Willamette Water Supply
Our Reliable Water

Just Add Water

2018 TACOMA PNWS-AWWA

Seismic Resiliency Lessons Learned Along the Way

April 25, 2018

Outline

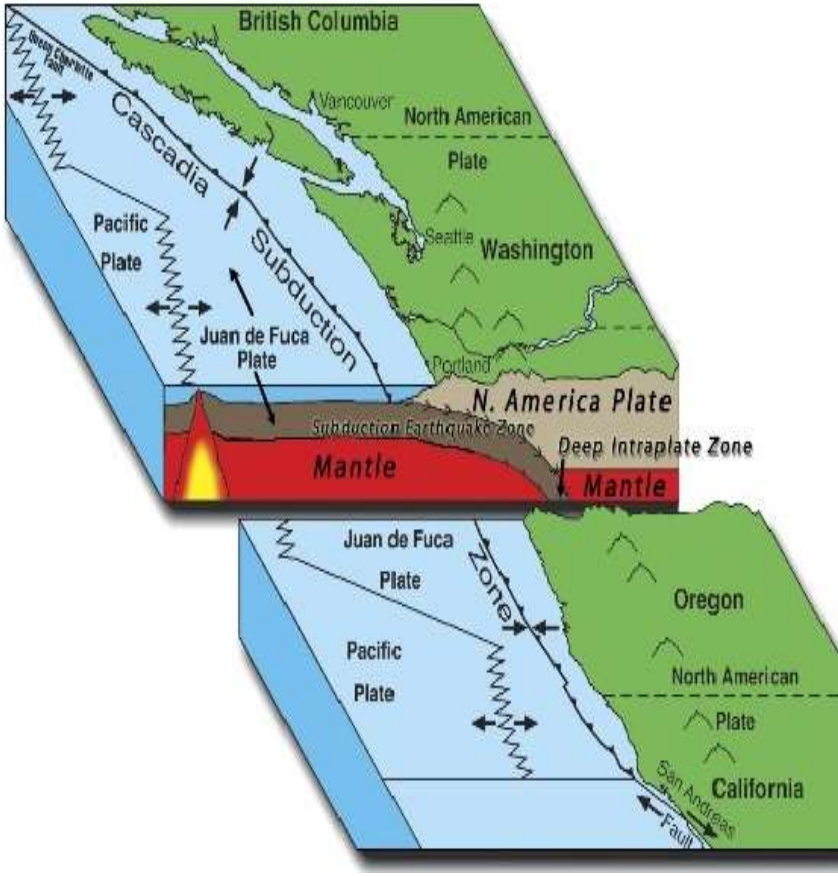
- Introduction & Program Overview
- Approach to Seismic Resiliency
- Types of Seismic Hazards
- Design of Resilient Facilities
- Application of Program Seismic Guidelines & Minimum Design Requirements

INTRODUCTION & PROGRAM OVERVIEW

Water System Failures Can Be Dramatic & Have Large Regional Impacts

Seismic Hazards are One of the Greatest Risks to Water Systems in our Region

- For the last 25 years, scientists have been aware of the possibility that a great earthquake caused by the Cascadia Subduction Zone could strike the Pacific Northwest in the next 50 years
- Great Subduction Zone Earthquakes are the largest earthquakes in the world and can produce magnitude 9.0 or greater earthquakes



Water Supply Program

- Modified water intake
- New water filtration plant
- 30+ miles of large diameter pipeline
- Water reservoirs
- Tualatin Valley Water District: 60% City of Hillsboro: 40%
- Scheduled completion: 2026

Tualatin Valley Water District

Hillsboro OREGON

Willamette Water Supply Program Mission Statement

Provide a cost-effective, reliable and resilient water supply system *by July 2026, that benefits current and future generations of the communities we serve and supports a vibrant local economy.*

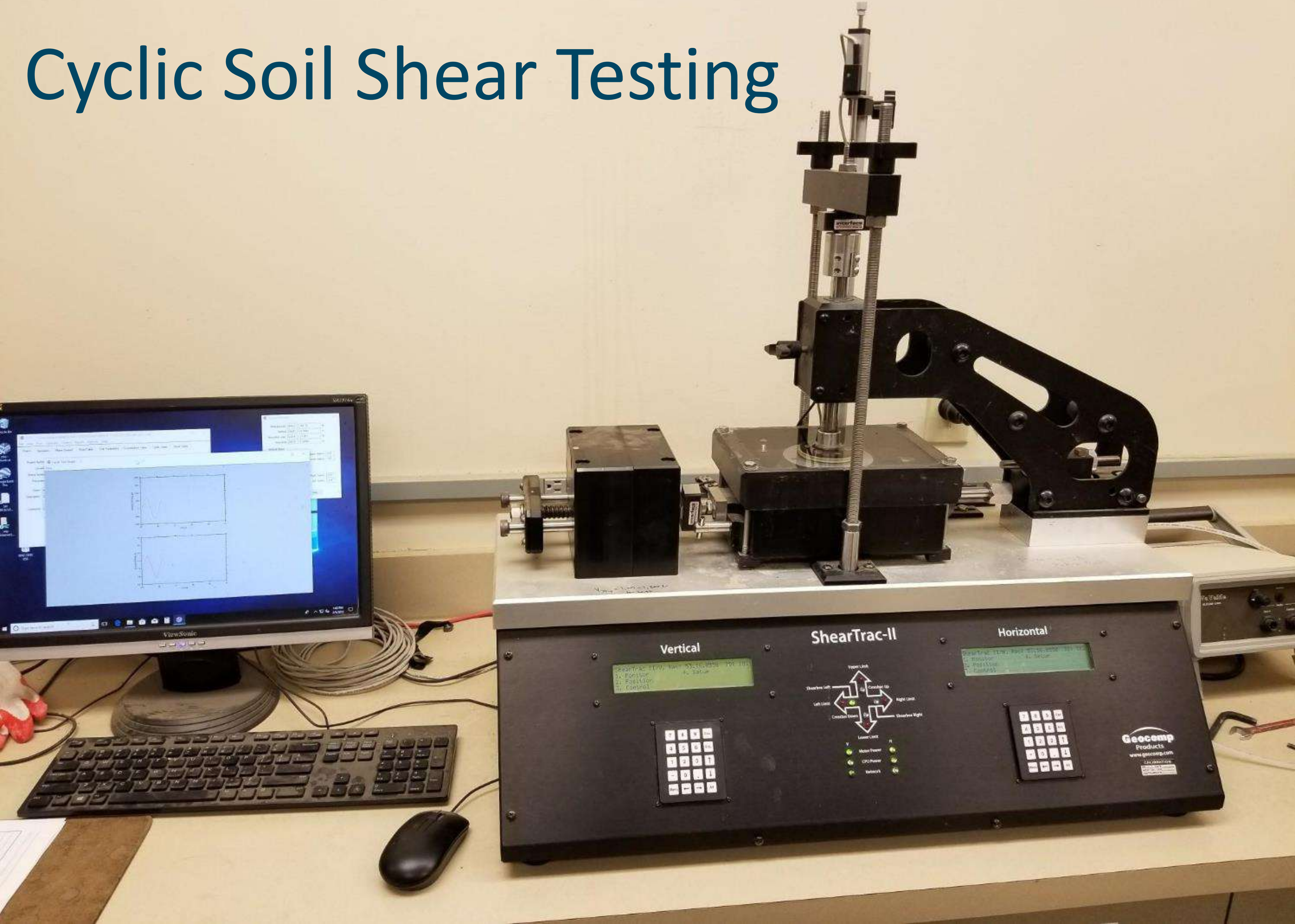
APPROACH TO SEISMIC RESILIENCY

Approach to Achieving Seismic Resiliency Goals

In designing the system, our team uses:

- ✓ Diverse critical thinking
- ✓ The latest seismic data

Cyclic Soil Shear Testing



Approach to Achieving Seismic Resiliency Goals

In designing the system, our team uses:

- ✓ Diverse critical thinking
- ✓ The latest seismic data
- ✓ Leveraging expertise from other critical infrastructure systems
- ✓ Input from industry experts

This approach is tailored to each system component to balance water supply resiliency and cost

Dr. O'Rourke Interview

CORNELL UNIVERSITY FOUNDED A.D. 1865

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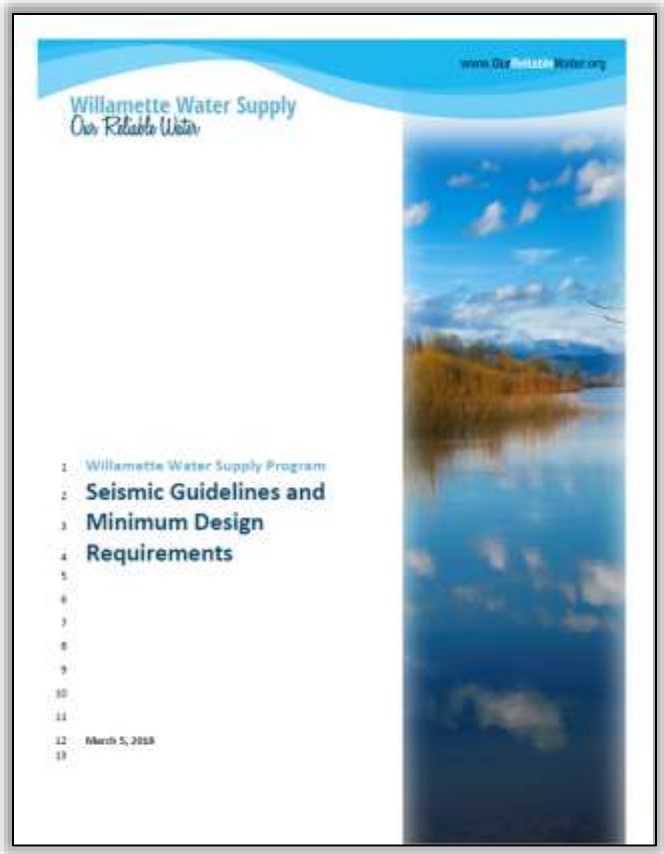
Seismic Guidelines and Minimum Design Requirements

