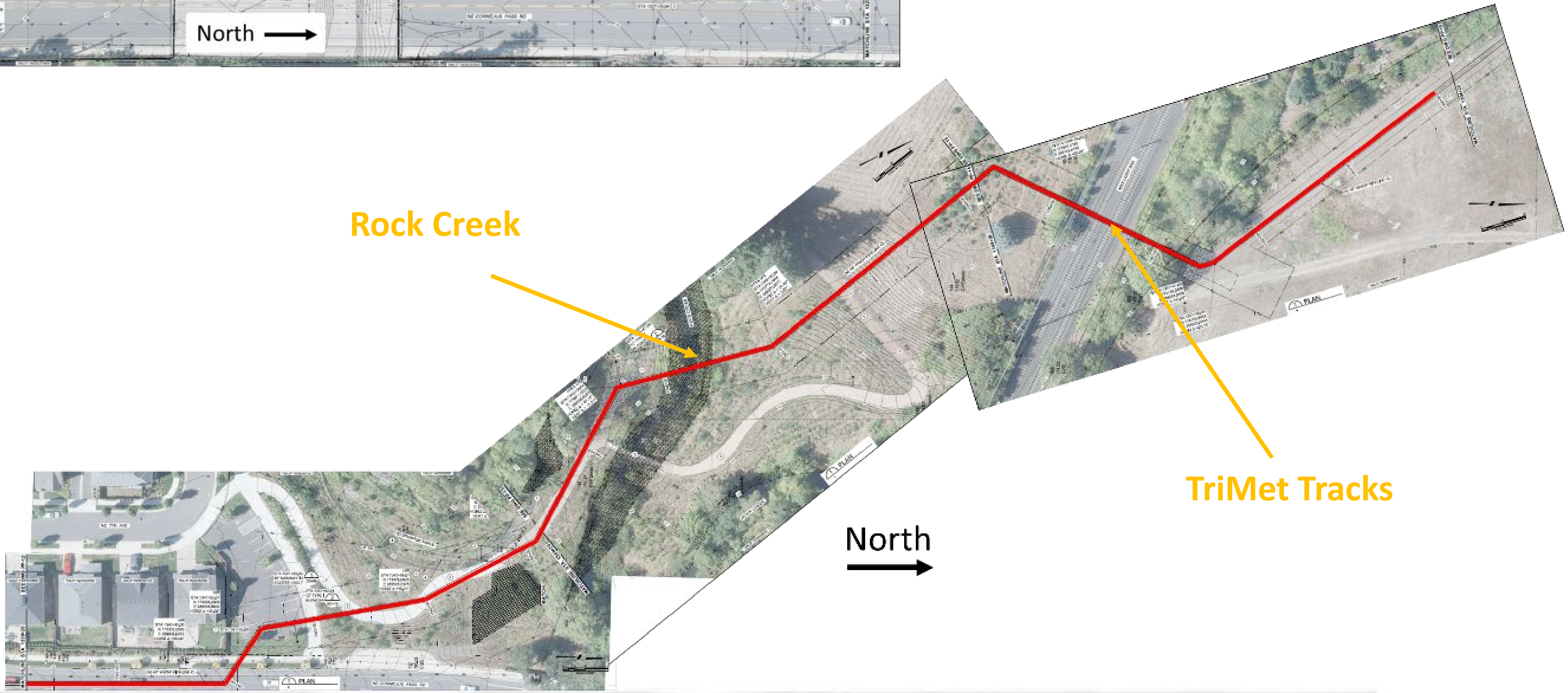
PLW_2.0 Pipeline:

- *3.3 miles welded 48-inch steel pipe*
- *Cornelius Pass Road from SE Frances to HWY 26*
- *Two Creek Crossings*
  - *Beaverton Creek*
  - *Rock Creek*
- *Five Trenchless Crossings*
- *Three Turnouts*



Site Conditions





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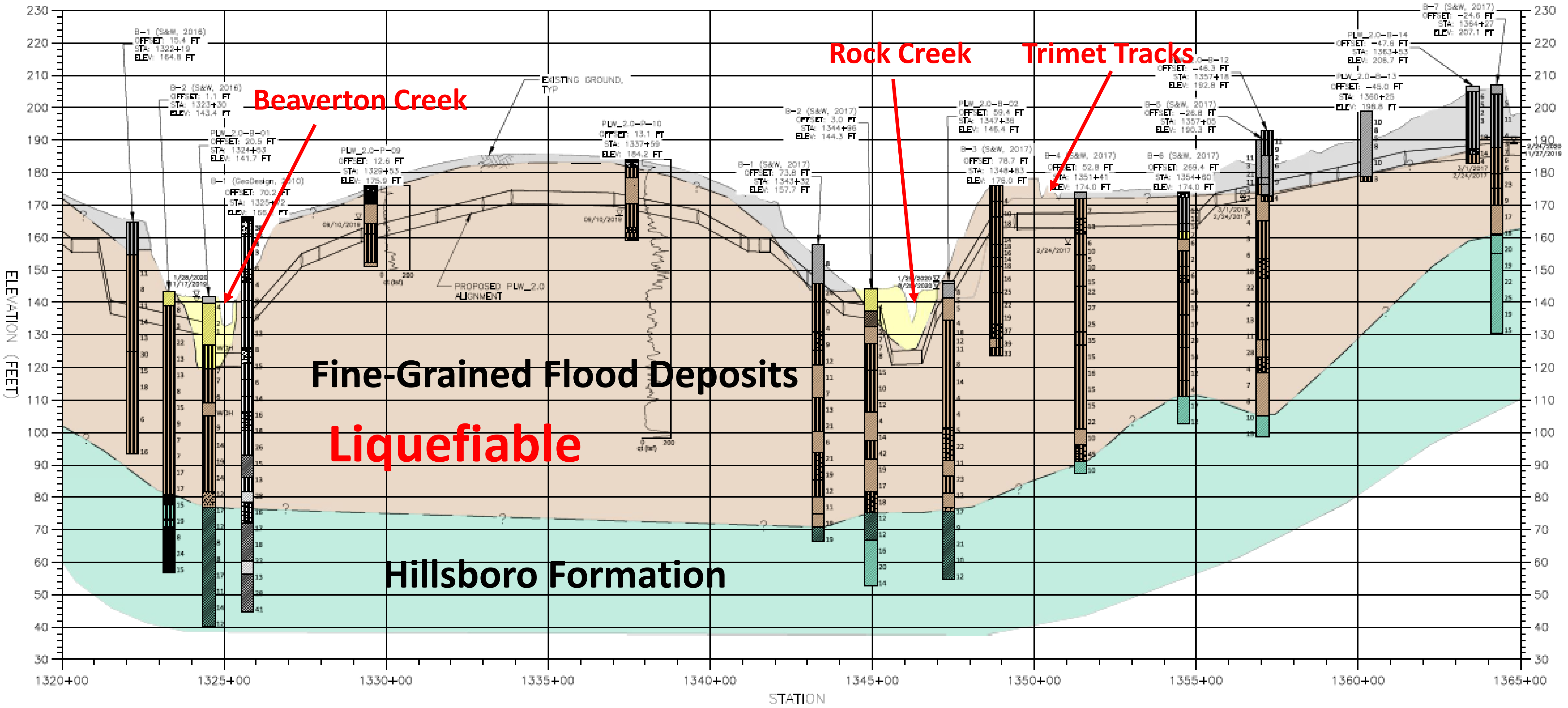
Subsurface Conditions



Seismic Hazards & Ground Deformation Analyses

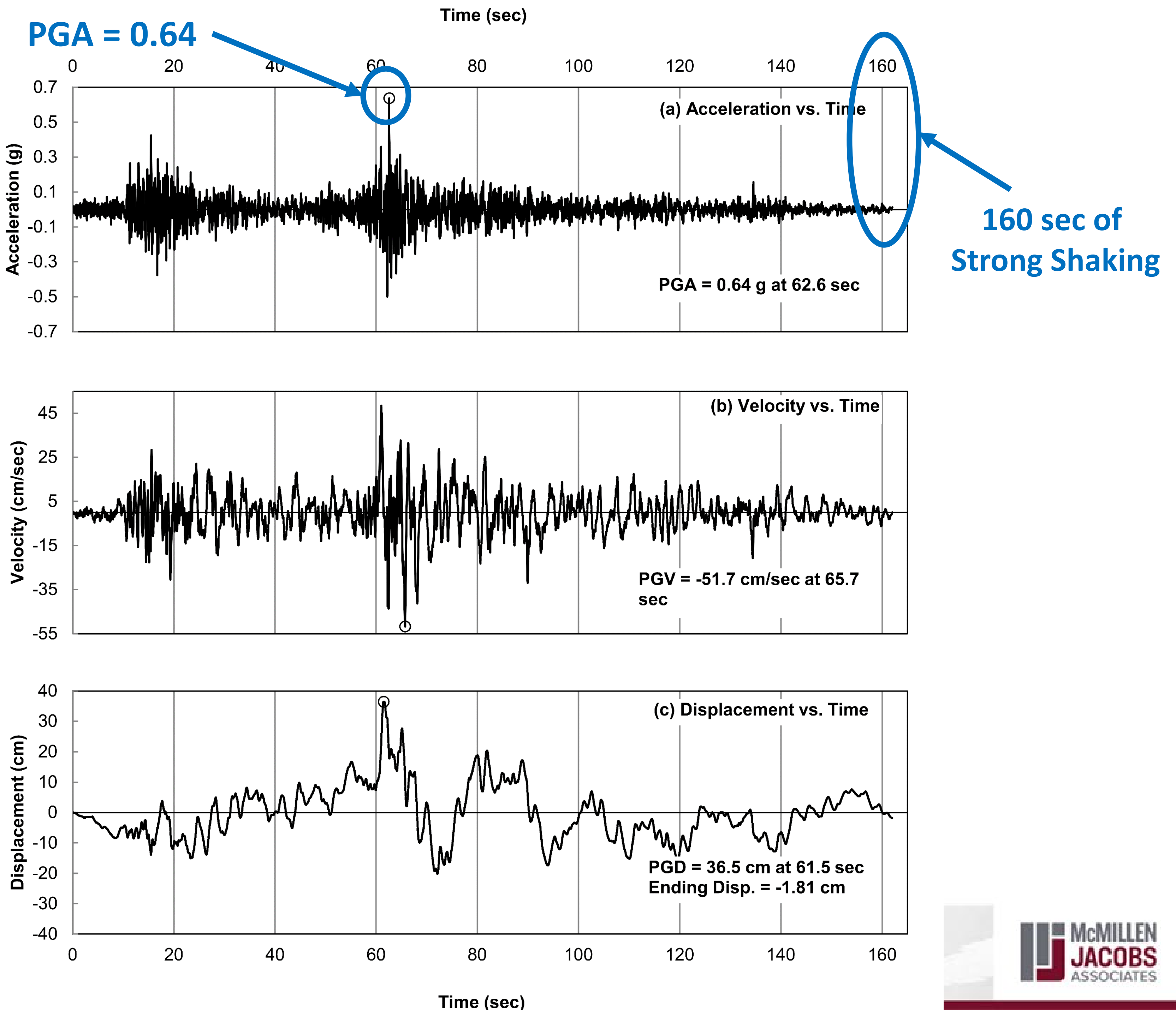
- Seismic hazards mainly from local crustal EQs and Cascadia Subduction Zone EQs;
  - Design Earthquake Event: 2,475 years event;
  - Liquefaction of Fine-Grained Flood Deposits and Recent Alluvium
  - Lateral spreading and seismic slope failure generated lateral movement
- Conducted seismic liquefaction and ground deformation modeling using FLAC with 5 ground motions;
- Soil constitutive models of PM4SAND
- Soil liquefaction potential (excess pore water pressure ratio – Ru) is high for shallow silt and sand deposits, and low for deeper sand and clay deposits

