

Seismic Design Quality Control Practice to Improve Overall Seismic Performance of Large Water Transmission System Pipelines & Facilities

AWWA PNWS Conference - April 29, 2022

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Engineering and Construction Manager
Willamette Water Supply Program

Outline

- Willamette Water Supply Program Background
- Expert Advisors, Workshops, & Approach
- Seismic Guidelines
 - (MDR Checklists, Pipeline Limit States, Inaccessible Areas, CML Checks)
- Facilities Specific Considerations
 - (Project specific resilience workshops & meetings, Inaccessible Areas, Peer Review, ASCE 7 vs. ASCE 41 review approach, Raw Water Facilities Physical Model Witness Test, Seismic Certification Checklist)
- Seismic Ground Shaking QC Tool
- GIS Hazard Tool
- Concluding Remarks

Willamette Water Supply Program

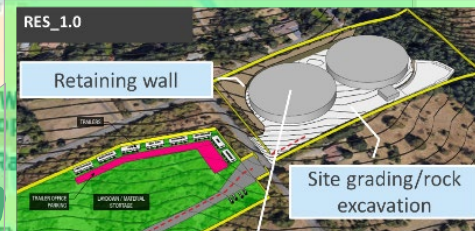
Mission Statement: Provide a cost-effective, reliable and resilient water supply system by July 2026, that benefits current and future generations of the communities we serve and supports a vibrant local economy.



30+ Miles of 66" & 48" Welded Steel Pipelines

It's important to think about this as a "system" when considering seismic resilience

Willamette Water Supply
Our Reliable Water



15 MG Storage Tanks



New Water Treatment Plant



Modified River Intake

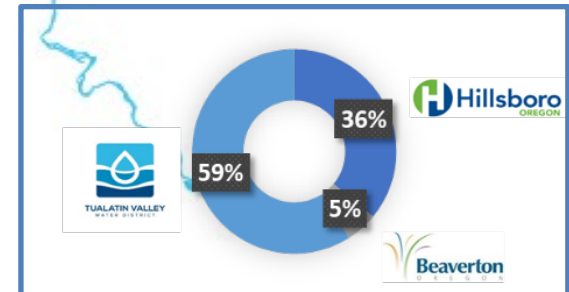
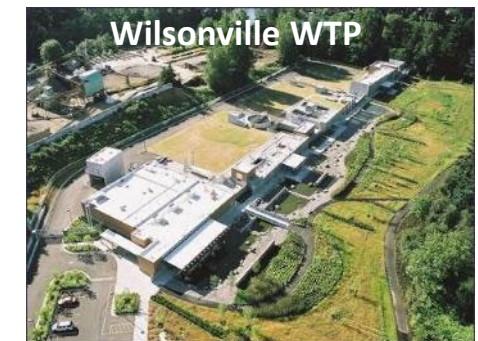


Image from the Regional Water Providers Consortium

Expert Advisors, Workshops, & Approach

- Needed to figure out our approach to incorporating seismic resilience in the design:
 - Assembled internal team to help
 - Review of existing projects
 - Identified where to place responsibility
 - Identified owner minimum requirements
 - Identified design consultant scope of work items
 - Special seismic reviews
 - Seismic workshops
 - Use of checklists
 - Future activities involving “Operations” & “Resiliency Planning”
 - Seismic experience & approach important part of design consultant selection