History of Development

- **Seismic Resiliency Workgroup Meeting #1 – 10/7/16:** Overview of program and LOS goals
- **Seismic Resiliency Workgroup Meeting #2 – 3/16/17:** Overall approach & seismic framework
- **Seismic Resiliency Workgroup Meeting #3 – 9/20/17:** Reviewed draft standards [released Seismic Guidelines and Minimum Design Standards (version 0.0) 10/31/17]
- **Seismic Resiliency Workgroup Meeting #4 – 3/15/18:** Reviewed updates and new sections on Facilities and Peer Review
- **Seismic Resiliency Workgroup Meeting #5 – TBD:** Focus updates related to pipelines and facilities and new sections pertaining to Operational Considerations and Resiliency Planning
- **Seismic Resiliency Workgroup Meeting #6 – TBD:** Intended to include any additional updates plus other topics not yet addressed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Willamette Water Supply Program
Seismic Guidelines and Minimum Design Requirements

March 5, 2018

TYPES OF SEISMIC HAZARDS

Evaluate Project Specific Hazards

Table 6-1. Types of Seismic Hazards

Hazard Category	Subcategory/Description	
A. Ground Shaking	Transient ground motions and ground strain (Section 6.3)	
B. Permanent Ground Deformation	**1.** Liquefaction (Section 6.4)	**a.** Settlement (Section 6.6)
		b. Lateral Spreading (Section 6.7)
	2. Soft or weak soils below infrastructure (Section 6.8)	
	3. Seismically induced landslides (Section 6.9)	
	4. Abrupt Offsets (Section 6.10)	**a.** Differential Movement
		b. Soil Transitions
		c. Fault Ruptures
C. Nearby infrastructure by others designed to lesser standards (Section 6.11)		
D. Other applicable hazards (Section 6.12)		

Ground Shaking. **Ground shaking represents transient ground motions that are propagated through the ground due to the seismic fault movement. This hazard includes loading on the infrastructure that only exists while the ground shaking is ongoing. Once the ground shaking stops, the transient loading imposed on the infrastructure subsides.**

Evaluate Project Specific Hazards

Table 6-1. Types of Seismic Hazards

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D. Other applicable hazards (Section 6.12)		

Permanent Ground Deformation. **Permanent ground deformation (PGD) represents permanent movements that can impose loading on infrastructure. The movement and loading from the different subcategories of hazards remain following the end of the transient ground shaking from seismic waves. PGD is the "irrecoverable movement that persists after the shaking has stopped" (O'Rourke et. al., 2015). The different types of PGD may act separately or in combination depending on the specific characteristics of the hazard area under investigation.**

Evaluate Project Specific Hazards

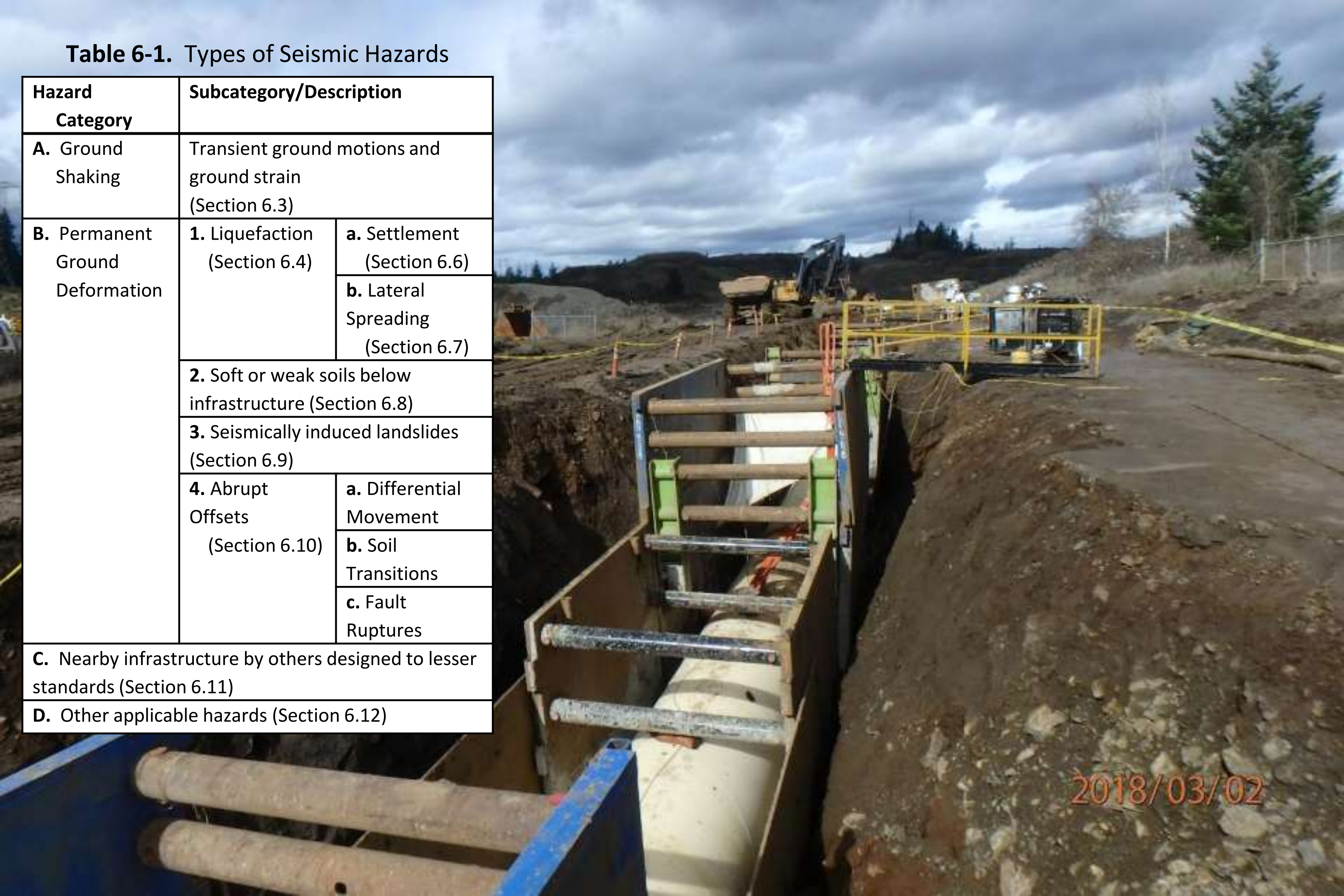

Table 6-1. Types of Seismic Hazards

<table>
<tr><th>Hazard Category</th><th colspan="2">Subcategory/Description</th></tr>
<tr><td>A. Ground Shaking</td><td colspan="2">Transient ground motions and ground strain (Section 6.3)</td></tr>
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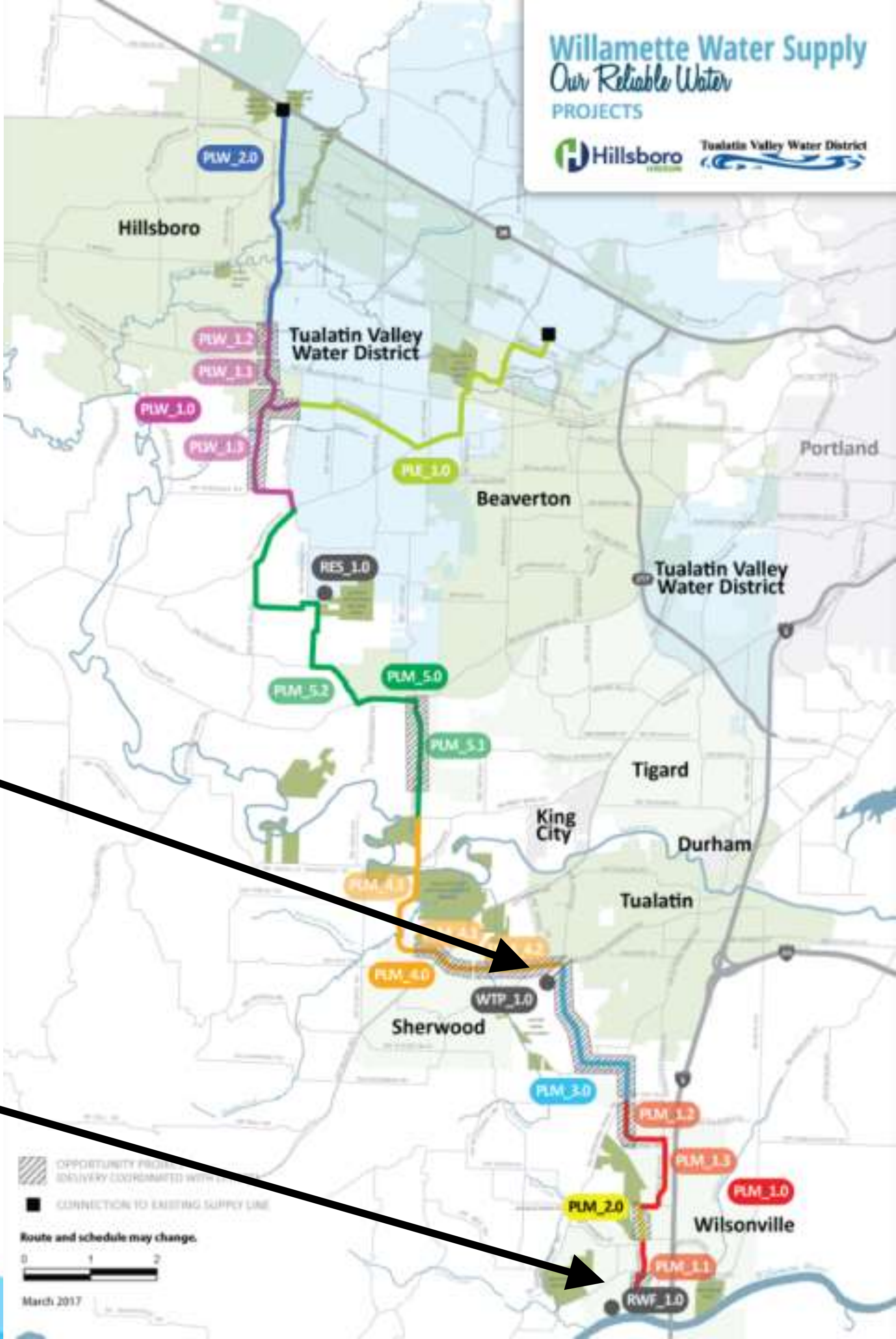
DESIGN OF RESILIENT FACILITIES