Ground Motions

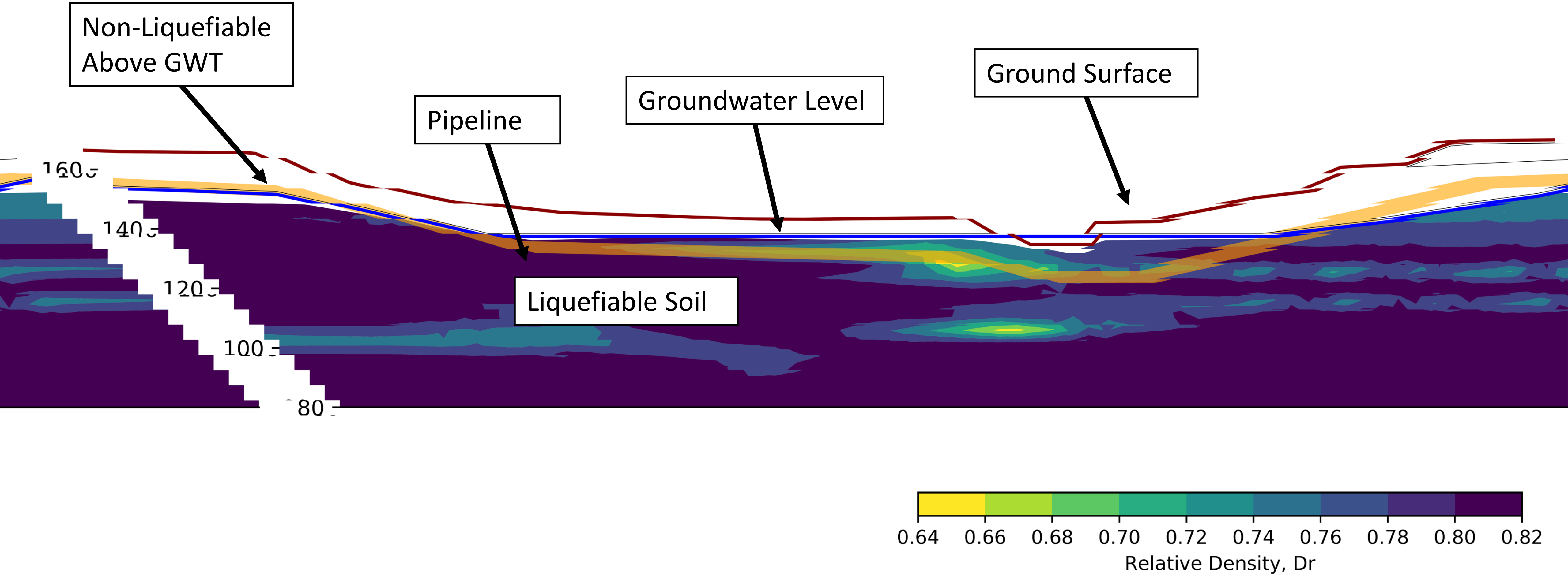
Input Ground Motion 1

Cascadia Subduction Zone
Scaled to D/C Boundary

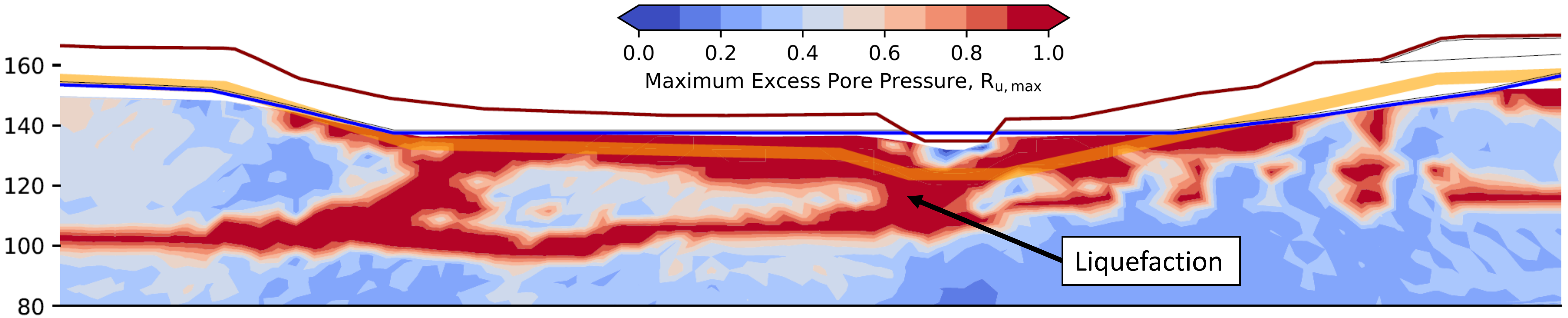
Source:
2011 Tohoku (Great Japan Earthquake)
Taiwa (MYG09)
Magnitude 9.0