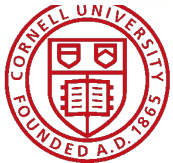
Expert Advisors, Workshops, & Approach

Involved Literature Review

American Lifelines Alliance



Pipeline Research
Council International
LEADING PIPELINE RESEARCH



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RECLAMATION



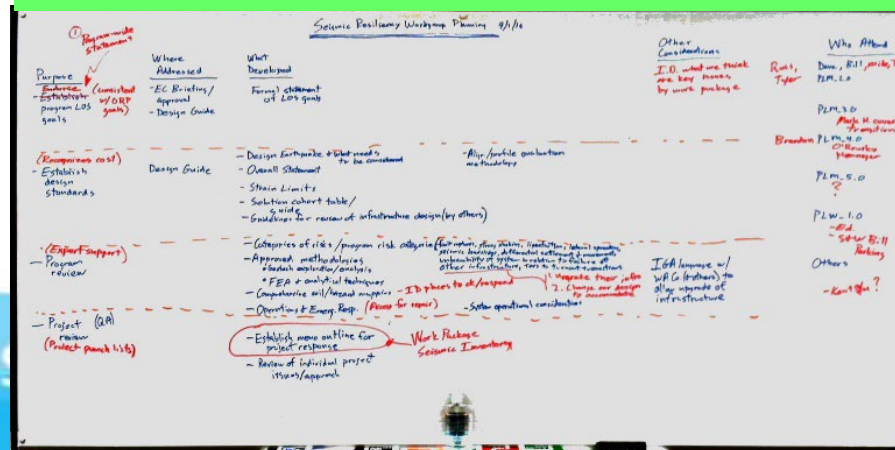
Engaging Outside Seismic Experts



Held a Series of Seismic Resiliency Workgroup Meetings

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Planning Out Our Approach



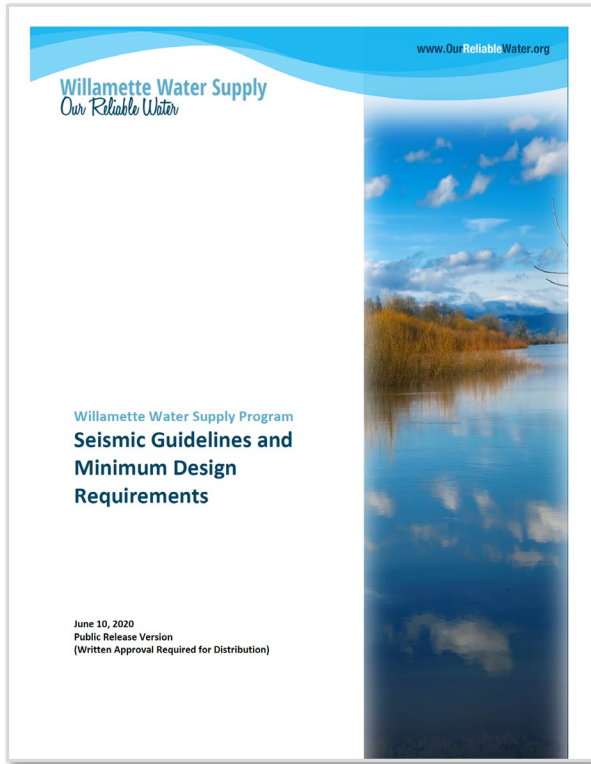
WWSP Seismic Resiliency Workgroup
(SRWG) Meeting No. 1

October 7, 2016



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Expert Advisors, Workshops, & Approach



June 10, 2020, Version 1.1

(First release June 8, 2018)

Seismic Design Framework (at the core of the seismic guidelines):

- Step 1** – Identify Service Priorities
- Step 2** – Establish Level of Service Goals
- Step 3** – Establish Design Earthquake
- Step 4** – Evaluate Project Specific Seismic Hazards
- Step 5** – Establish Design Standards and Methods
- Step 6** – Design for Seismic Risk Mitigation

These guidelines support consistency across all the project designs

Seismic guidelines included the use of checklists for the consultant to use during their design development

Expert Advisors, Workshops, & Approach

Based on advice from Dr. O'Rourke early in the development of our seismic guidelines (2016):

- *What you do should be technically defensible*
 - *It also needs to be practical to implement*
 - *Peer review and independent quality control checks are crucial*
- *You should be able to explain what you're doing to a non-technical audience*
 - *You need to understand clearly your performance objectives, and then*
 - *Be able to communicate what you're doing and why in simple terms*
- *Focus your design effort in the most problematic locations*
 - *Targeting the right level of design on the site-specific seismic hazard*
 - *Allows you to implement seismic resiliency in a cost-effective manner*



Dr. Thomas O'Rourke

Seismic Guidelines

- Recognized the Need for Checklists
 - Supports consistency across the program
 - Makes “Design Consultant” have to report out
 - Allows “Owner” to review understanding and approach to seismic issues

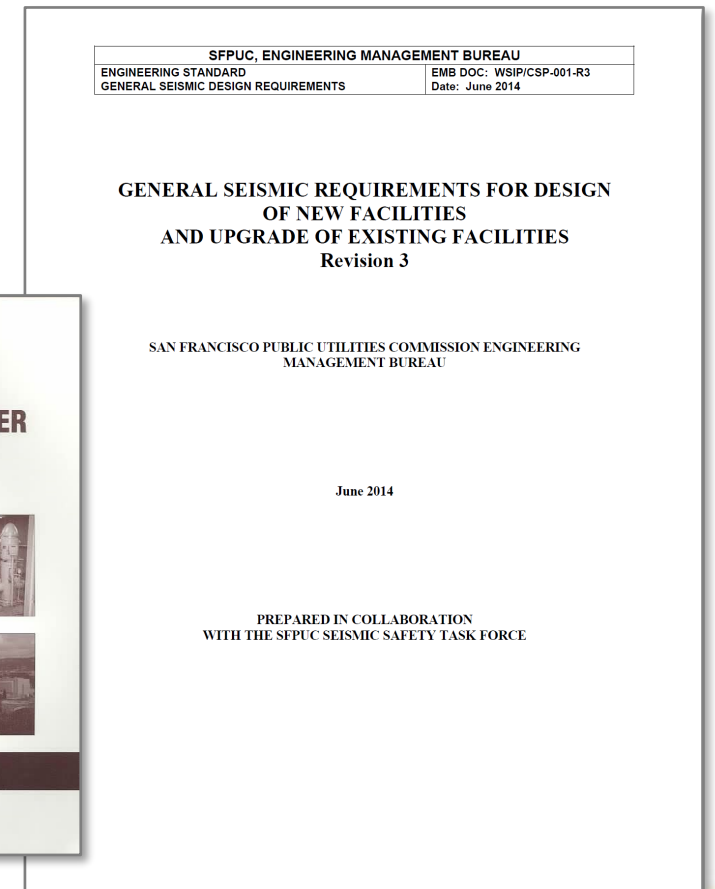
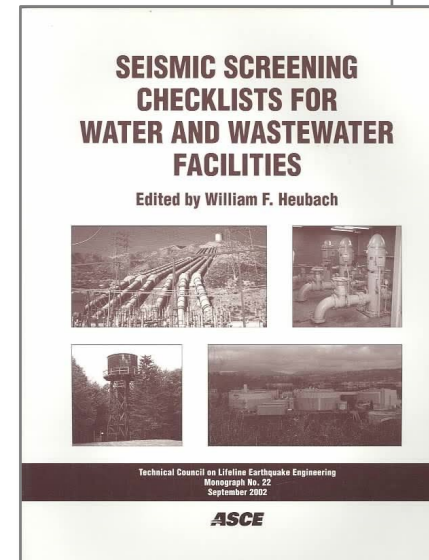
Evaluate Project Specific Hazards