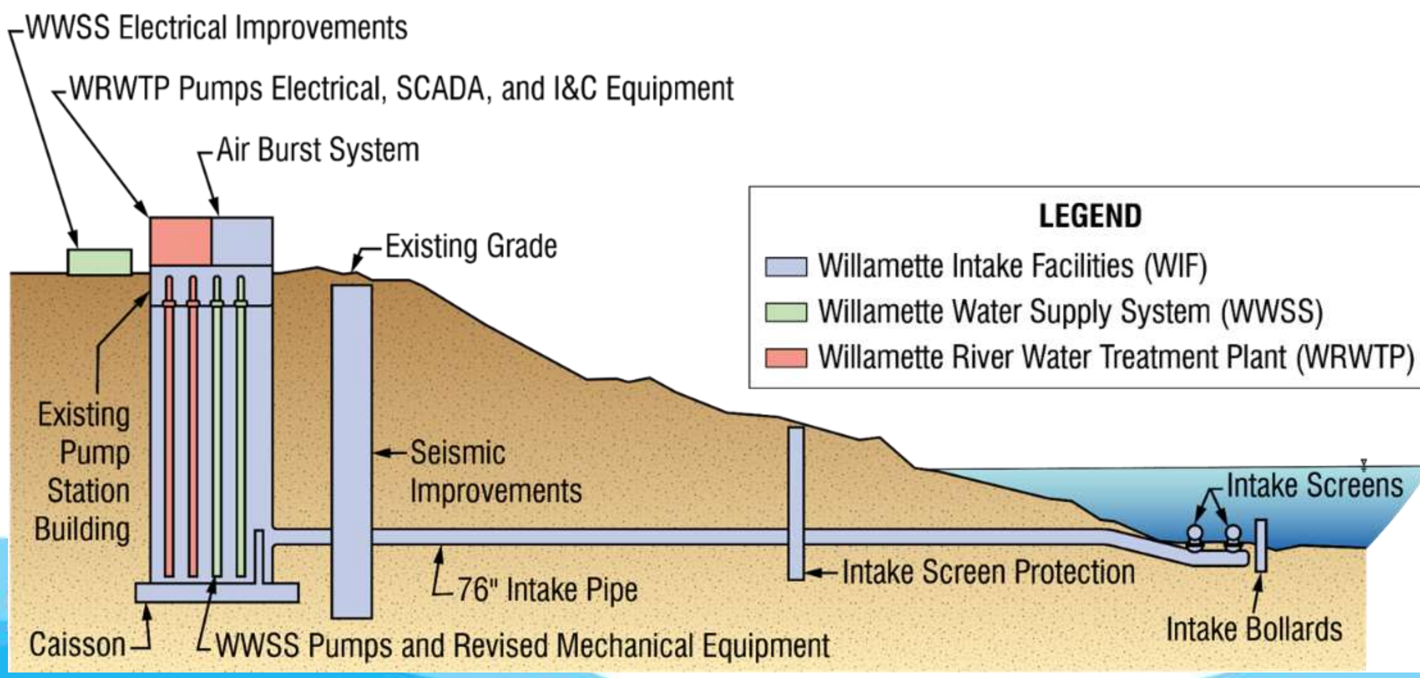
Increased Focus on Facilities

Water Treatment Plant

Raw Water Facilities



Raw Water Facilities



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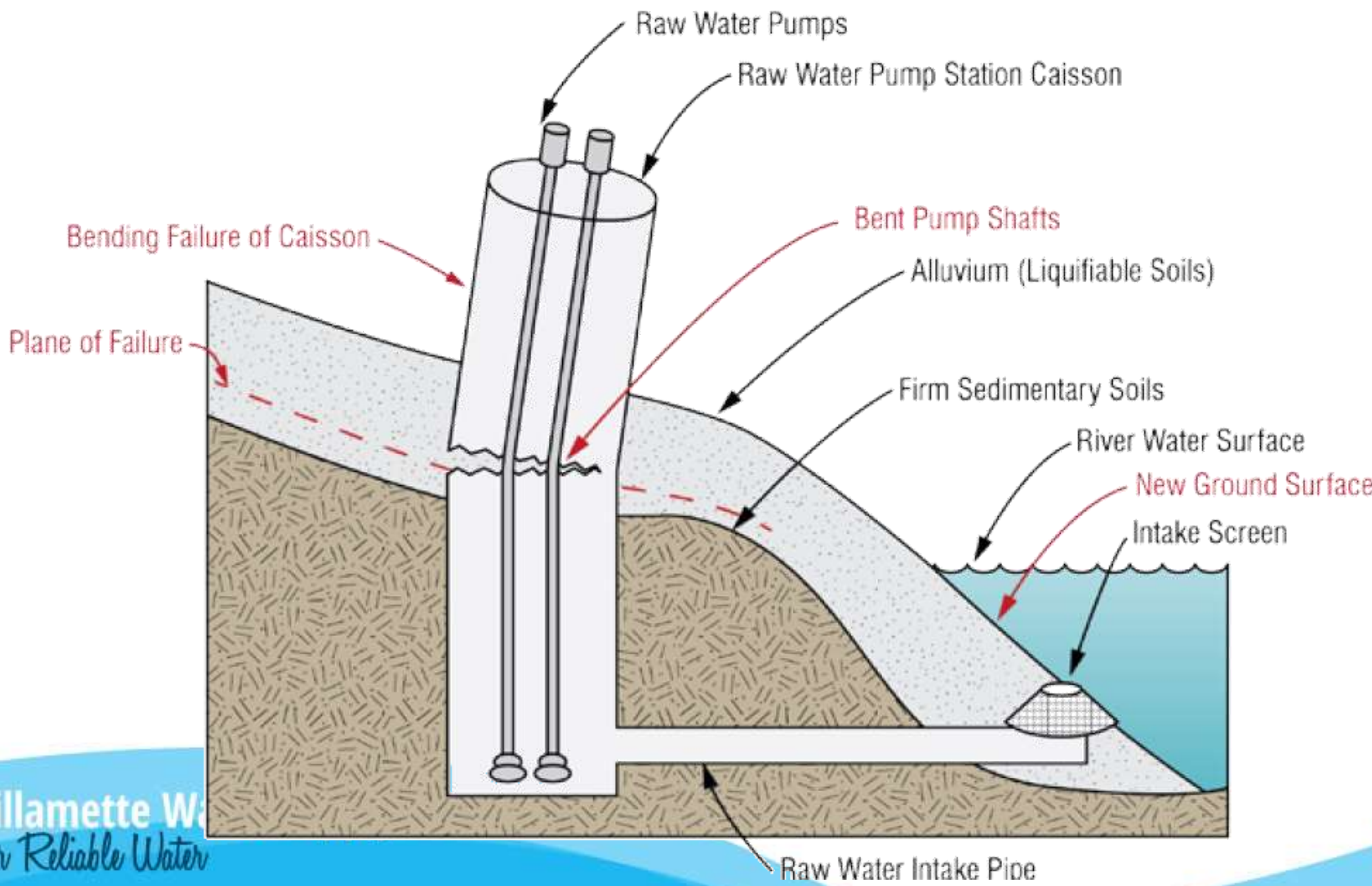
Addressing Existing Caisson Vulnerability