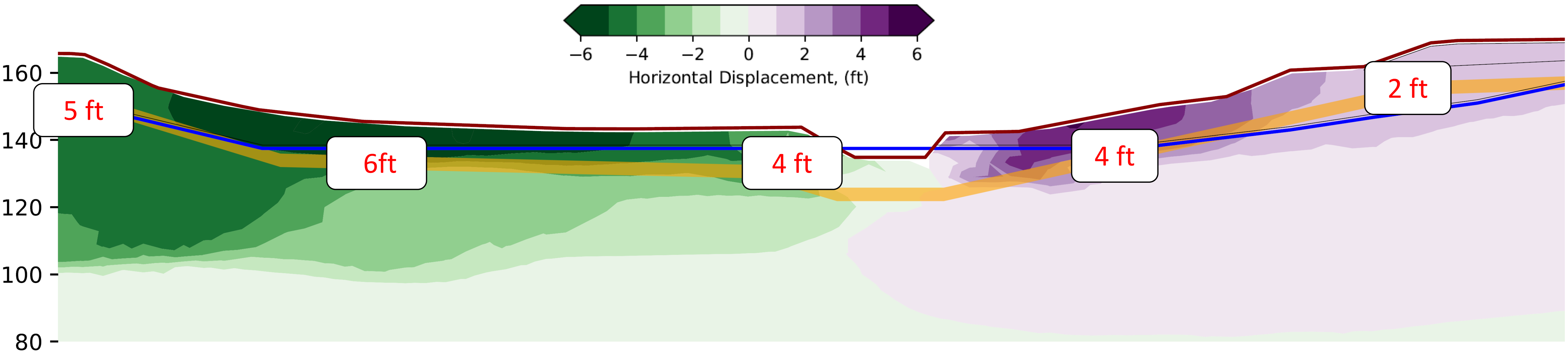


Beaverton Creek Seismic Ground Deformation Modeling

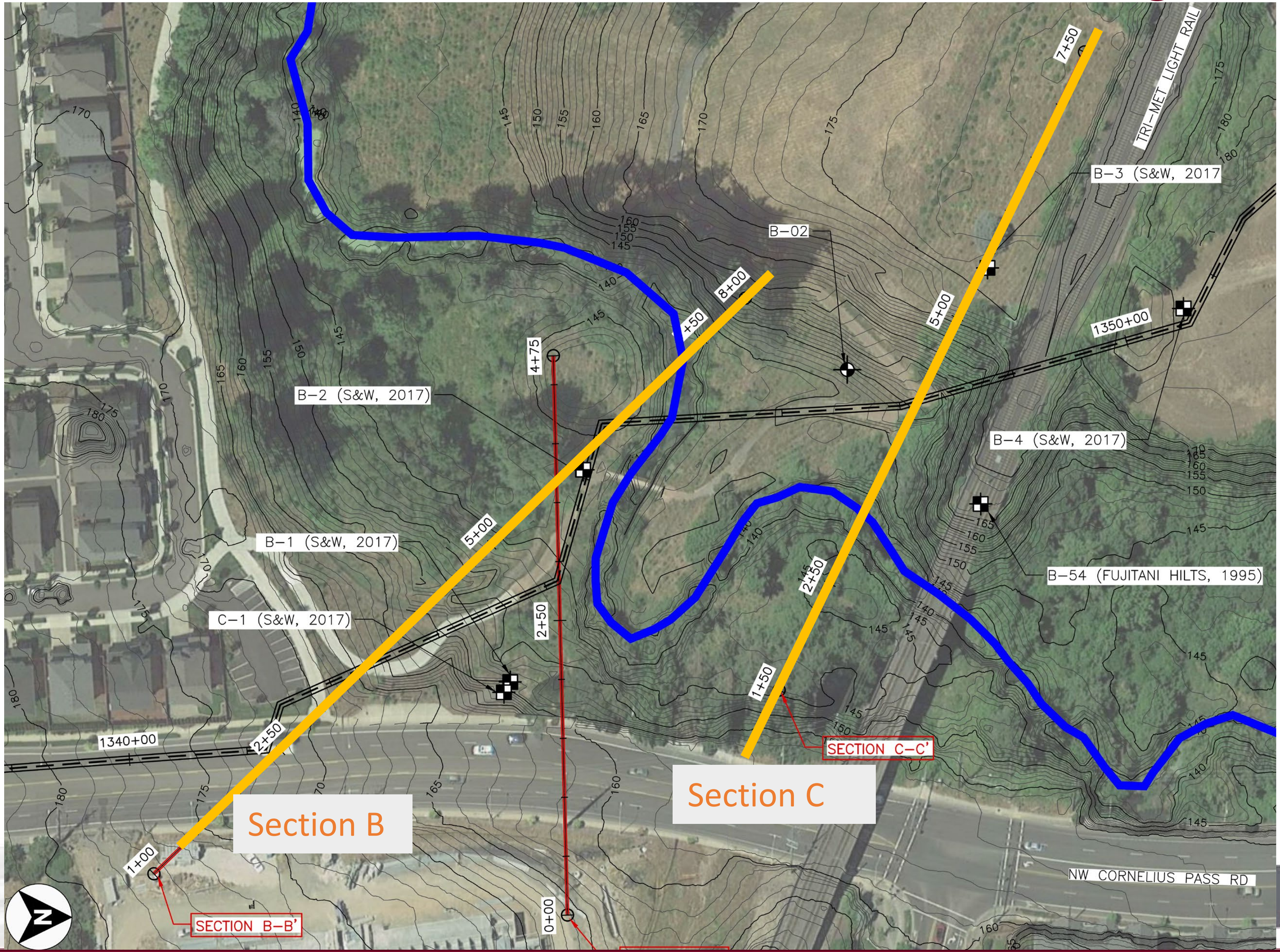


Beaverton Creek Seismic Ground Deformation Modeling





Rock Creek Seismic Ground Deformation Modeling



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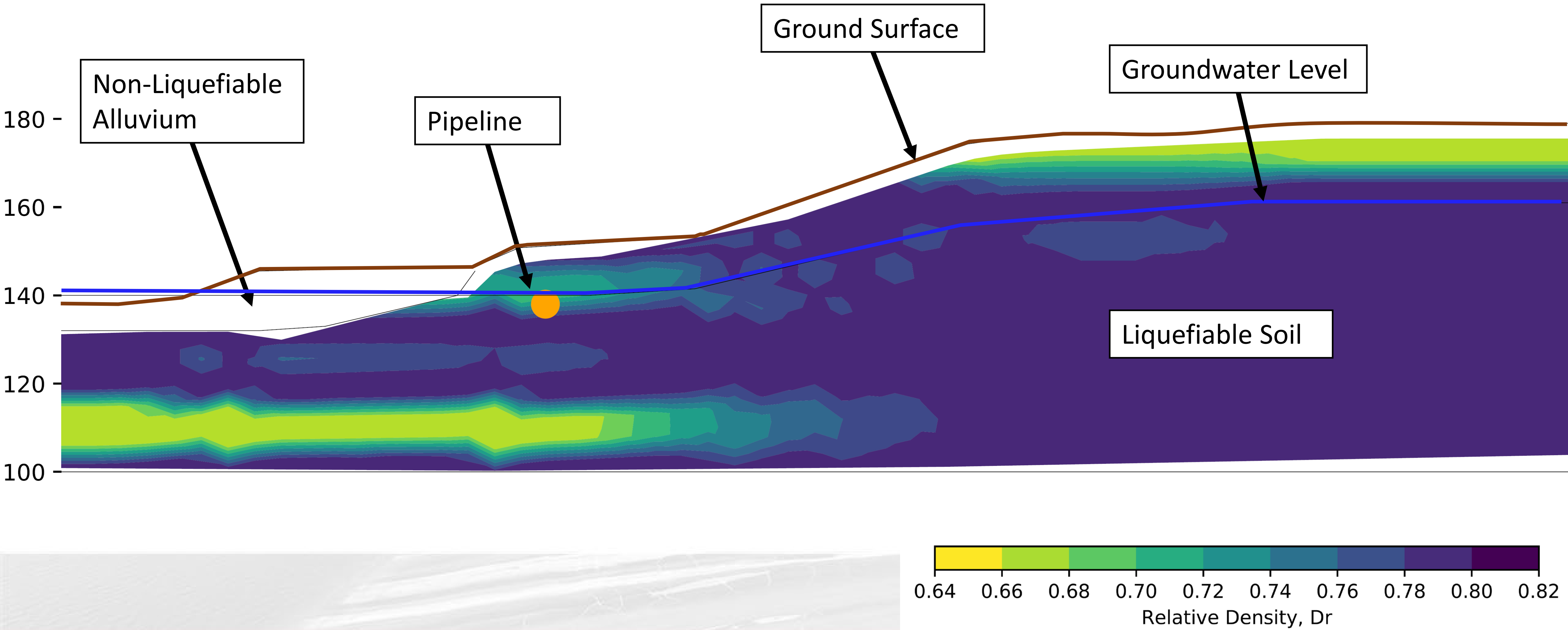
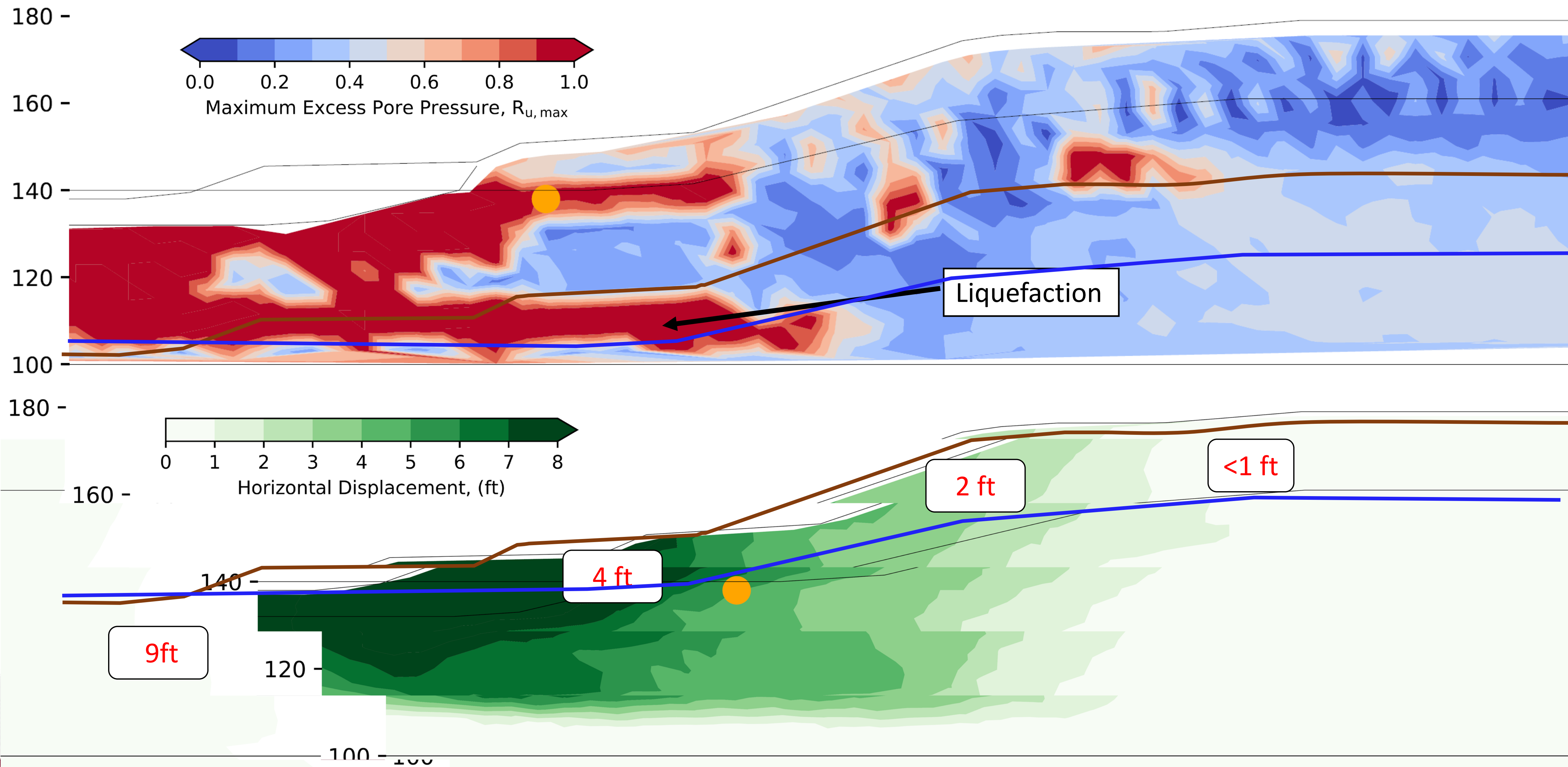
Rock Creek Seismic Ground Deformation Modeling



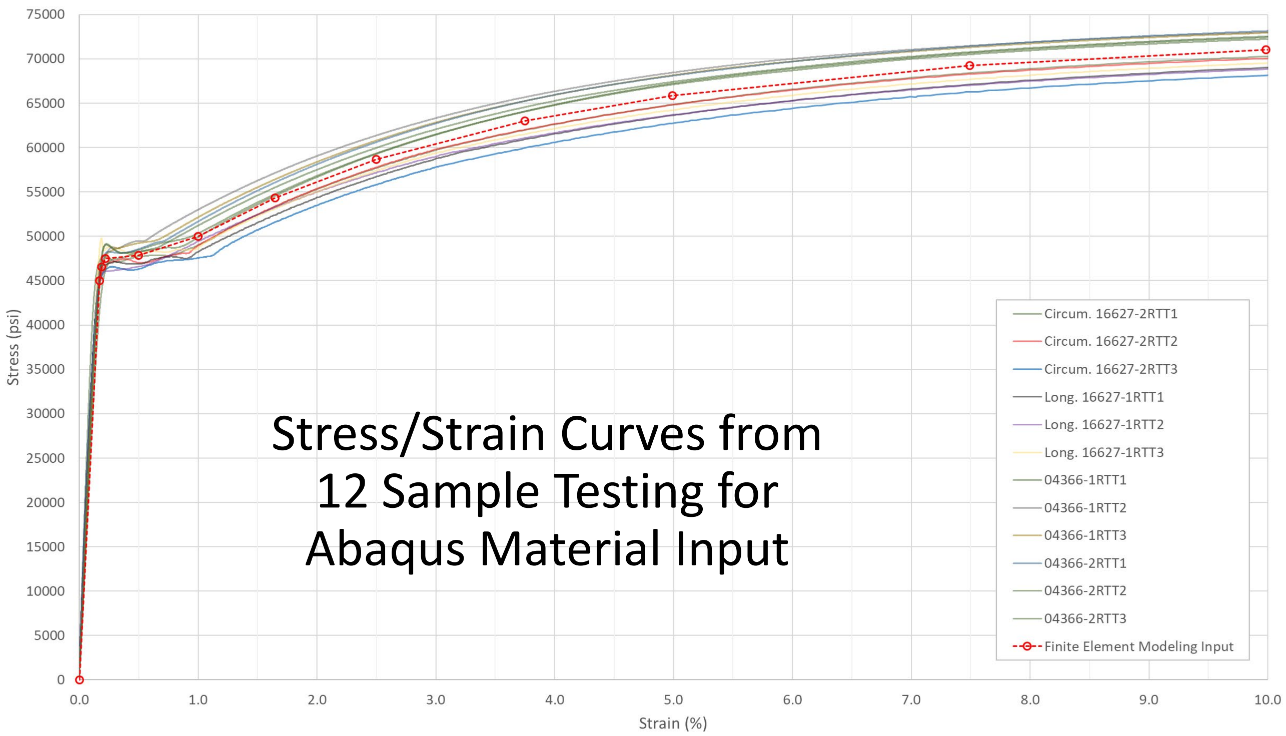
Rock Creek Seismic Ground Deformation Modeling