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 Rupture		
C. Nearby infrastructure by others designed to lesser standards (Section 6.11)		
D. Other applicable hazards (Section 6.12)		

Seismic Guidelines

- Recognized the Need for Checklists
 - Supports consistency across the program
 - Makes “Design Consultant” have to report out
 - Allows “Owner” to review understanding and approach to seismic issues



Seismic Guidelines

- Minimum Design Requirement Checklists



“I came away... with a kind of theory: under conditions of complexity, not only are checklists a help, they are *required* for success.”

Atul Gawande

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Guideline Section	MDR	Description	Seismic Design Minimum Requirements for Analysis and Reporting	Analyses Performed	Analyses Meet Requirements (Y/N)	Results
Section 6.2 Geotechnical Site Characterization for Seismic Hazards	MDR 6.2.1	Spatial Variability	Describe how the spatial variability of potentially liquefiable soils was considered and describe the classification of soil layers that are expected to be liquefiable.			
	MDR 6.2.2	Soil Property Variability	Describe how variations in soil properties were established.			
	MDR 6.2.3	Field Measurements and Lab Data	Describe how field measurements and laboratory testing have been incorporated into the seismic hazard analysis and site-specific site-response analysis.			
Section 6.5 Residual Strength Parameter	MDR 6.5.1	Liquefaction Hazard Assessment	Describe approach used as part of liquefaction hazard assessment and results including soil characterization. Also, describe liquefaction triggering procedures used, any discrepancies in results noted between methods, and how discrepancies were resolved.			
	MDR 6.5.2	Factors of Safety for Liquefaction and Residual Strengths	Describe results of factor of safety calculations for liquefaction. Include assumptions for undrained residual soil strengths.			
Section 6.6 Liquefaction Induced Settlement	MDR 6.6.1	Liquefaction-Induced Settlement	For design purposes use professional judgment regarding use of the empirical based results for predicted liquefaction-induced settlement except where cyclic direct shear tests are performed to establish more refined results. Describe procedures used to estimate liquefaction-induced settlement, the expected magnitude, any discrepancies noted, and how resolved.			
Section 6.7 Lateral Spreading	MDR 6.7.1	Lateral Spreading	Identify where lateral spreading is expected, procedures used to screen for lateral spreading, estimate of expected maximum movement, and how mitigated.			
Section 6.8 Soft or Weak Soils Below Pipe	MDR 6.8.1	Soft or Weak Soils Below Pipe	Identify where soft or weak soils are expected below the pipe or other infrastructure, procedures used to screen for soft or weak soils, estimate of expected maximum movement, distribution of lateral spreading ground displacements, and/or how mitigated.			