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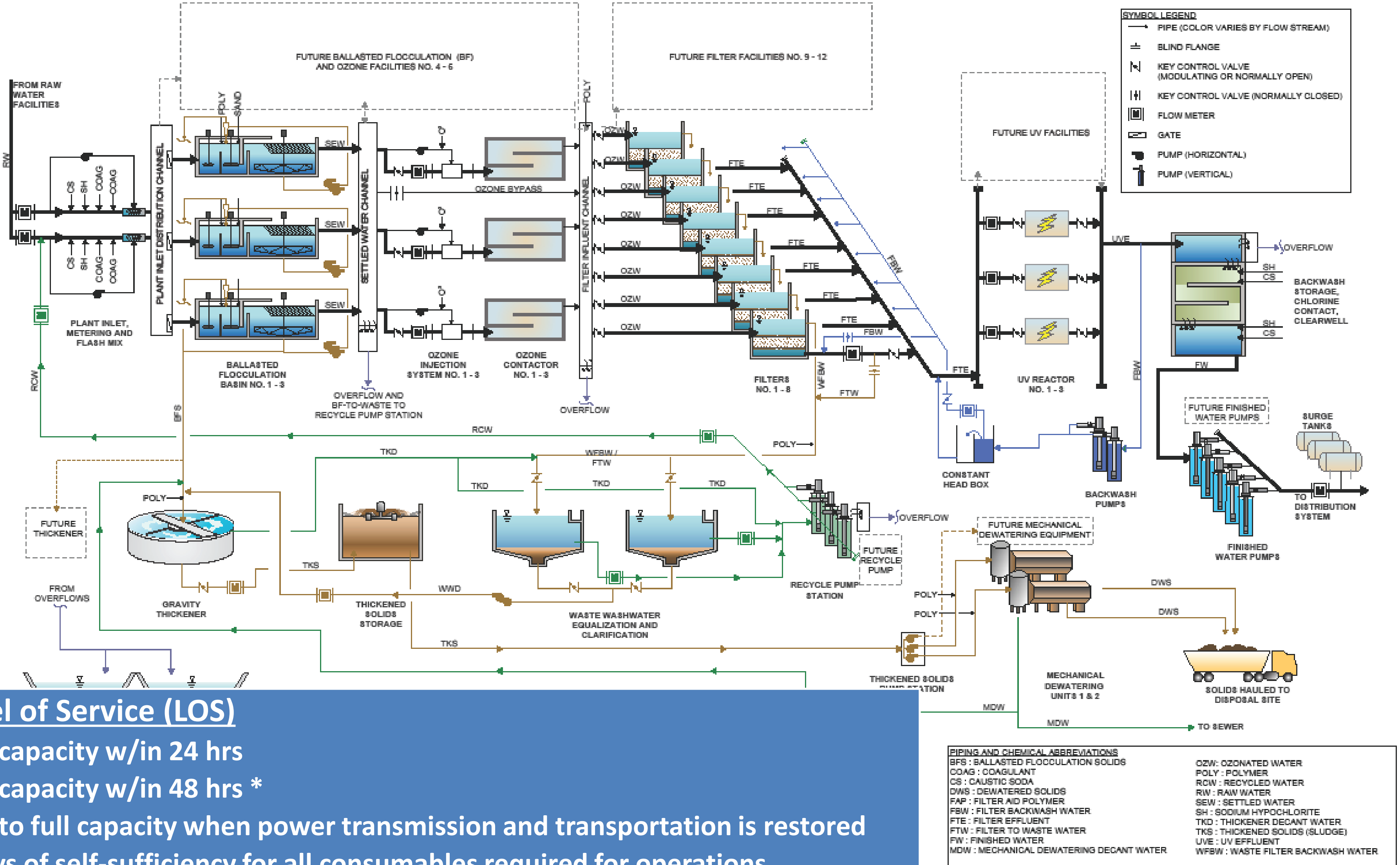
Conceptual Water Treatment Plant Layout

New Seismic Guidelines for Facilities



Level of Service (LOS)

25% capacity w/in 24 hrs

50% capacity w/in 48 hrs *

90% to full capacity when power transmission and transportation is restored

5 days of self-sufficiency for all consumables required for operations

** Provide full treatment at 50% capacity*

APPLICATION OF PROGRAM SEISMIC GUIDELINES & MINIMUM DESIGN REQUIREMENTS

Strain-Based Design & Limit States for Welded Steel Pipe

Four (4) limit states pertain to the design of continuous welded steel pipelines (Karamanos, et. al, 2017)

- Tensile Strain Capacity
- Local Buckling
- Beam Buckling
- Joint Resistance

Figure 4.2 Tear at Wrinkle in Ciudad Nezahualcoyotl Pipeline (Mexico City, 1985)

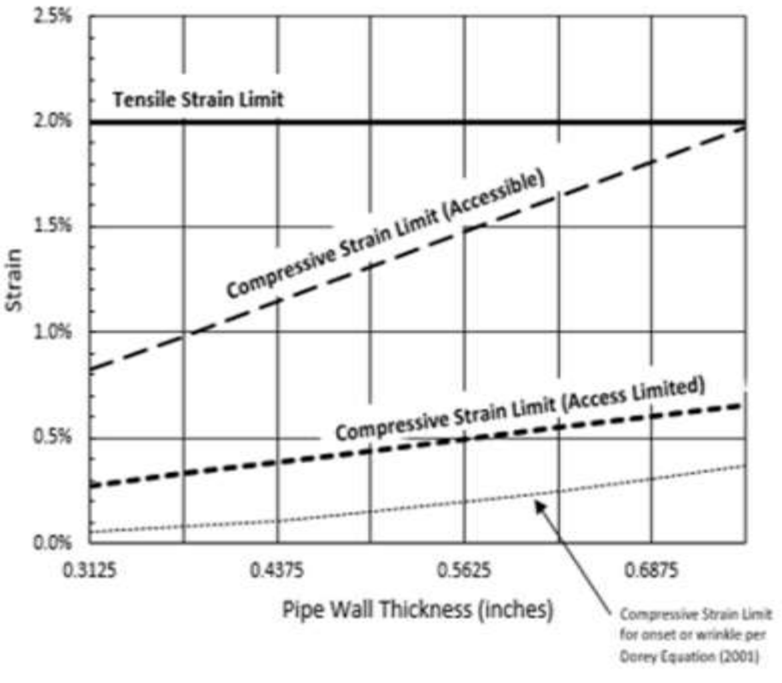


Figure 7.5 - Compressive and Tensile Strain Limit States

Strength of Lap Welded Joints

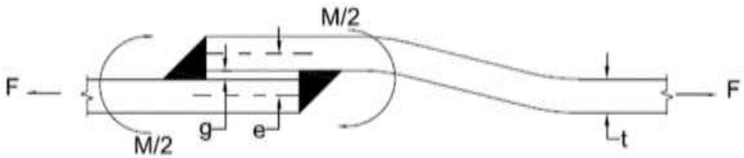


Table 7-2. Summary of Analytical and Large Testing Results on Axial Strength of Lap Welded Joints

Study or Reference	Joint Efficiency (JE)	D/t	Comments
Moncarz et. al (1987) [Ref. 3 in Figure 7.9]	0.4	216	Analytical evaluation of the failure of a 108-inch pipe subject to axial compression. Hoop stress was at 55% of yield.
Eidinger (1999) [Ref. 4 in Figure 7.9]	0.6	176	Analytical evaluation of un-pressurized 66-inch pipe with double welded lap joints and subject to axial compression.
Mason et. al (2010) [Ref. 1, 5, and 8 in Figure 7.9]	0.78 to 0.81 0.64 to 0.66 0.43	48 144 244	Experimental and analytical evaluation of unpressurized 12 to 36-inch pipe with single and double welded lap joints subject to axial compression. Wrinkling occurred in the curved portion of the bell.
Jones, T. O'Rourke, and J Mason (2012) [Ref.s 2, 6, and 7 in Figure 7.9]	0.50 to 0.65	50	Experimental and analytical evaluation of unpressurized pipe with single welded lap joints subject to axial compression. Reductions in the axial compressive capacity of pipelines with welded slip joints that can be as large as 50 percent.