Steel Pipe Material Properties

Steel Pipe Material Properties:

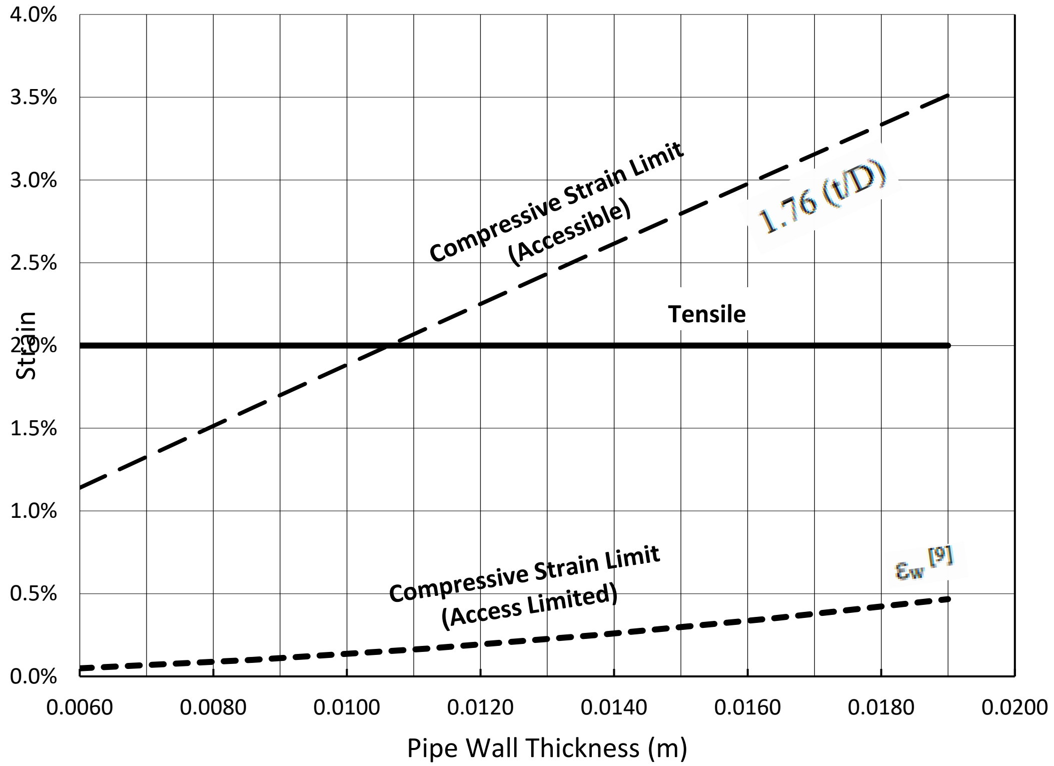
- Elastic Modulus: 29000 KSI
- Design Yield Strength: 50 KSI



Strain-Based Design for Steel Pipe

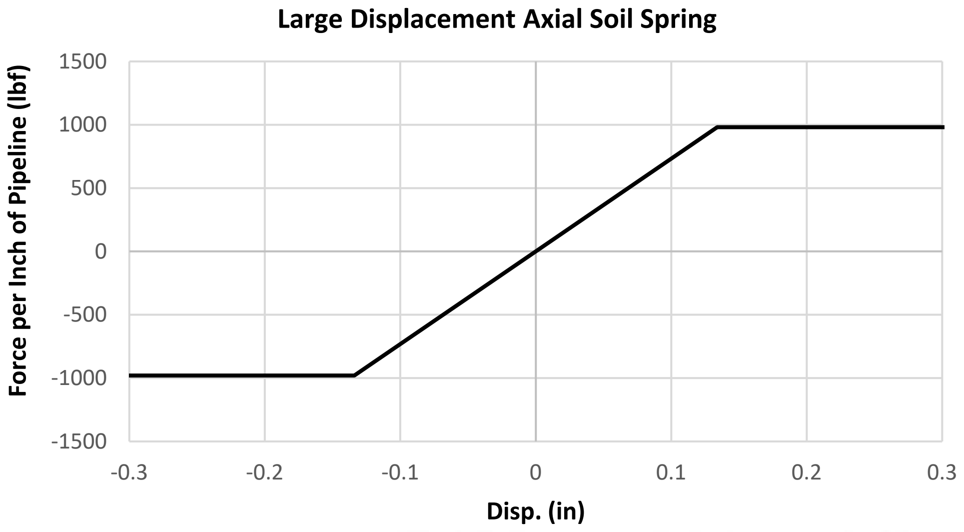
Accepted strain criteria:

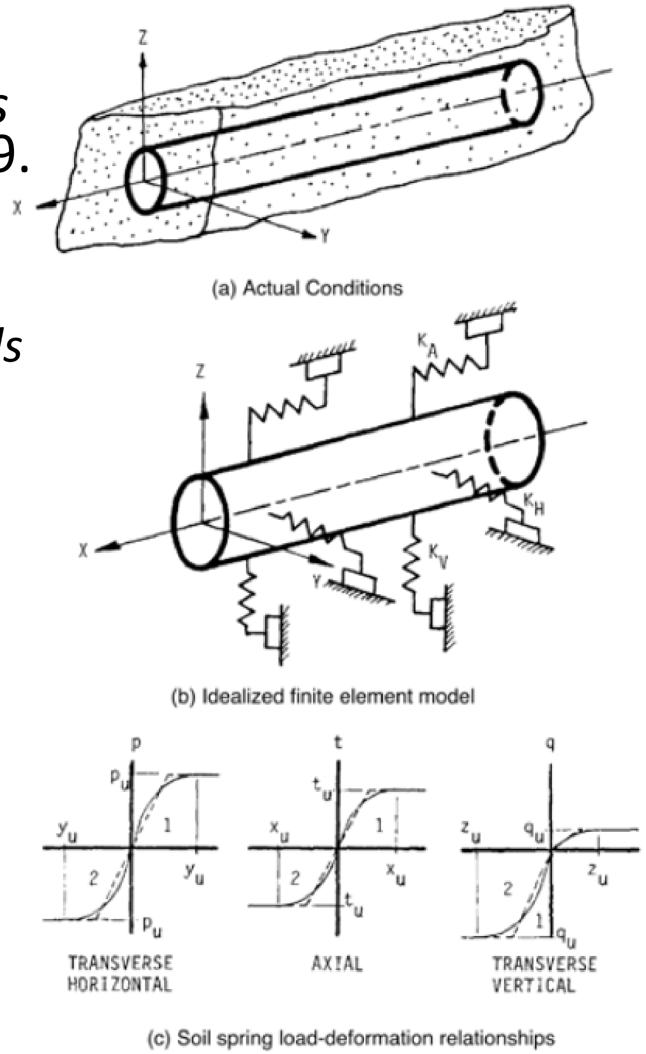
- Tension: 2%
- Compression: see graph



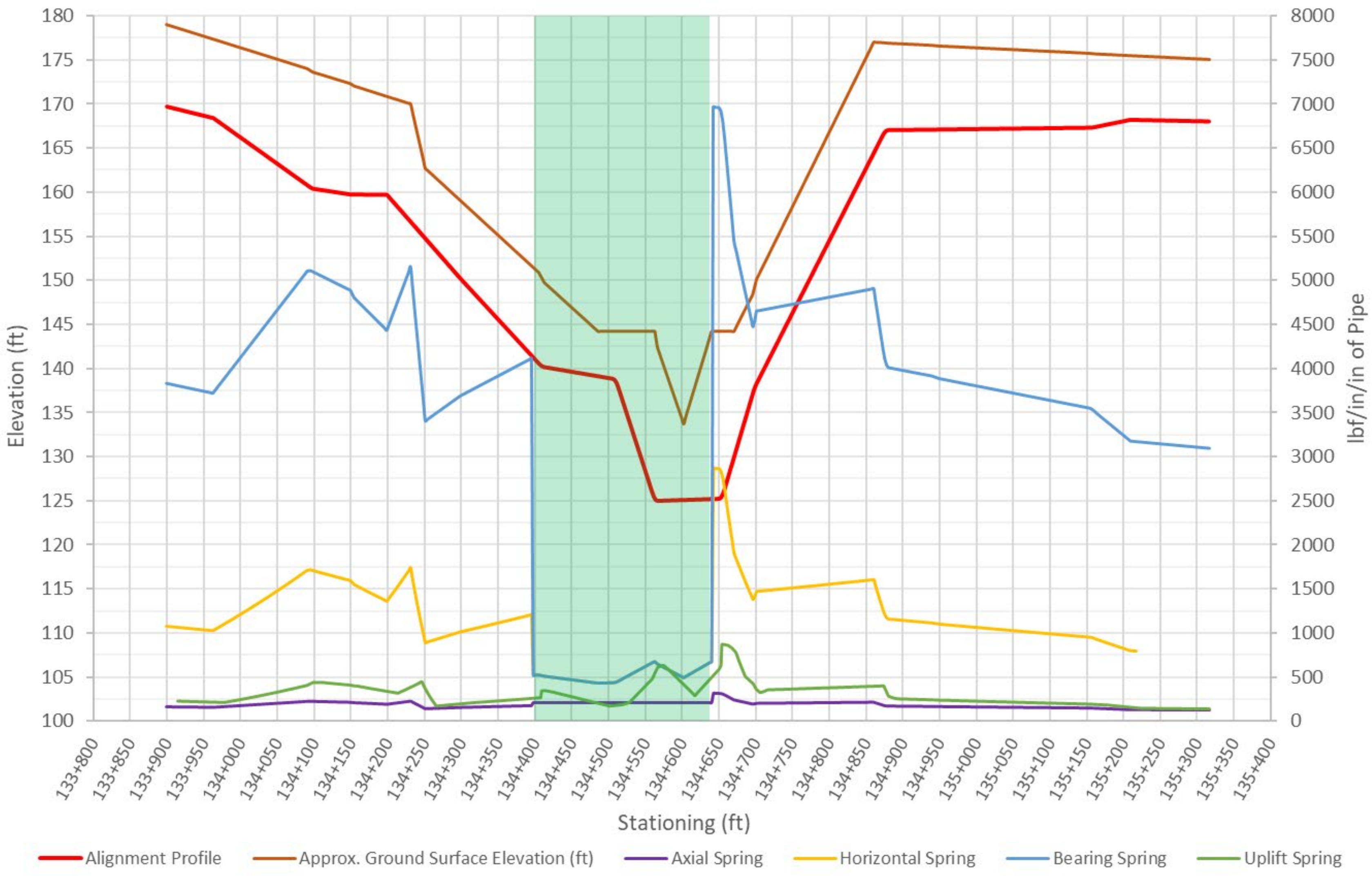
Representative Soil Springs

- *Guidelines for Constructing Natural Gas and Liquid Hydrocarbon Pipelines Through Areas Prone to Landslide and Subsidence Hazard,* PRCI, Jan. 2009.
- Adjusted for soil liquefaction/cyclic softening using Ru.
  - *Pore Pressure Ratio (Ru) = Pore Pressure Increase / Initial Effective Stress*
  - *FLAC modeling evaluated Ru to assess soil liquefaction/cyclic softening potentials*
  - *Using Ru to calculated effective stresses in soils during shaking*
  - *Using the adjust effective stress in soil restraint calculation*