March 5, 2018 Page 4 Seismic Guidelines and Minimum Design Requirements

Guideline Section	MDR	Description	Seismic Design Minimum Requirements for Analysis and Reporting	Analyses Performed	Analyses Meet Requirements (Y/N)	Results
Section 6.8 Soft or Weak Soils Below Pipe	MDR 6.8.1	Soft or Weak Soils Below Pipe	Identify where soft or weak soils are expected below the pipe or other infrastructure, procedures used to screen for soft or weak soils, estimate of expected maximum movement, and how it was mitigated.			
Section 6.9 Seismically-Induced Landslides	MDR 6.9.1	Seismic Slope Stability	Identify where seismic slope instability or flow failure is expected, evaluation procedures used, estimated maximum extent and magnitude of slope movement, expected additional loading on infrastructure, and how it was mitigated.			
Section 6.10 Abrupt Offsets	MDR 6.10.1	Abrupt Offsets	Describe expected types of abrupt offsets, evaluation procedures used, expected movement, and how they were mitigated.			
Section 6.11 Nearby Infrastructure by Others Designed to Lessor Standards	MDR 6.11.1	Adjacent Infrastructure	Describe the types of nearby infrastructure that may pose a risk to the WWSS, evaluation procedures used, and how the risks were mitigated.			
Section 6.12 Other Applicable Hazards	MDR 6.12.1	Other Hazards	Describe the types of other hazards that may pose a risk to the WWSS, evaluation procedures used, and how the risks were mitigated.			
Section 7.4 Limit State 1 for Continuous Pipe (Tensile Strain Capacity)	MDR 7.4.1	Limit State 1	Describe where Limit State 1 was considered, how evaluated, and confirm that this limit state criterion was not exceeded.			
Section 7.5 Limit State 2 for Continuous Pipe (Local Buckling – Compressive Strain Limit)	MDR 7.5.1	Limit State 2	Describe where Limit State 2 was considered, how evaluated, and confirm that this limit state criterion was not exceeded.			
Section 7.6 Limit State 3 for Continuous Pipe (Beam Buckling)	MDR 7.6.1	Limit State 3	Describe where Limit State 3 was considered, how evaluated, and confirm that this limit state criterion was not exceeded.			
Section 7.7 Limit State 4 for Continuous Pipe (Joint Resistance)	MDR 7.7.1	Limit State 4	Describe where Limit State 4 for permanent ground deformation was considered, how evaluated, and confirm that this limit state criterion was not exceeded.			
	MDR 7.7.2	Limit State 4	Describe where Limit State 4 for ground shaking was considered, how evaluated, and confirm that this limit state criterion was not exceeded (also see Section 7.9.2).			
Section 7.9.1 Weld Overmatching	MDR 7.9.1.1	Weld Capacity	Perform check on weld capacity and confirm weld strength exceed pipe strength (i.e. weld overmatching) by a minimum 15%.			

**WILLAMETTE WATER SUPPLY PROGRAM
SEISMIC GUIDELINES AND MINIMUM DESIGN REQUIREMENTS
MDR Checklist**

Project Name: _____
Project Phase: _____
Station Number: _____ to _____
Designer Consultant: _____
Engineer of Record: _____

Following completion of draft documentation, submit to the Program for review.

Final version of documentation shall be submitted to the Program and include signatures from the following key staff representing that they have reviewed and approved the content of the documentation:

- Project Manager
Name: _____ Signature: _____
Date: _____
- Seismic Task Lead
Name: _____ Signature: _____
Date: _____
- Project Engineer
Name: _____ Signature: _____
Date: _____
- Lead Geotechnical Engineer
Name: _____ Signature: _____
Date: _____
- Lead Structural Engineer
Name: _____ Signature: _____
Date: _____

Draft seismic checklist submitted at 60% design and final signed version submitted with 90% design

Seismic Guidelines

- Pipeline Limit States Identified

Limit States for Welded Steel Pipe Established for “Pressure Integrity” Performance Goal

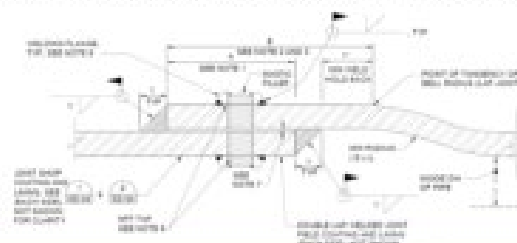
Four (4) limit states pertain to the design of continuous welded steel pipelines (Karamanos, et. al, 2017)

- Tensile Strain Capacity
- Local Buckling (Compressive Strain Capacity)
- Beam Buckling
- Joint Resistance (Joint Efficiency)

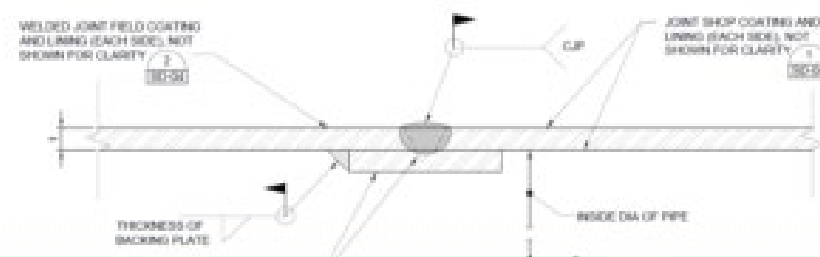


Example of “Local Buckling” Failure

ASCE ■ Figure 4.2 Tear at Wrinkle in Cladded Neoprene-lined Pipeline (Benton City, 1985)



Double Lap Welded Joint (JE = 0.50 for 66"x 3/8" wall)



Full Penetration Butt Weld Joint (Joint Efficiency = 0.90)

Seismic Guidelines

- Accessibility for repair considerations for Limit State 2 “Local Buckling – Compressive Strain Limit”



Alignment Crossing
Chicken Creek to Right

In those areas where the pipe is expected to be reasonably assessable for repairs following the design earthquake, maximum allowable design compressive strain is limited to $1.76 t/D$ (where t is the wall thickness and D is the pipe diameter), consistent with maintaining pressure integrity per the ALA (2005) and PRCI (2009) guidelines.