Strength of Lap Welded Joints

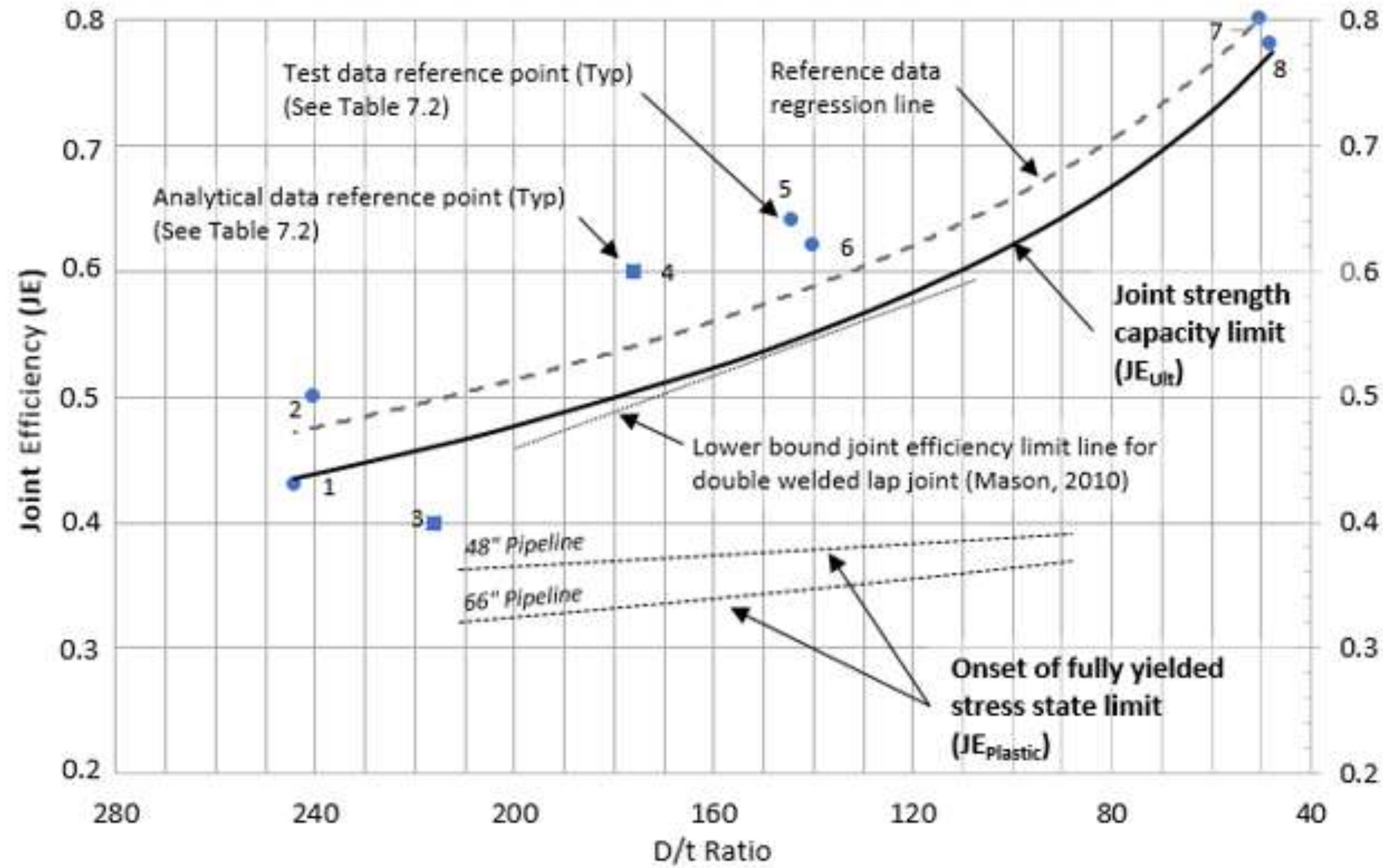
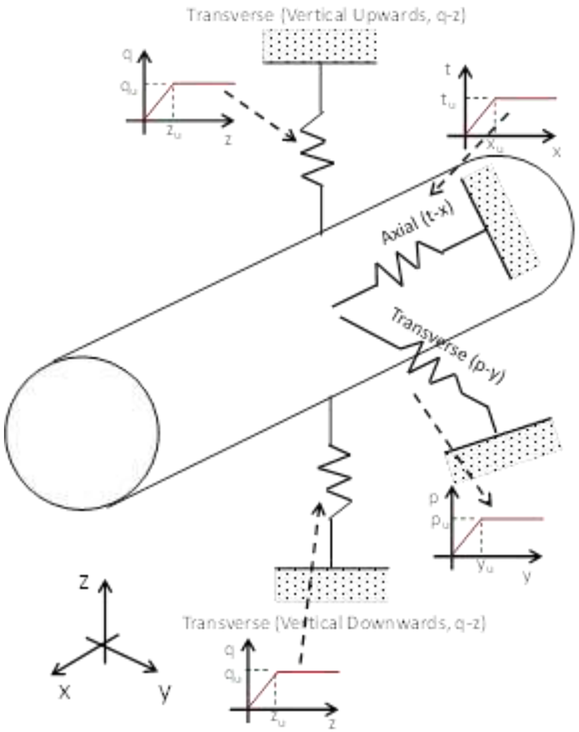
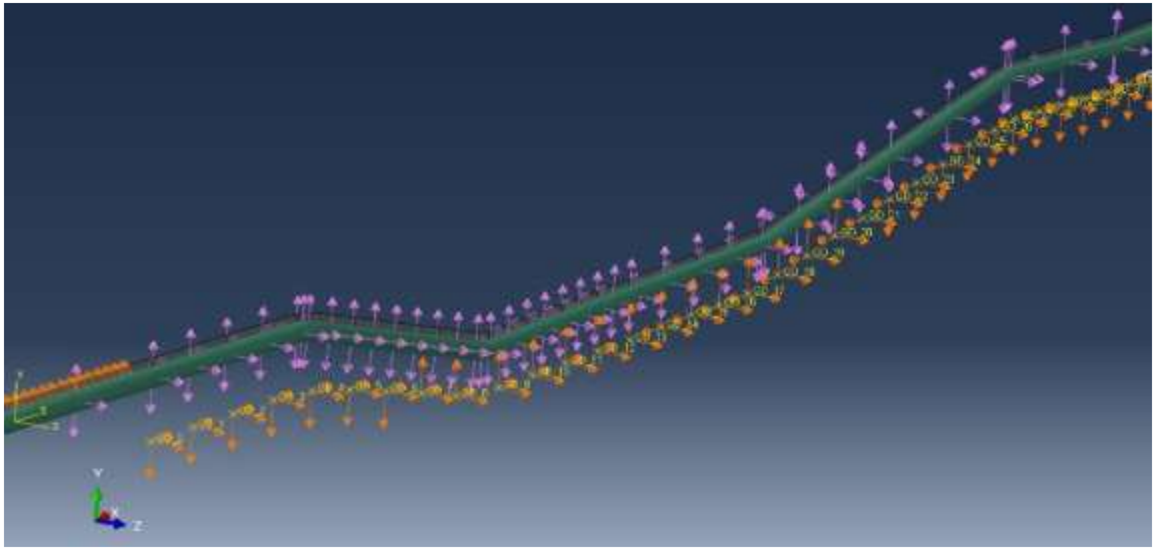


Figure 7.7 - Lap Welded Joint Efficiency vs. Wall Thickness

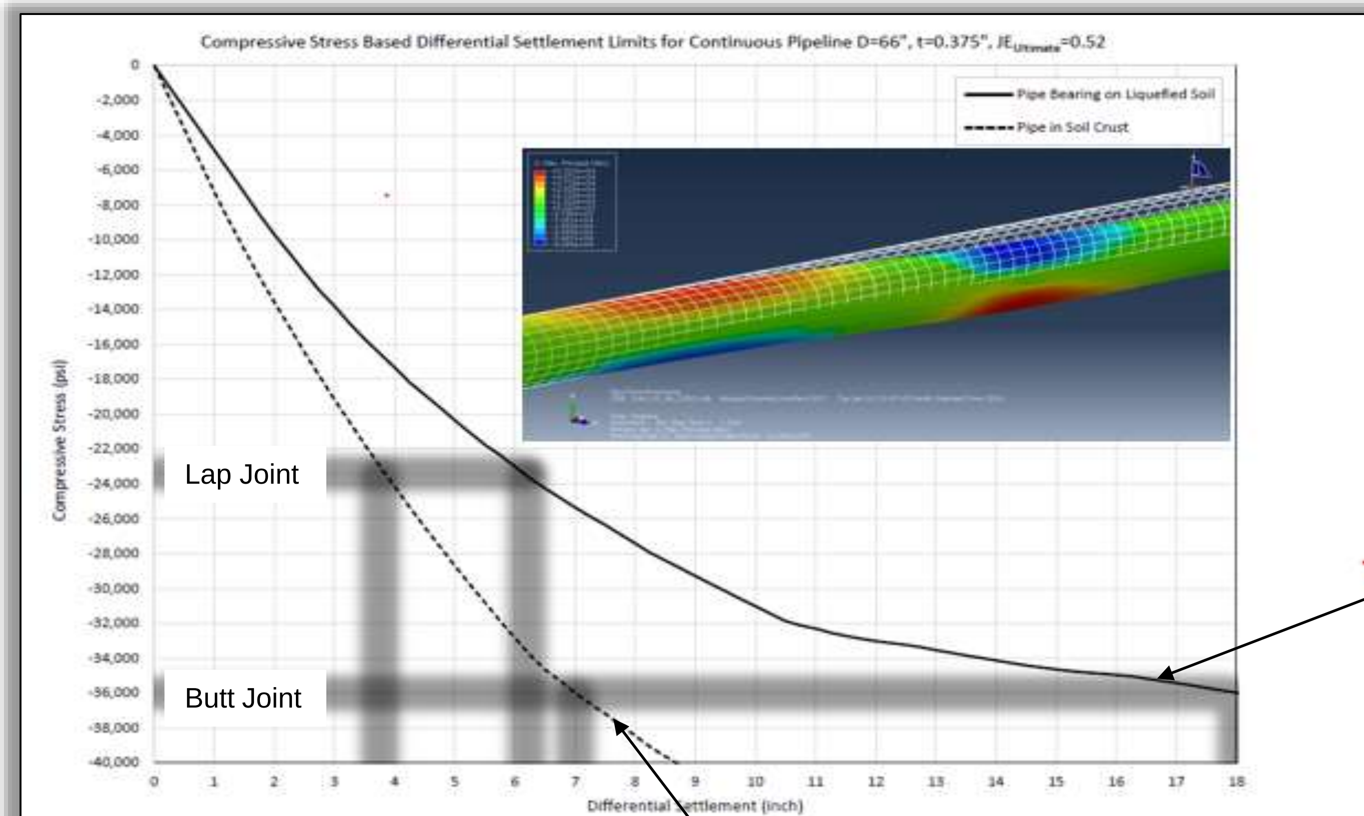
Soil/Pipe Interaction Modeling

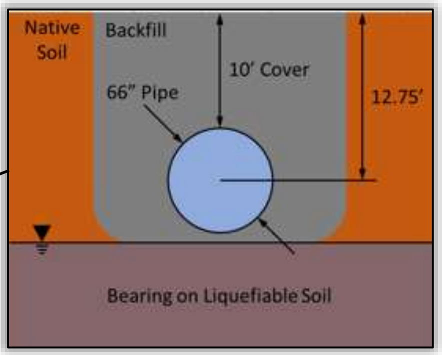


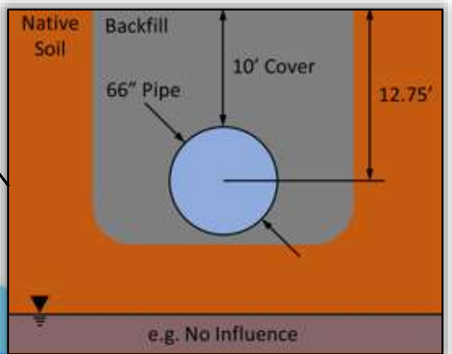


- Adjustments to soil springs based on installation depth, pipe backfill, and groundwater level may be warranted to suit specific site conditions.