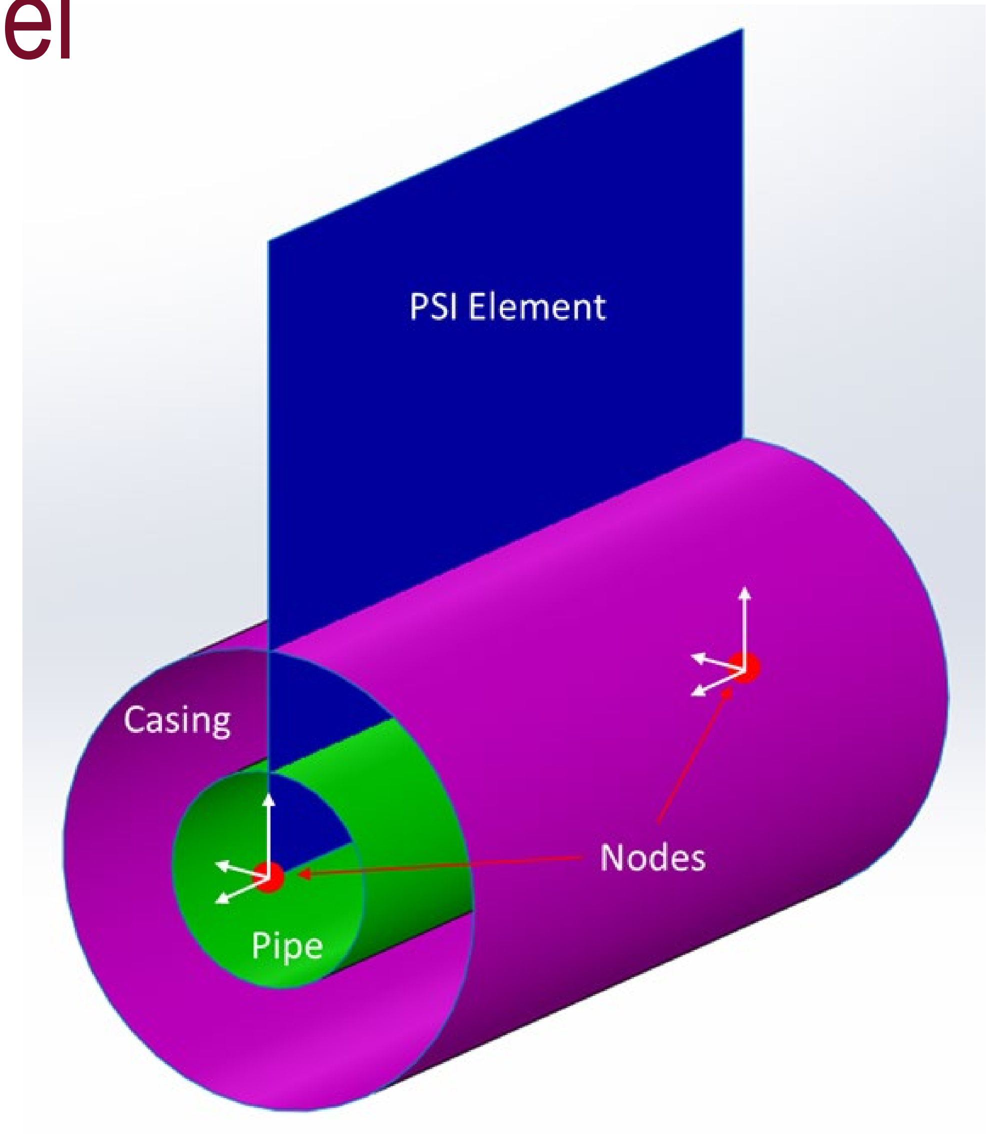
Soil Springs – Rock Creek



ABAQUS Pipe Soil Interaction Model

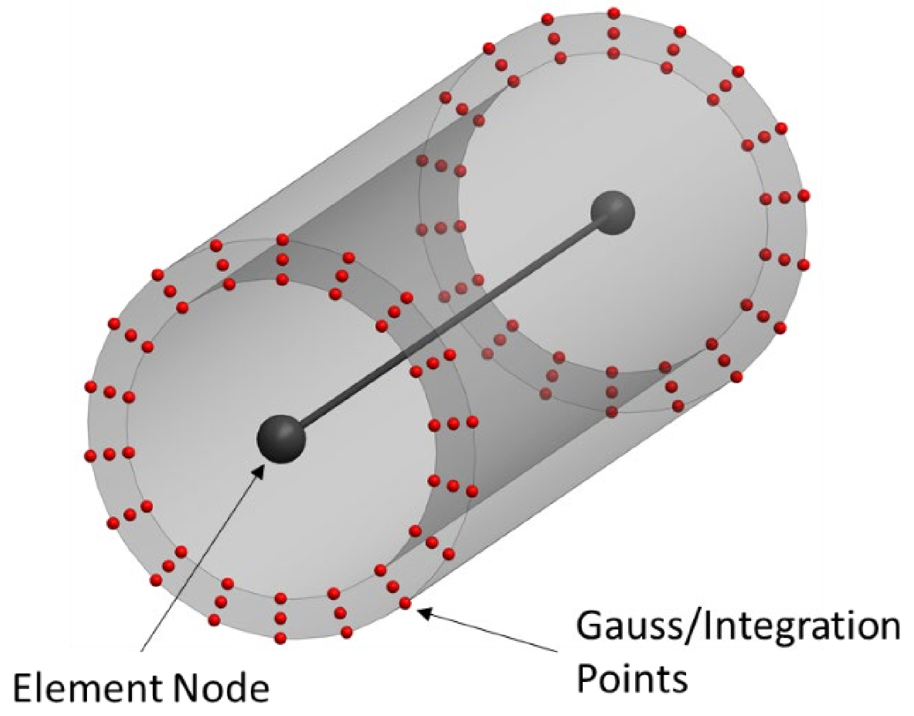
Developed Abaqus Finite Element Analysis (FEA) models

- Pipe is modeled with beam-type elements (elbow elements, using a full shell formulation around the circumference)
- Soil-pipe interaction are modeled with PSI elements
- Stiffness of PSI element are represented by Soil springs
- Ground deformations (in multiple directions) are applied at the far-field edge of the PSI element



ABAQUS Pipe Soil Interaction Model

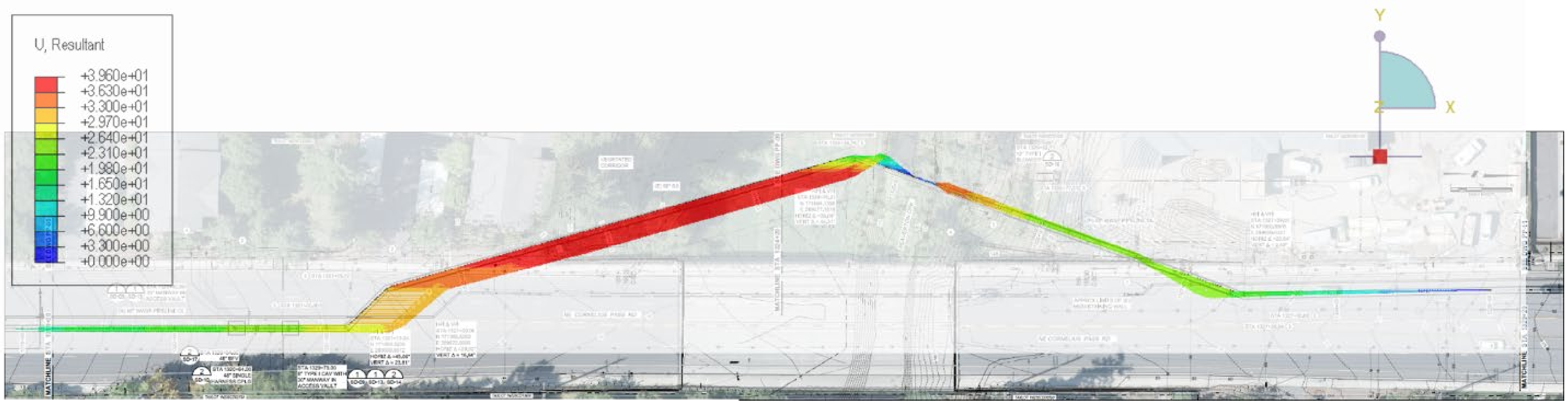
- Can capture internal pressure
- Can accurately capture nonlinear response of ovality which increase elastic flexibility of the pipe
- Can assess strain/stress at multiple points along the pipe circumference and through thickness



Abaqus Models – Beaverton Creek

- Modeling was performed in an iterative process.
- Started with an initial pipe thickness (i.e. 0.375”).
- Areas of the pipeline with tensile and compressive strain exceeding the program limits were identified.
- The pipe wall thickness was increased in these areas and the model was rerun.
- This process was repeated until the limits for tensile and compressive strain were met.