For areas where the pipe is not expected to be accessible or where access is limited (e.g. trenchless crossings and sensitive environmental areas), the compressive strain is limited to 33 percent of the accessible limit to achieve a minimum safety factor of 3 against the pressure integrity limit. An even lower bound compressive strain limit can be considered based on professional judgment and specific circumstances, such as locations that are particularly critical to system performance.

Seismic Guidelines

- Cement Mortar Lining Serviceability Limit State Identified

Figure 7-10 shows the limit for protecting lap welded pipe with a cement mortar lining expressed as internal pressure by site class (for Site Class BC, C, CD, D, and E). Internal pressures that fall above the line represent a condition where the addition of transient ground shaking strains could result in localized load conditions that are detrimental to the performance of cement mortar lining at the joint. Where these conditions exist, alternative linings, thicker pipe wall, and/or butt welded joints may be considered.

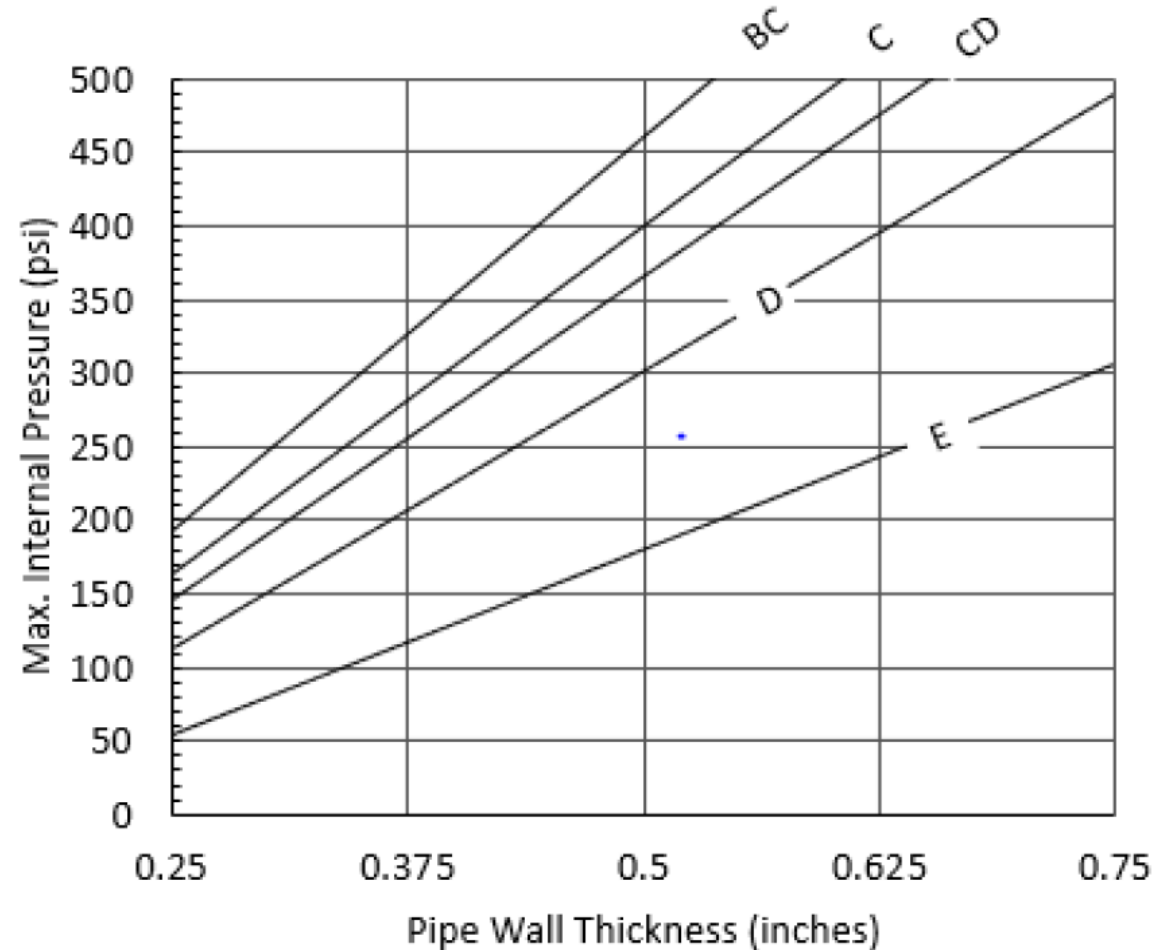
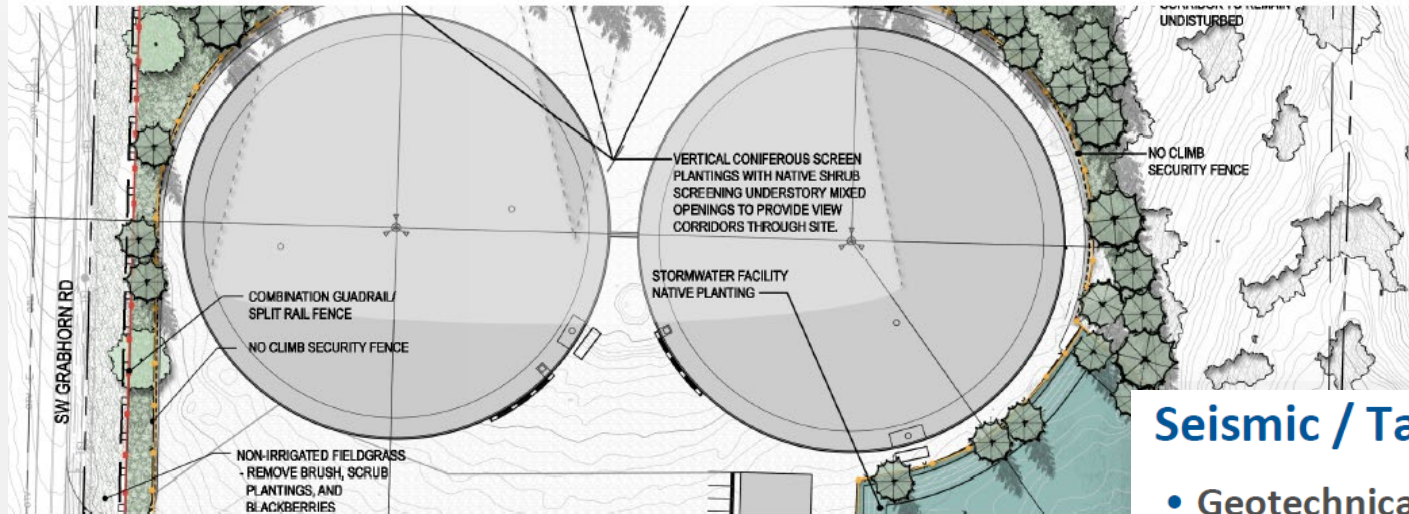