Settlement Threshold Analysis







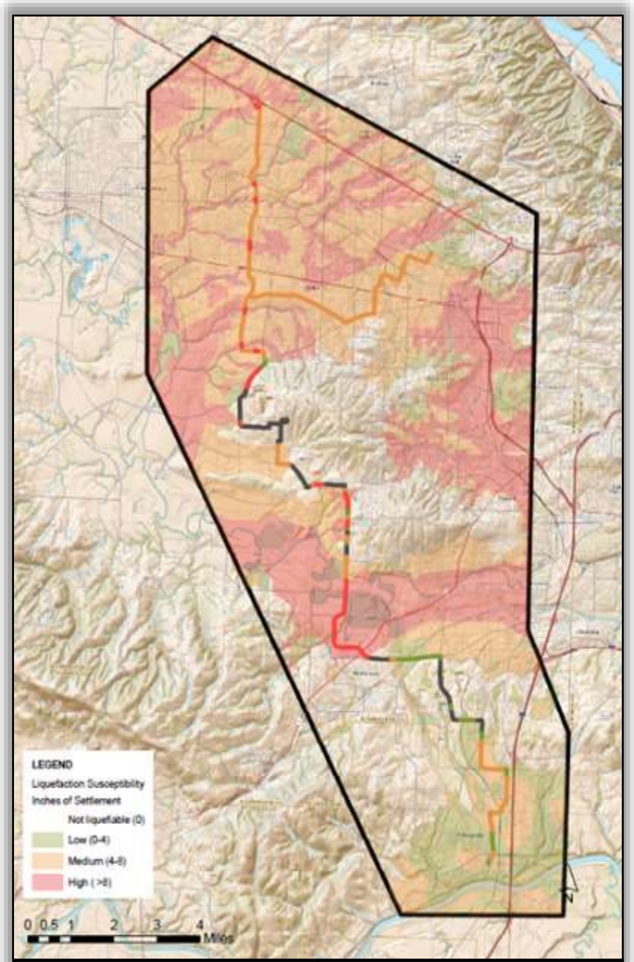
Settlement Threshold Analysis

Provides design guidance on where the use of lap welded and butt welded joints is appropriate based on anticipated vertical differential ground settlement

Allowable Differential Settlement Thresholds for 66-inch Diameter Pipe*

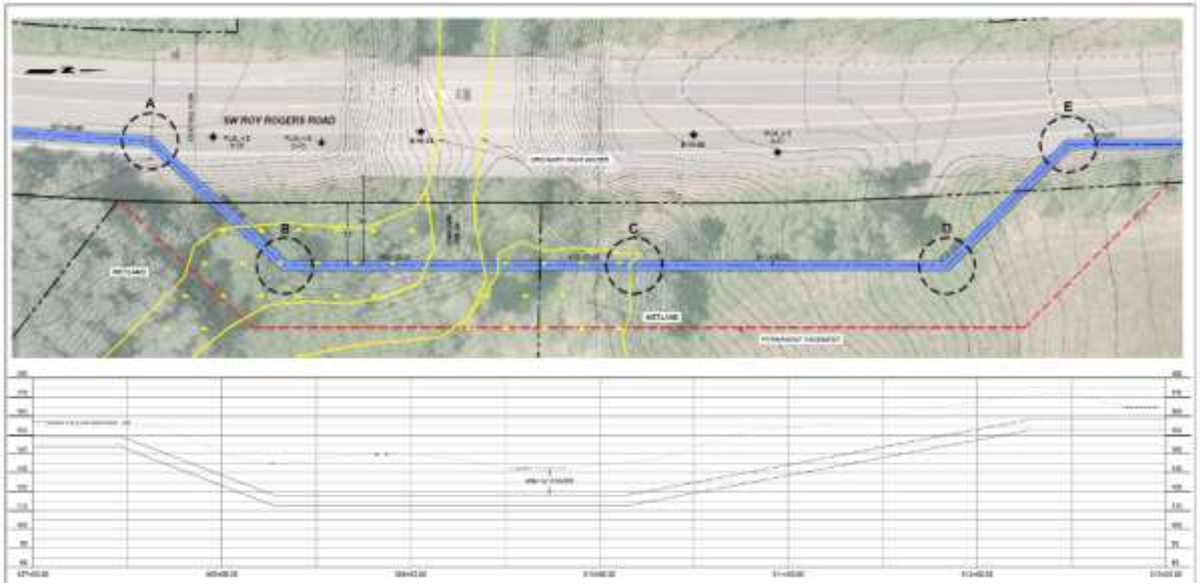
Pipe Wall Thickness (in)		Bearing in Liquefiable Soil		Bearing in Soil Crust	
		Lap Joint (in)	Butt Welded Joint (in)	Lap Joint (in)	Butt Welded Joint (in)
5/16	0.3125	5	15	3	6.5
3/8	0.3750	6	18	4	7
1/2	0.5000	9	20	5	8.5
5/8	0.6250	12	20	6.5	9.5
3/4	0.7500	17	20	8	10.5

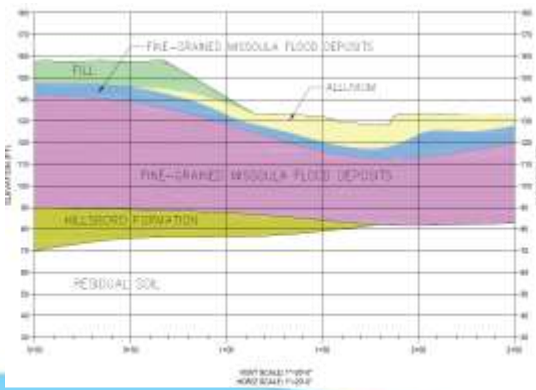
* These values are specific to WWSP soils and site conditions. Allowable differential settlement values will vary depending on soils present, corresponding response to settlement, and other considerations.

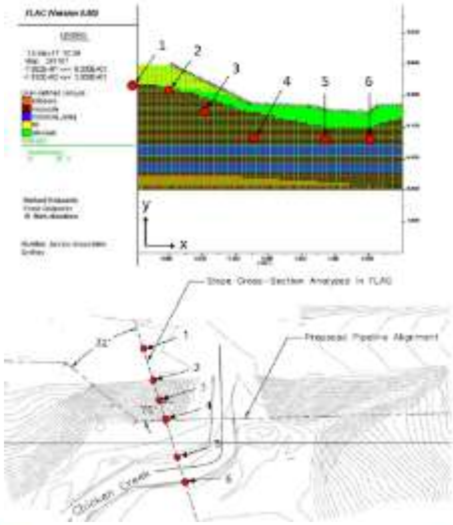


% of Alignment	Hazard
100%	Ground shaking
~60%	Settlement
~10%	Lateral movement

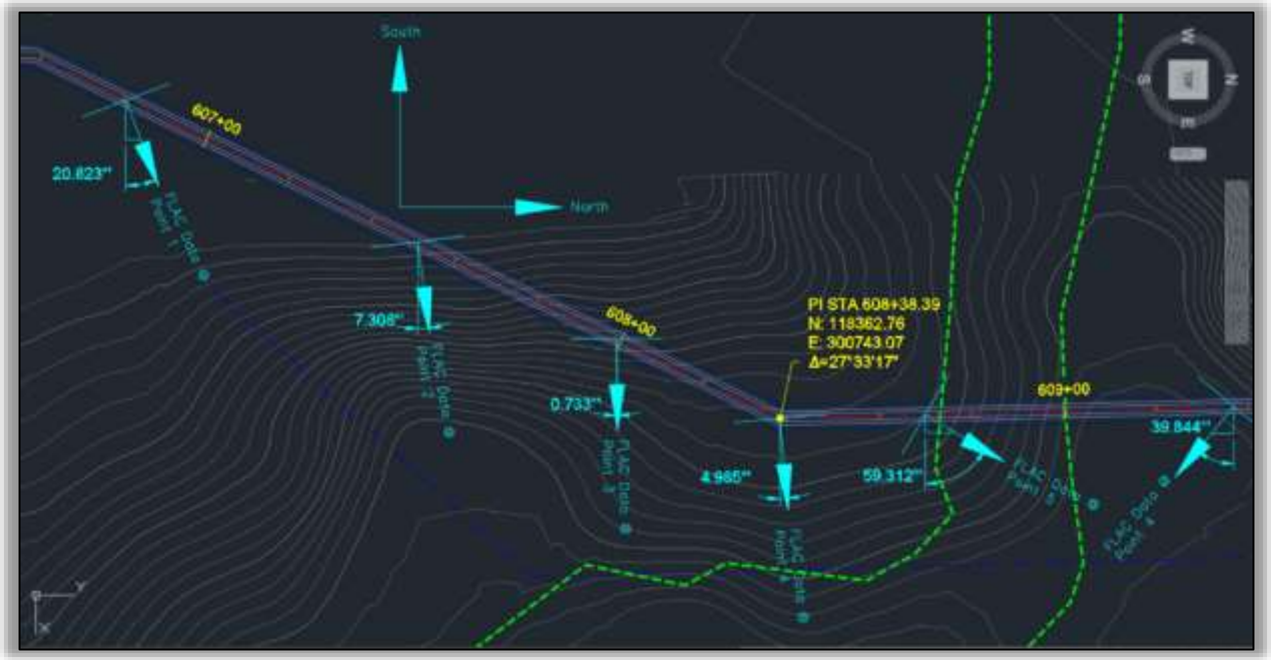
Lateral Spreading Analysis – Ground Deformations