Stationing Range		Thickness (inches)
1319+00	1321+00	0.500
1321+00	1325+68.21	0.875
1325+68.21	1327+45	0.750
1327+45	1329+40	0.563



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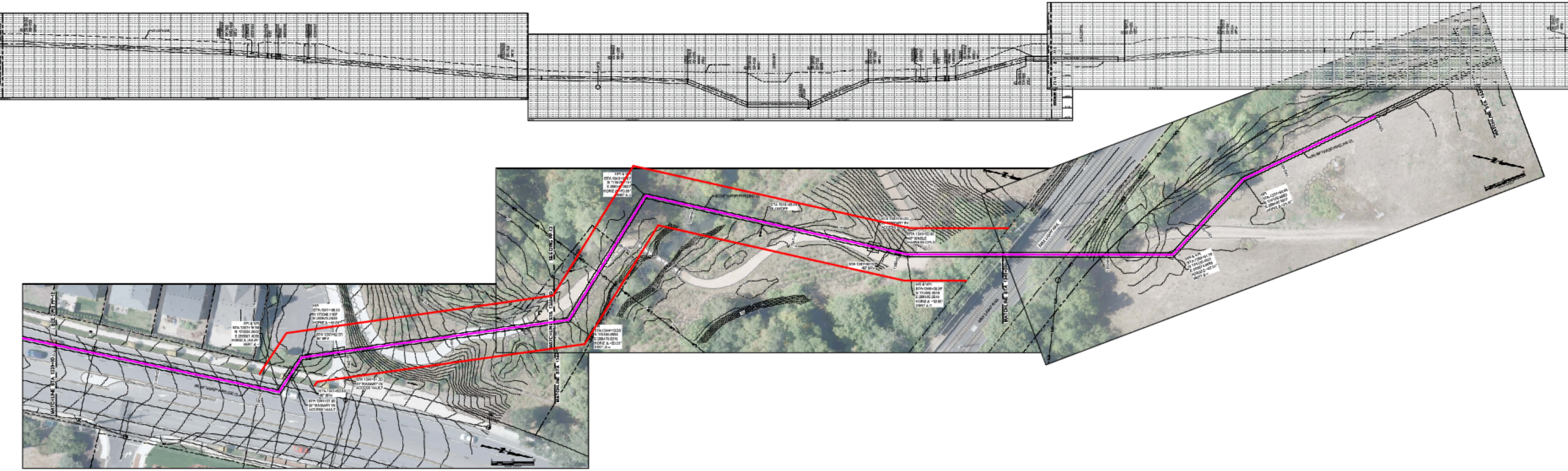
Abaqus Modeling – Rock Creek



Plan View of Rock Creek Alignment with Soil Node Displacement Superimposed

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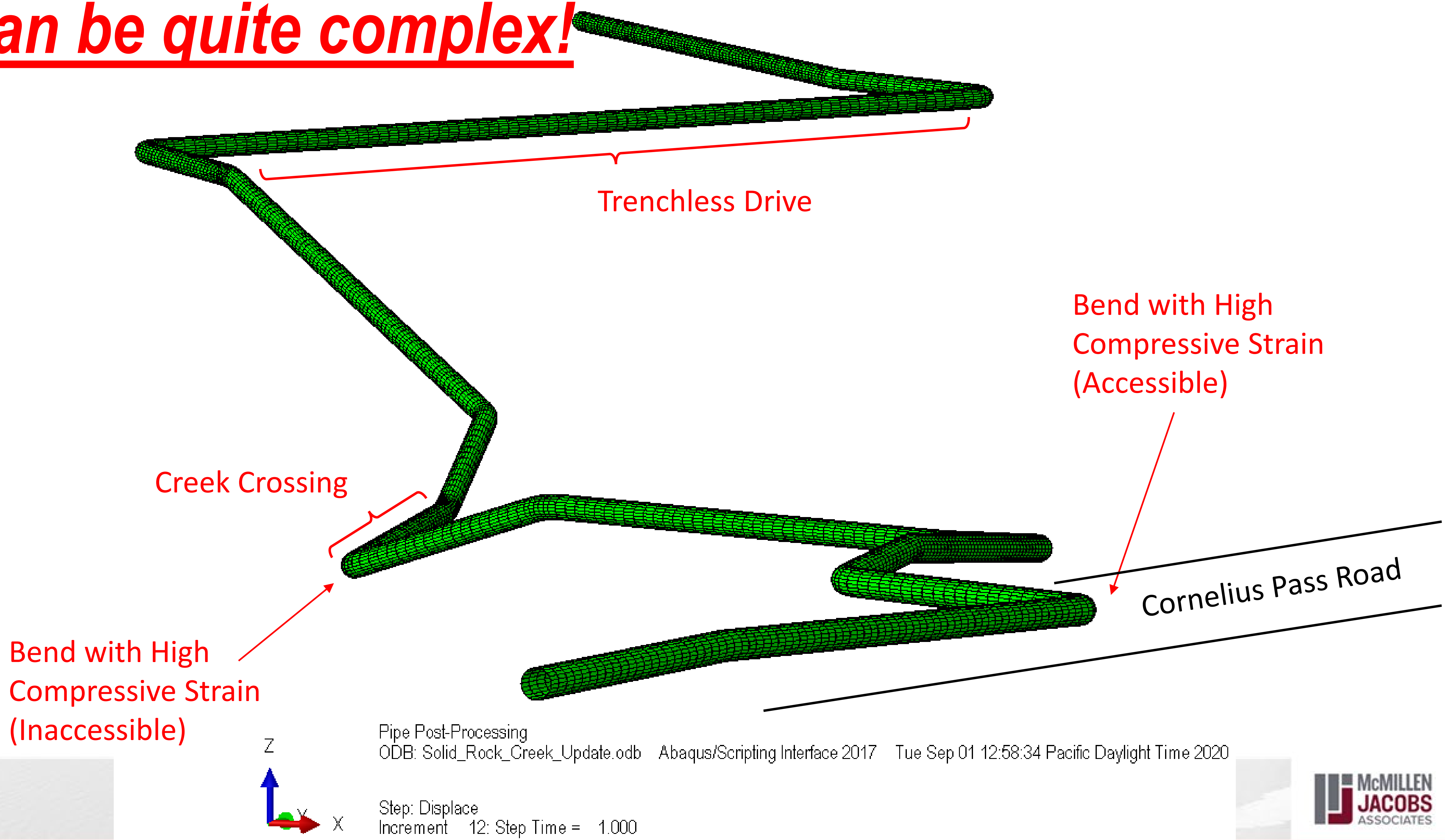
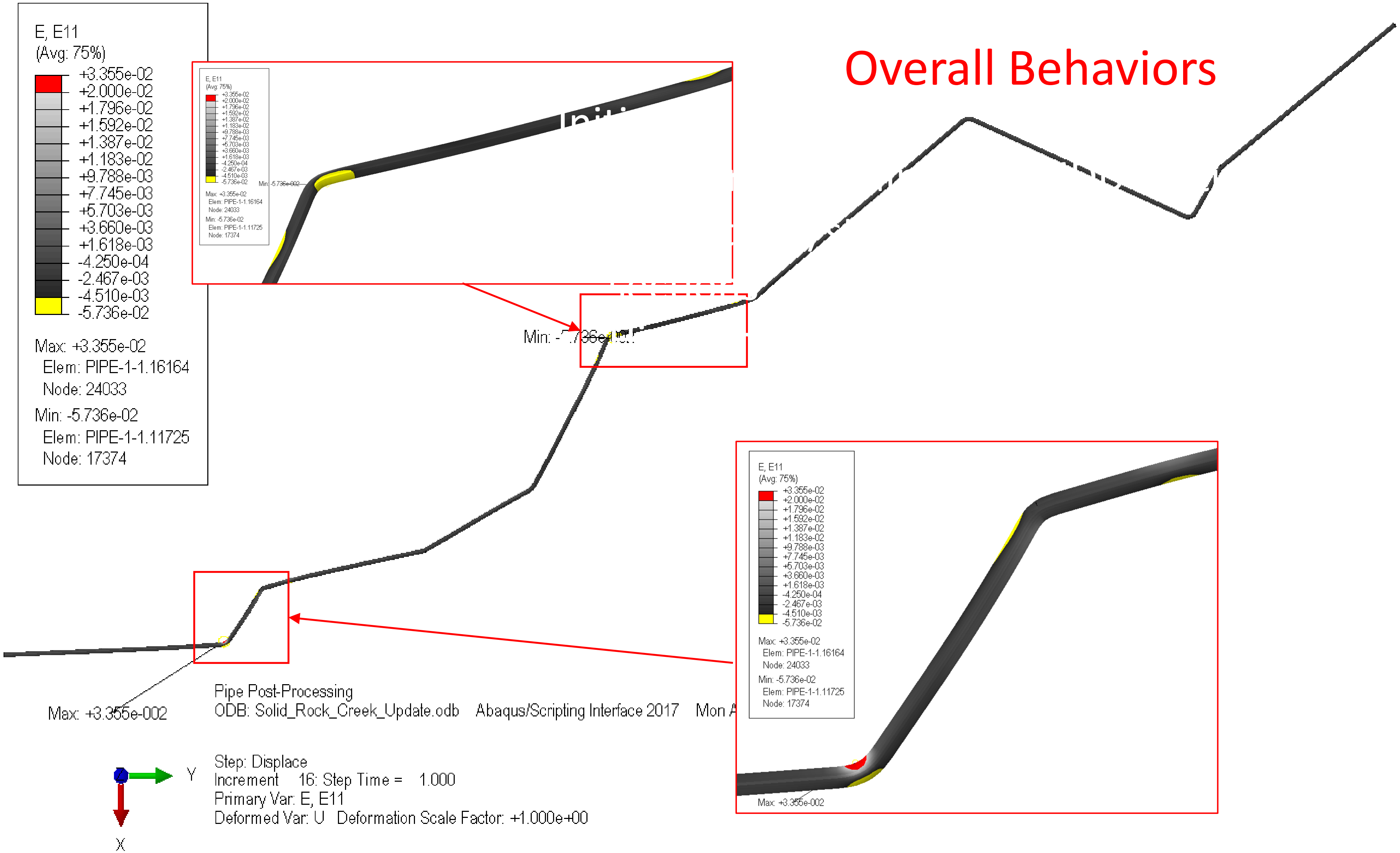
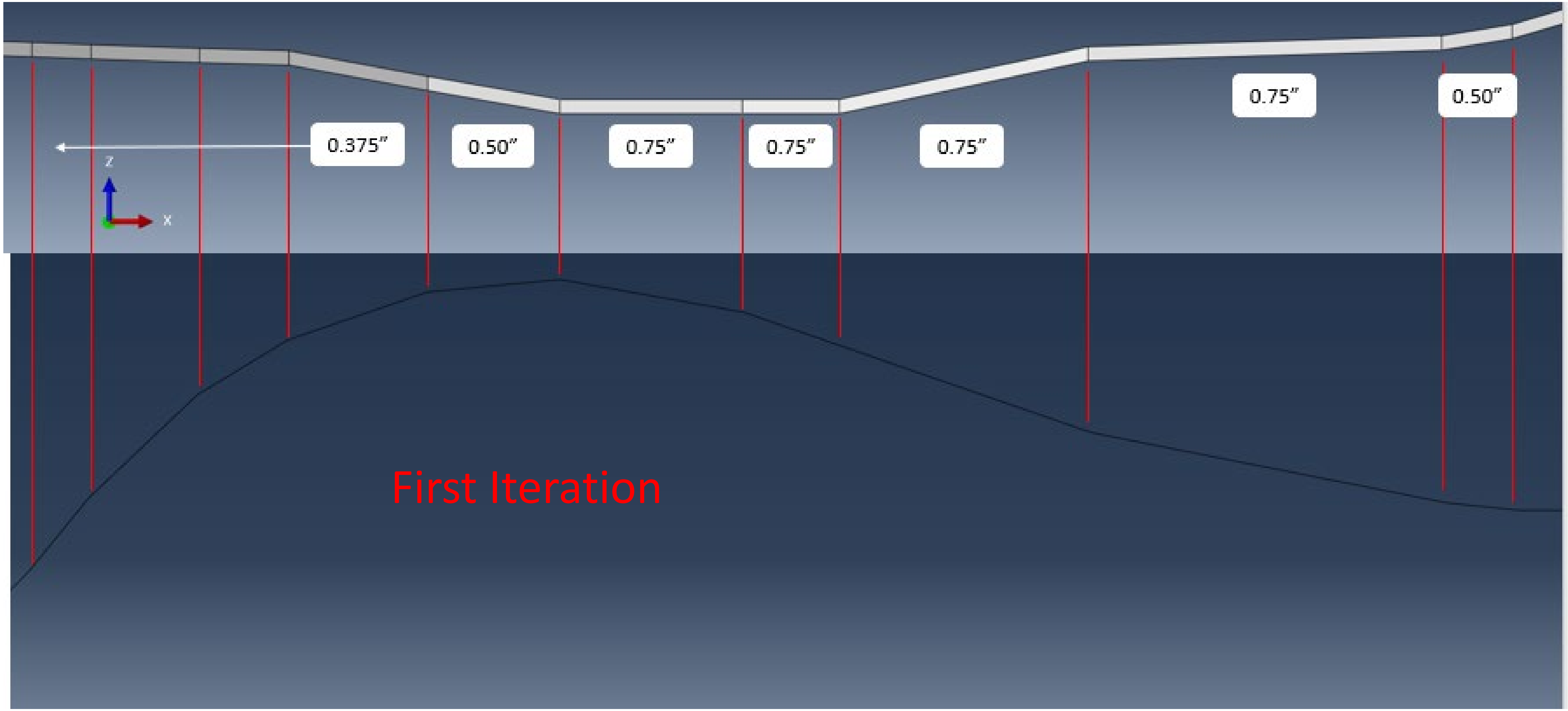
It can be quite complex!