Figure 7-10 Maximum Internal Pressure for Lap Welded Pipe to Maintain Cement Mortar Lining Performance during Transient Ground Shaking for 66-inch Pipe with Lap Joints

Facilities – Project Specific Meetings



RES_1.0 Design Progress Meeting Seismic Design / Tank Design Discussion

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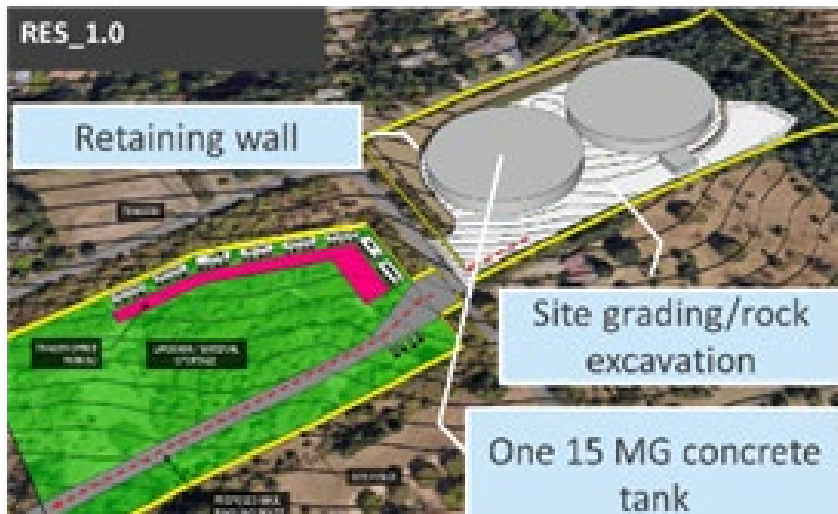
Seismic / Tank Discussion Topics

- Geotechnical / Seismic Hazards
 - Summary of Subsurface Information
 - Site-Specific Spectral Values
- Tank / Structural Design
 - Preliminary Sloshing Analysis
 - Sloshing with Aftershocks (Resiliency Follow-up)
 - Ground Motions for Structural Design
 - Tank Concrete Work
 - Corrosion Hazards / Solutions
 - Post-EQ Inspections (Resiliency Follow-up)

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Facilities – Inaccessible Areas

Reservoir



Email Correspondence Sent: Tuesday, September 08, 2020 2:11 PM

An open action item from August 13, 2020 reads as follows: “Prepare list of reservoir structure areas that are un-inspectable after design EQ and subject to 110% capacity requirement.”