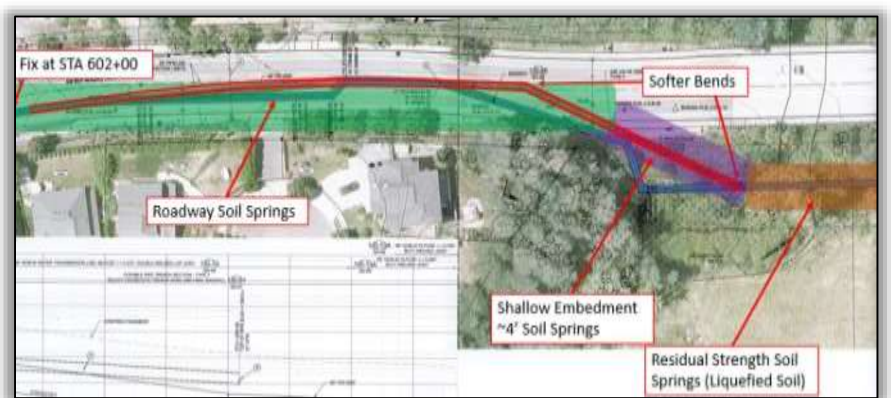


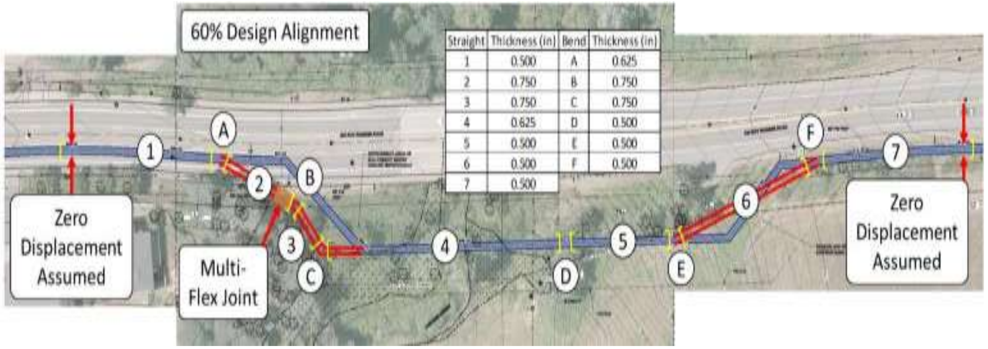




Lateral Spreading Analysis – Pipe Model

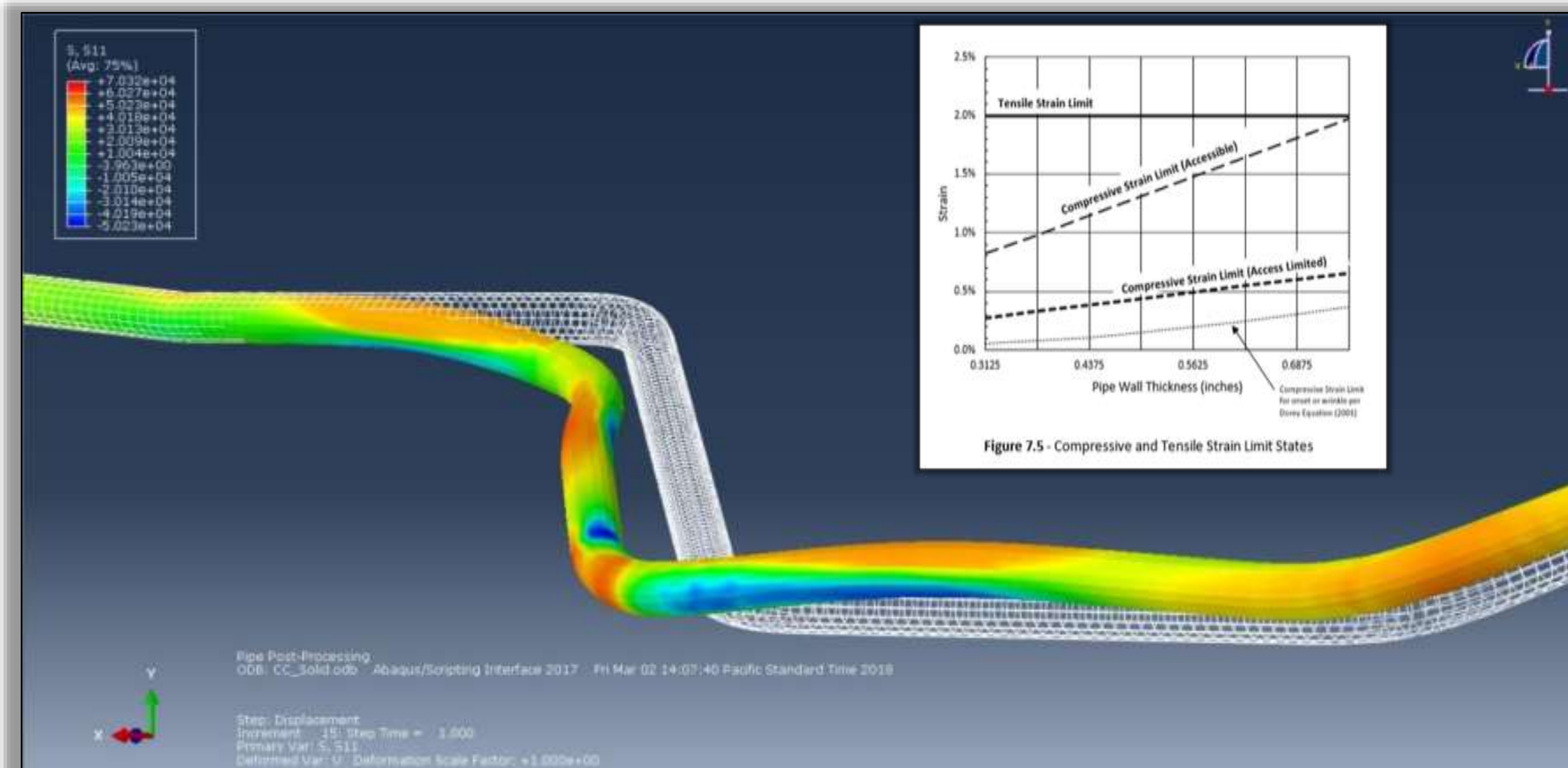




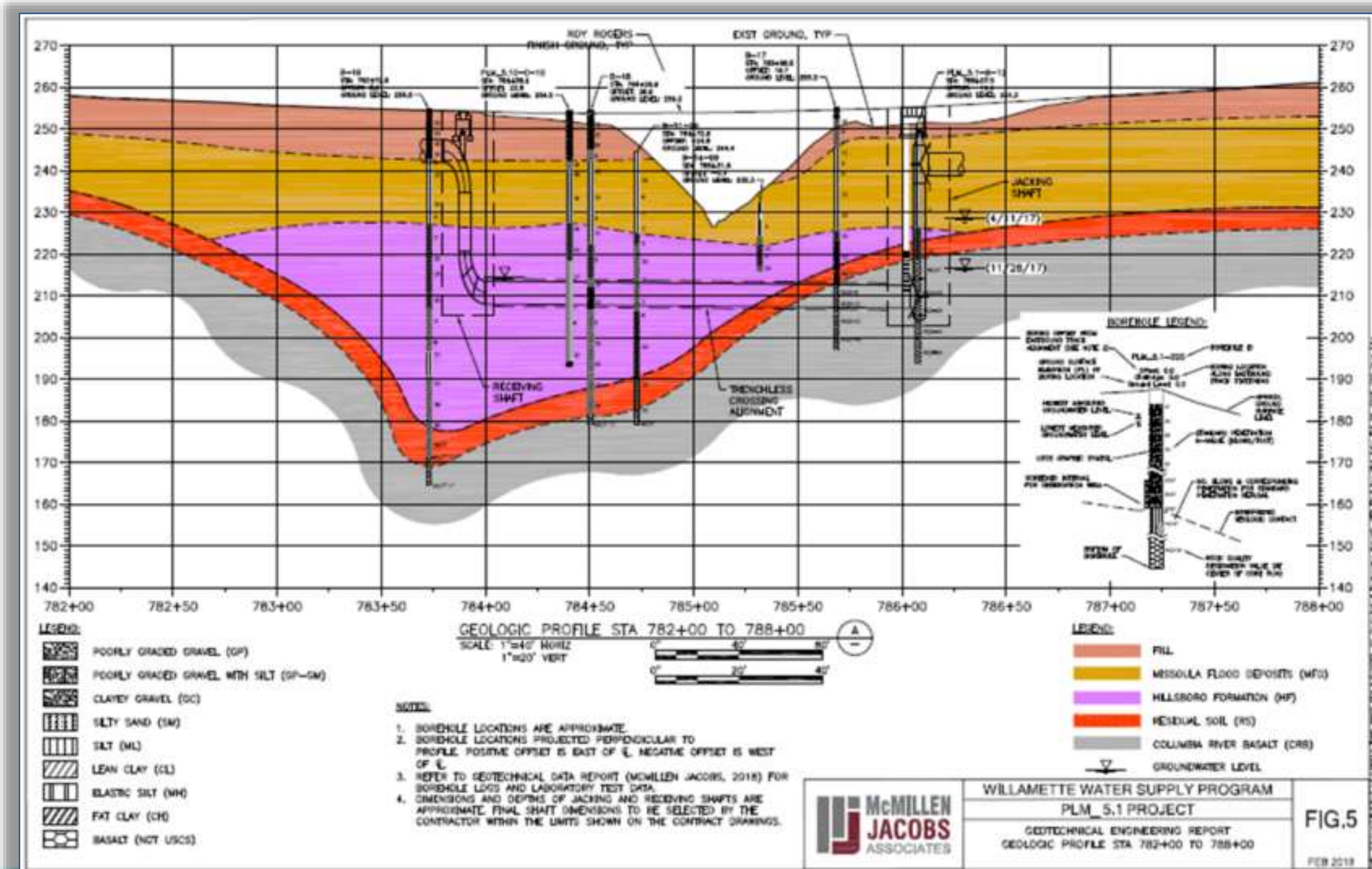


Straight	Thickness (in)	Bend	Thickness (in)
1	0.500	A	0.625
2	0.750	B	0.750
3	0.750	C	0.750
4	0.625	D	0.500
5	0.500	E	0.500
6	0.500	F	0.500
7	0.500		