Abaqus Modeling - Rock Creek



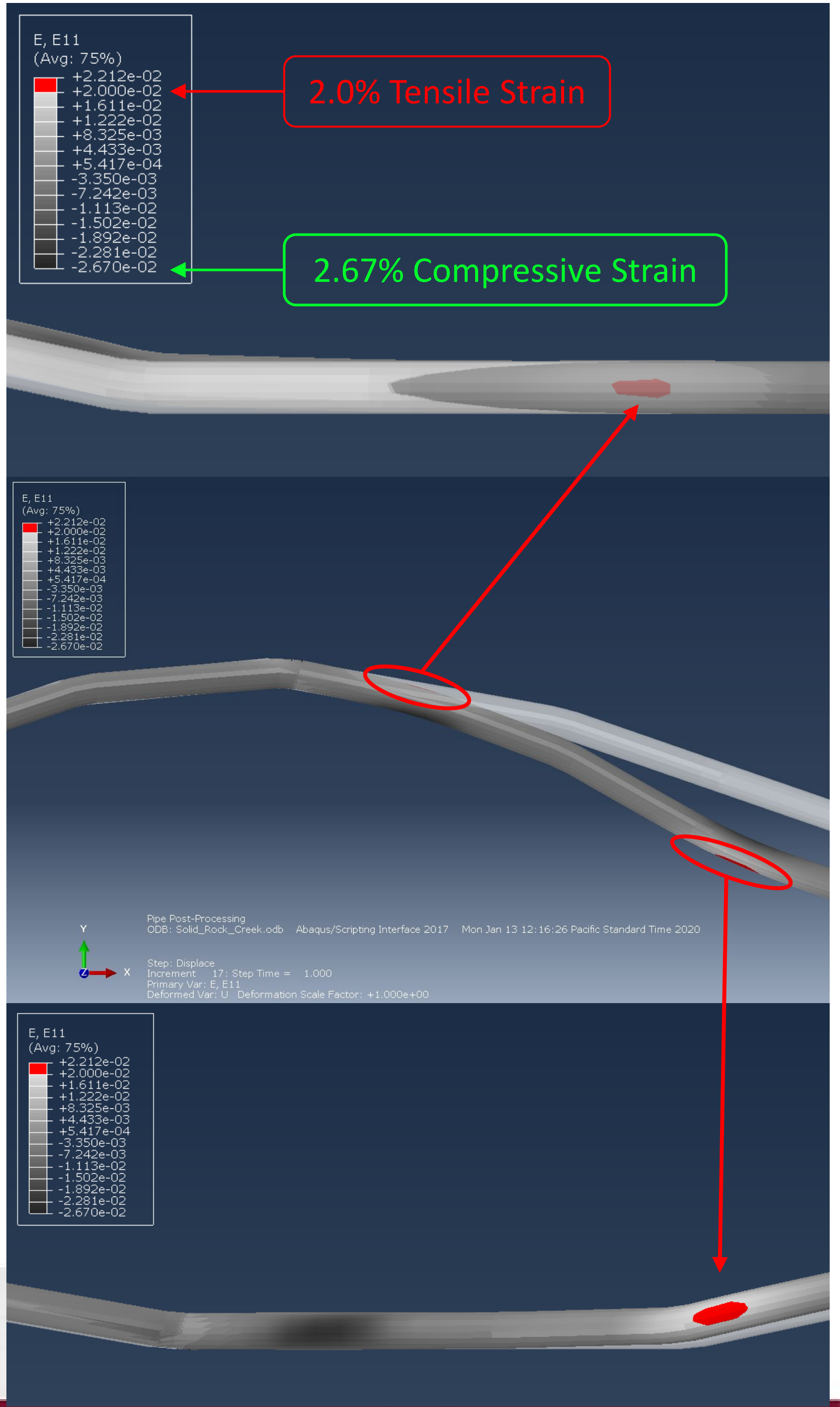
Abaqus Modeling - Rock Creek First Iteration



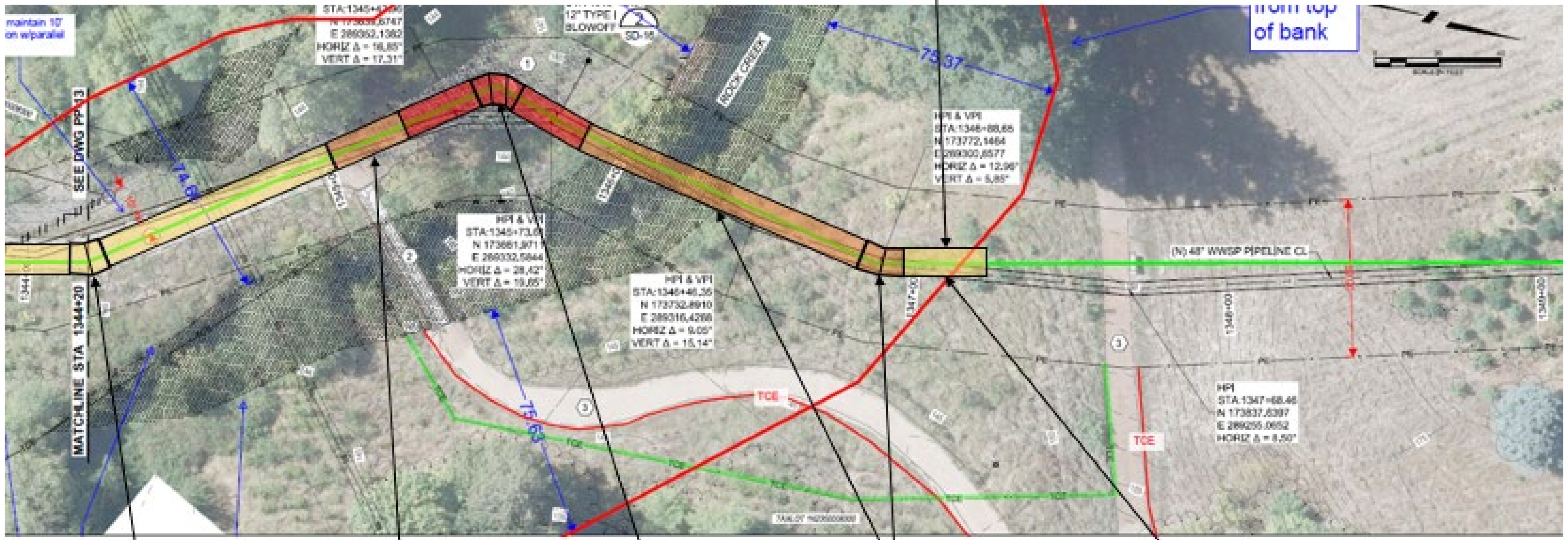
Abaqus Modeling - Rock Creek First Iteration

Section of Pipe Wall Over Allowable Accessible Tensile Strain Limits

Offset as % of Pipe Thickness →	40%	2001 ALA Guidance PRCI 2014 Normal Operability	PRCI Seismic Guidelines for a Pipe Butt Weld (Dorey et. al., 2001)	2005 ALA for Water Pipelines (1.76t/D)
Thickness (in)	Offset (in)	Tensile Strain	Compressive Strain	Pressure Integrity Compressive Strain
0.375	0.150	2%	0.111%	1.35%
0.500	0.200	2%	0.188%	1.80%
0.625	0.250	2%	0.285%	2.23%
0.750	0.300	2%	0.400%	2.67%