The proposed list of items we plan on designing to 110% of demand due to their importance to the seismic capacity of the tank and their un-inspectable location immediately after an earthquake are:

- Plastic hinge regions of reservoir columns
- Column capital or base. Only as required to force the hinge into the columns
- Seismic Cables in walls. Both tensile capacity and anchorage to wall footings
- Strands wrapping the tank that are below ground
- Anchorages for all interior appurtenances and overflow box
- Core Wall as required for below ground strand increase

Facilities – Inaccessible Areas

Water Treatment Plant



- Addressed through:
 - Extensive structural and geotechnical subject matter expert (SME) engagement
 - Thorough review of load cases considered as part of the design process

Facilities – Peer Review

13.0 Peer Review

The peer review process is intended to be a thorough independent verification of various primary design elements involving both separate and interrelated structural and geotechnical aspects of projects identified by the WWSP. These peer reviews are intended to focus on the more complex structural, geotechnical, and seismic aspects of the various projects. The intent of the peer review is to confirm that Program seismic goals and objectives have been addressed. Key tasks of a peer review may include, but are not limited to the following:

- Confirm that primary elements of design reviewed are free of errors and omissions.
- Confirm the adequacy and reasonableness of key design assumptions.
- Confirm the intended design appears to be constructible given current technologies and construction techniques.
- Confirm project design criteria and compliance with appropriate codes.
- Confirm that the design appears to meet the seismic LOS goals for operability following the Design Earthquake and adheres to the Program seismic guidelines and minimum design requirements.

The peer review process is not intended to serve as value engineering, development of alternative but equal designs, or a non-constructive critique of work by other design professionals.

Additional subsections that follow identify responsibility of tasks by the DCs and Peer Reviewers, different levels of peer reviews, documentation required by Peer Reviewers, the schedule for peer reviews, and a description of the anticipated peer review process.

13.1 Task Responsibility

Design Consultants are solely responsible for their design and the adequacy of the design to meet the intended goals, objectives, and code requirements associated with the project. Comments by Peer Reviewers are intended to support the design process of DCs, but shall in no way relieve DCs of their responsibilities associated with their design. DCs are expected to provide appropriate documentation (as described in this section), engage in open and honest communication with Peer Reviewers to explain their design and related assumptions, and to ask clarifying questions of the Peer Reviewers to ensure their comments are correctly understood and adjudicated. DCs are expected to correct their design where deficiencies are found. Aside from the peer review process identified in this section, DCs are expected to engage its own rigorous quality control and quality assurance procedures with additional internal peer reviews as appropriate.

Peer Reviewers will be engaged by the WWSP and provide objective reviews of the DCs' design at various stages of development. Peer Reviewers will be comprised of subject matter experts within the Program's team of consultants but may also include external consultants as required. The Peer Reviewers shall provide clear and constructive comments that identify apparent deficiencies in the design, identify where ambiguity exists with the design or related assumptions, identify believed inconsistencies with code requirements, and engage in