Lateral Spreading Analysis – Pipe Design



Abrupt Offset



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Abrupt Offset Analysis

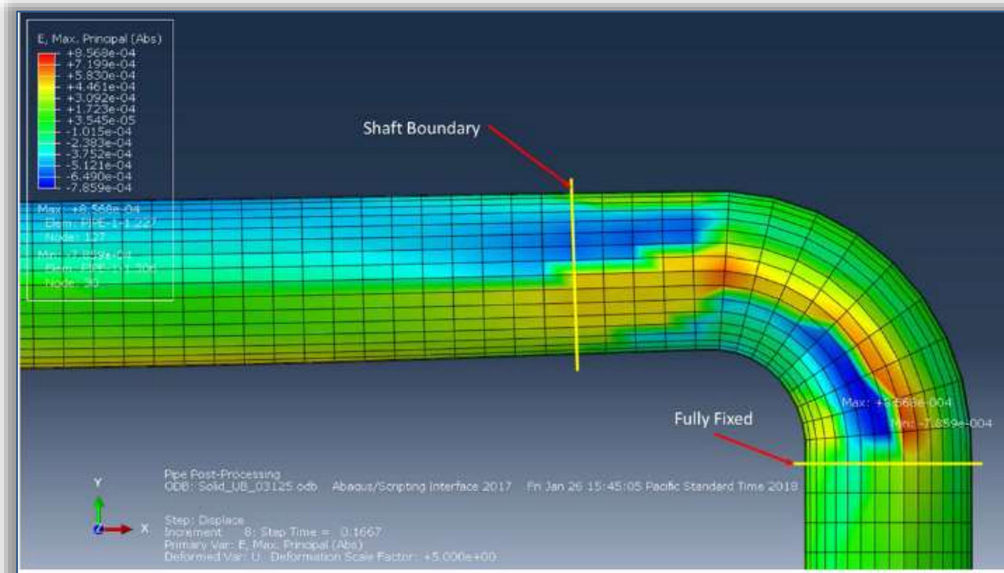

Figure 14: Max Tensile and Compressive Strain in Pipeline (Occurring in 90-Degree Bend).

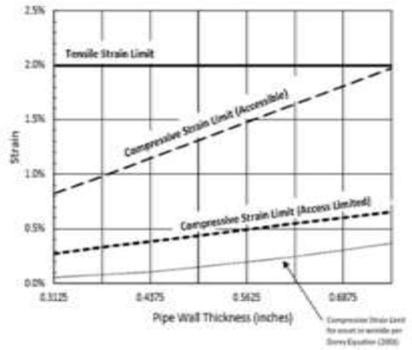

Figure 7.5 - Compressive and Tensile Strain Limit States

- Max Compressive Strain: 0.28%
- Max Tensile Strain: 0.24%

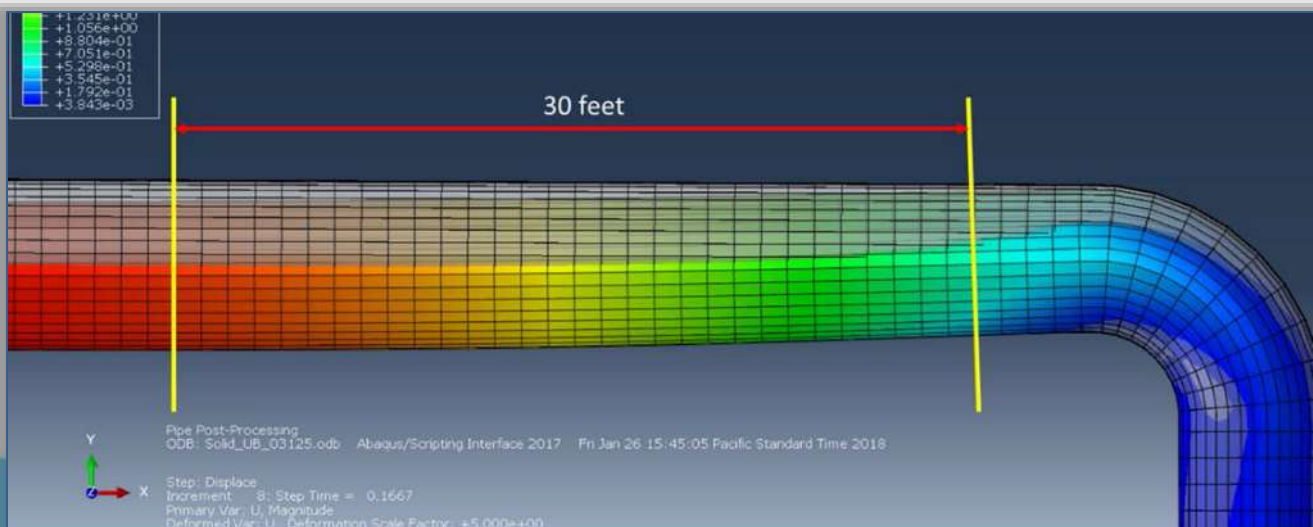

Figure 13: Distance Beyond Receiving Shaft Wall Until Pipeline Displacement Matches Vertical Soil Settlement

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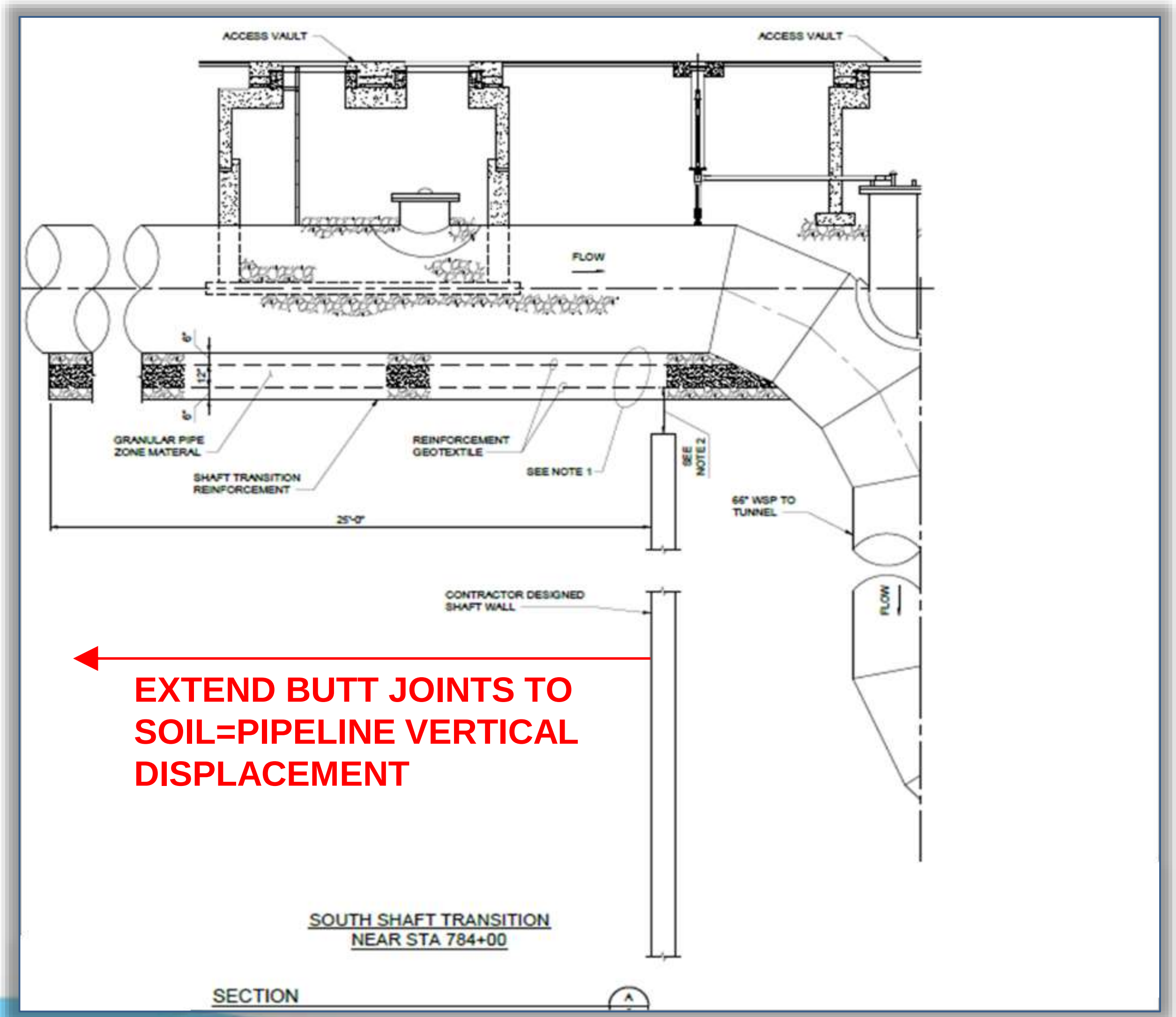
Abrupt Offset Design Mitigation



Thank you!

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