Abaqus Modeling - Rock Creek Second Iteration



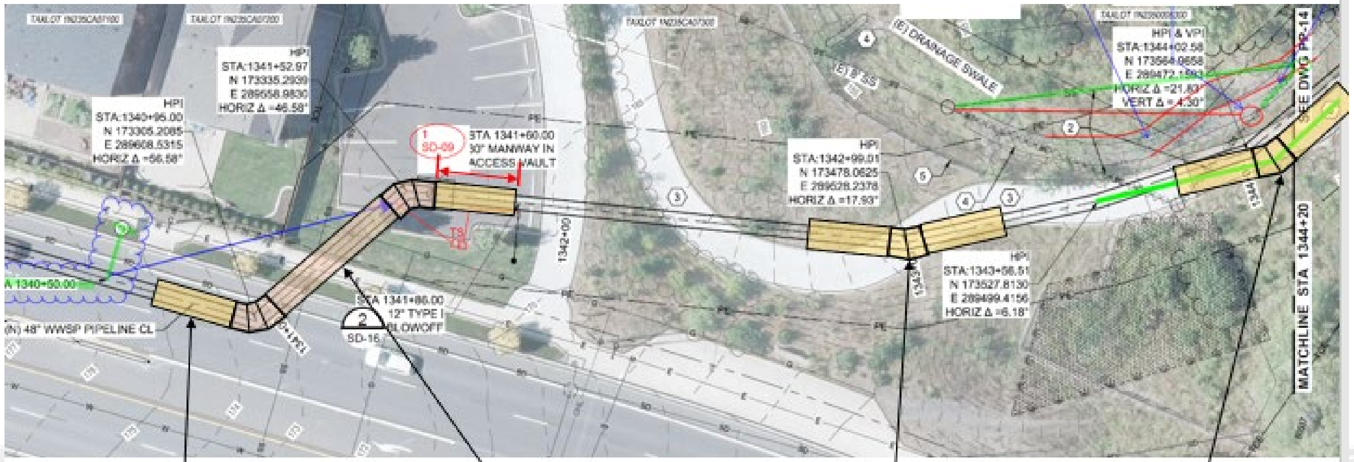
1/2 (0.500) Inch

3/4 (0.750) Inch

(1.000) Inch

3/4 (0.750) Inch

1/2 (0.500) Inch



1/2 (0.500) Inch

5/8th (0.625) Inch

1/2 (0.500) Inch

1/2 (0.500) Inch

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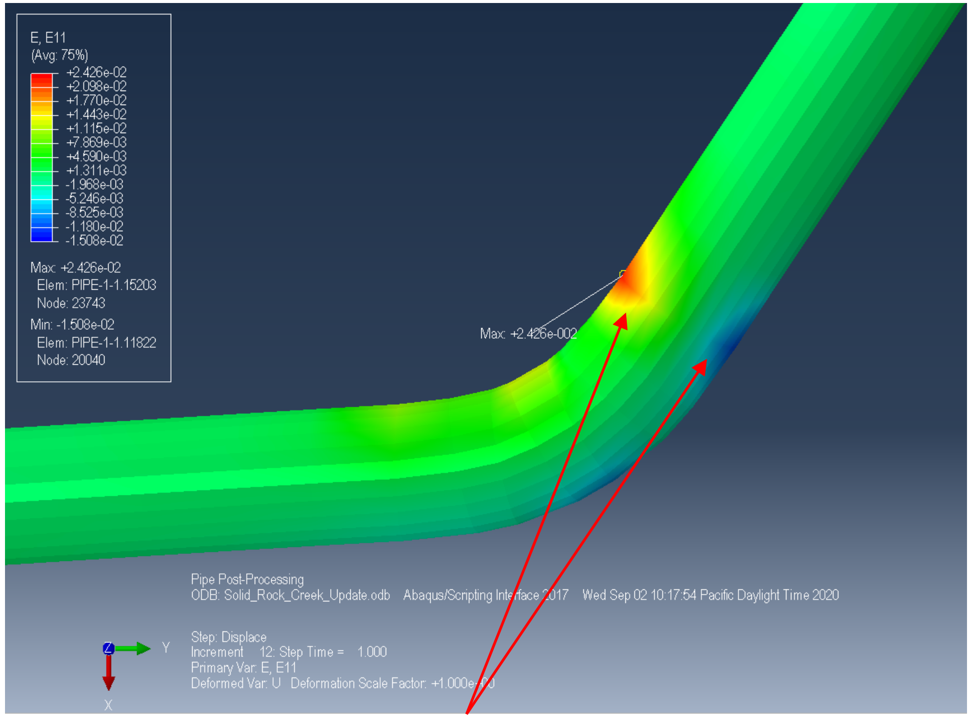
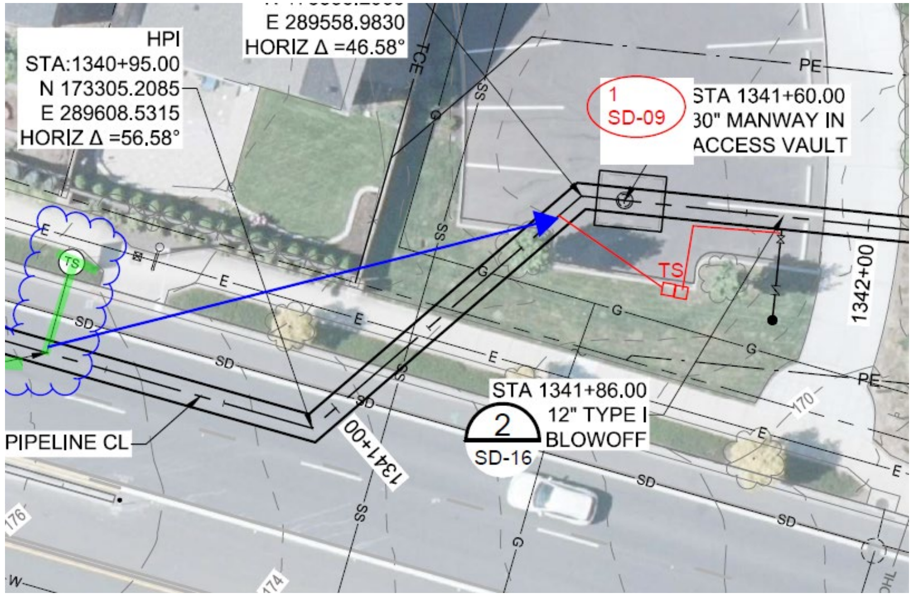
Abaqus Modeling - Rock Creek Second Iteration

- Improved seismic performance
- Still some localized areas with excessive strains (especially after mitered bends), but generally ok.





Excessive Strain Concentrated in ½” Pipe Body

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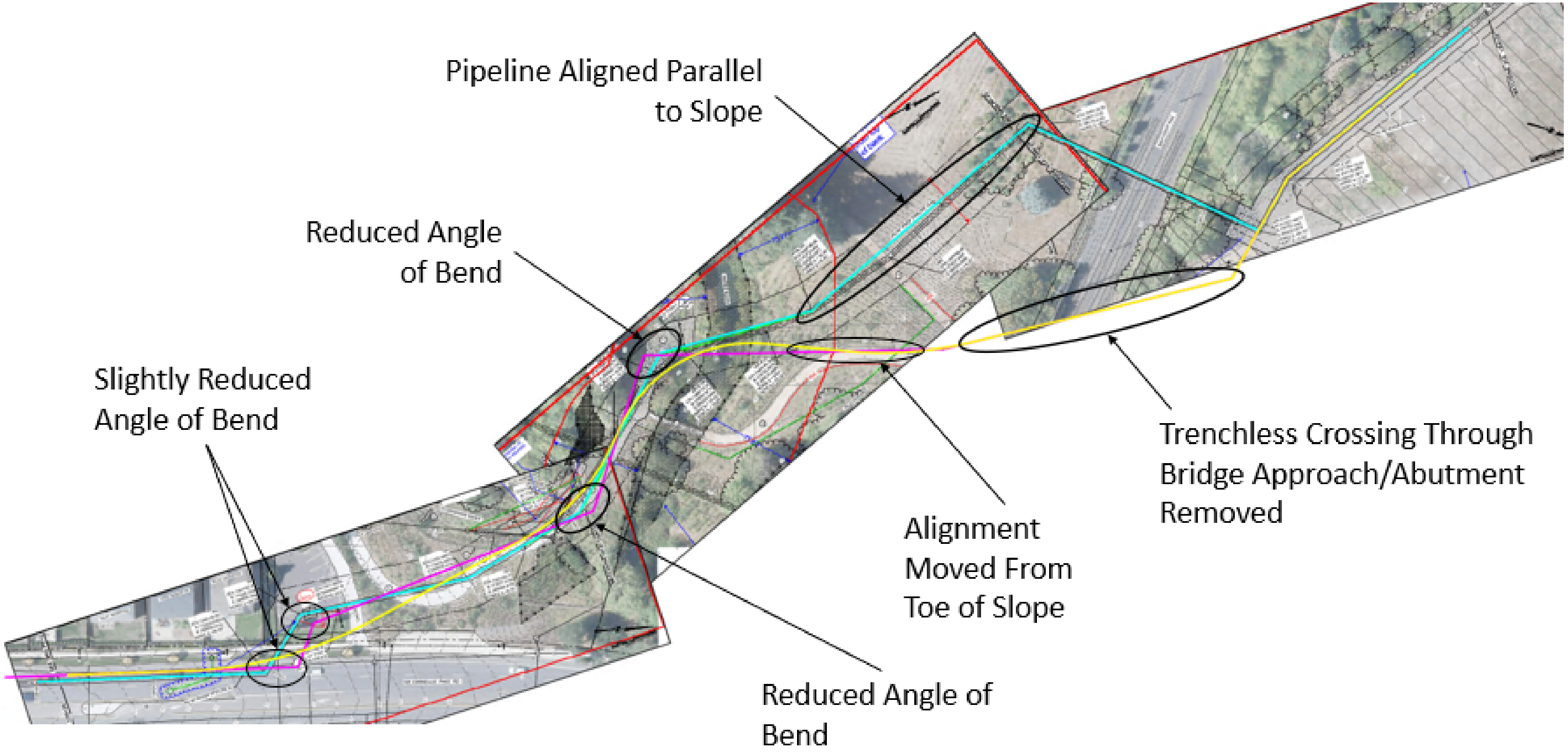
Abaqus Modeling - Rock Creek Third Iteration

- Recommended revision in alignment



Summary

- Extensive seismic hazards and ground deformation analyses are conducted
- Dynamic soil modeling (FLAC) indicates potentially high seismic ground deformation hazards at some potions of the pipeline;
- Stress conditions during liquefaction/cyclic softening were considered using excess pore pressure ratio (Ru) and the soil restraints were adjusted accordingly;
- Finite element soil-pipe interaction model (Abaqus) were developed and analyzed;
- Soil-pipe interaction modeling results are used to guide the selection of appropriate pipe sections to resist the ground deformation loads
- In addition to increasing pipe thicknesses, smoothing the bends and minor alignment adjustment will improve pipe seismic performance.

Thank You

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