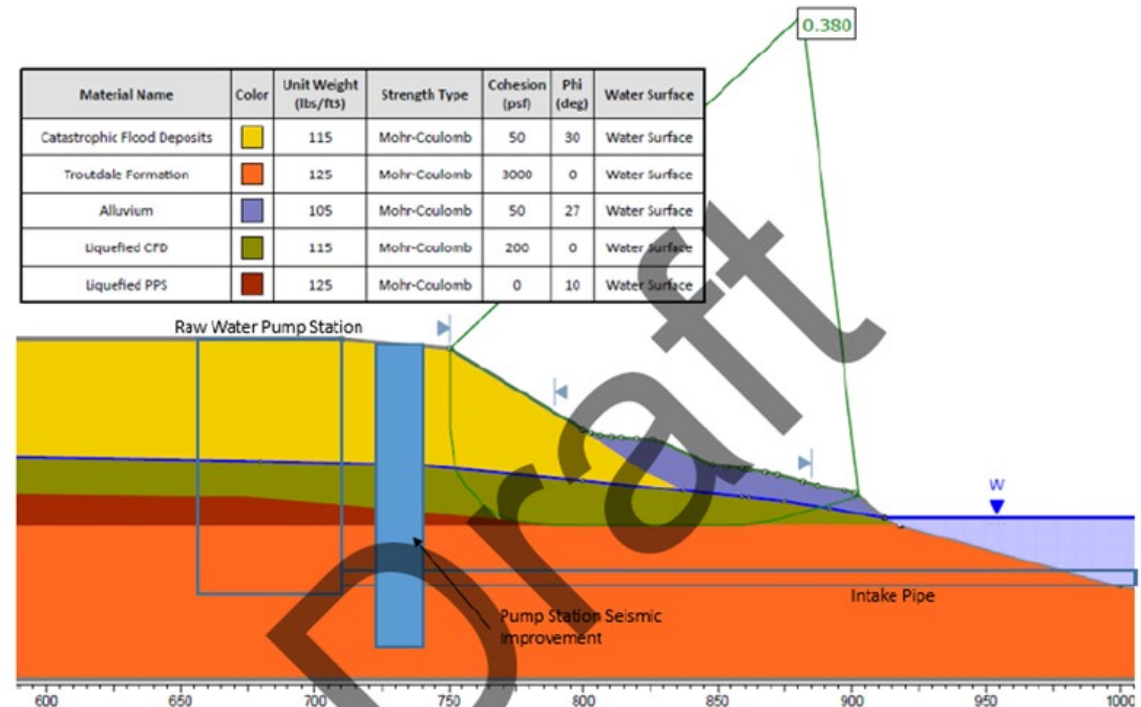
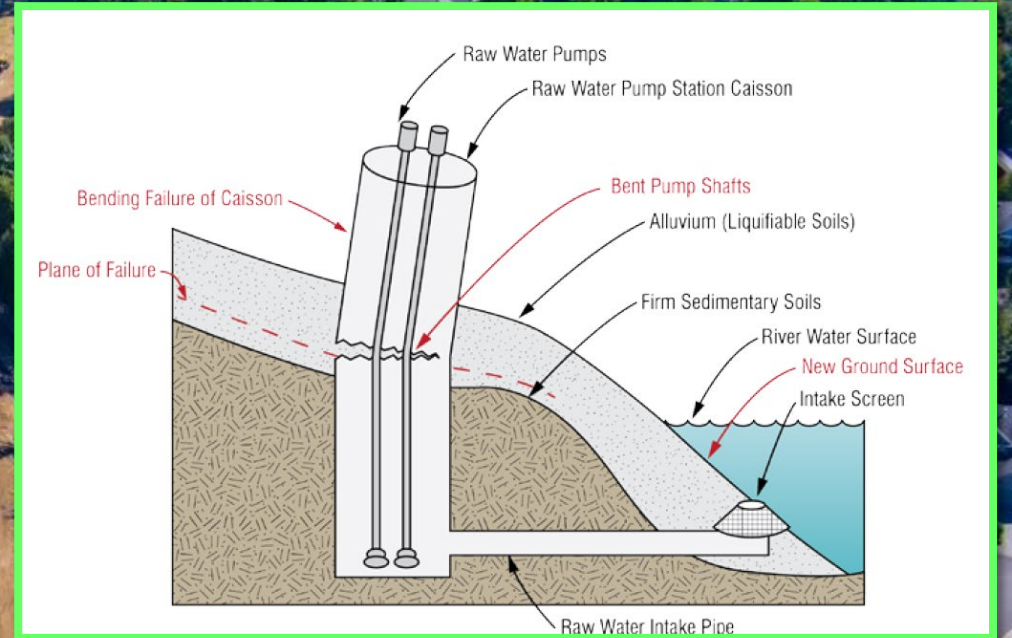
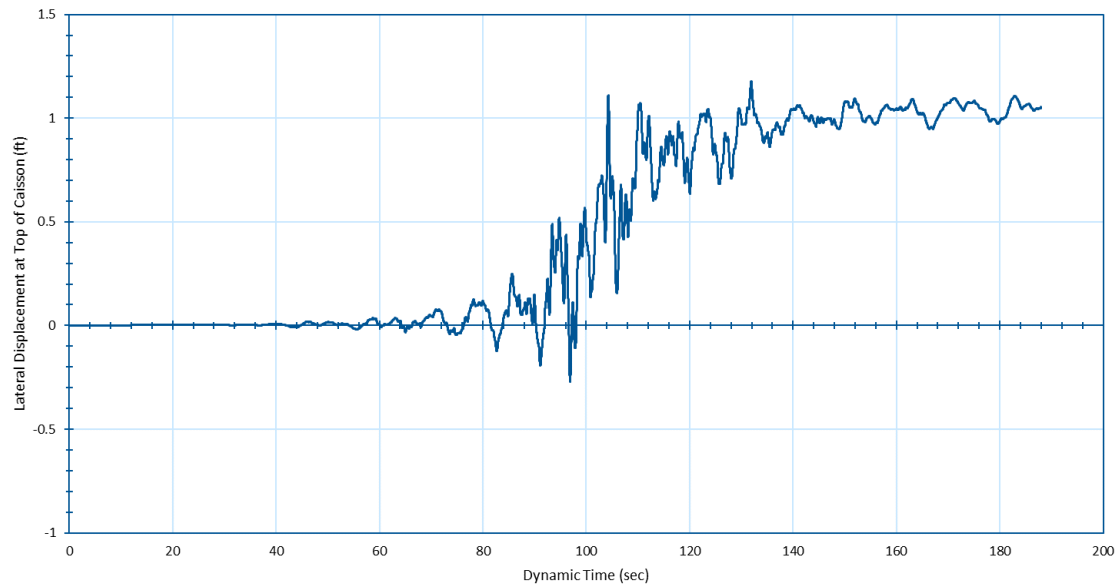
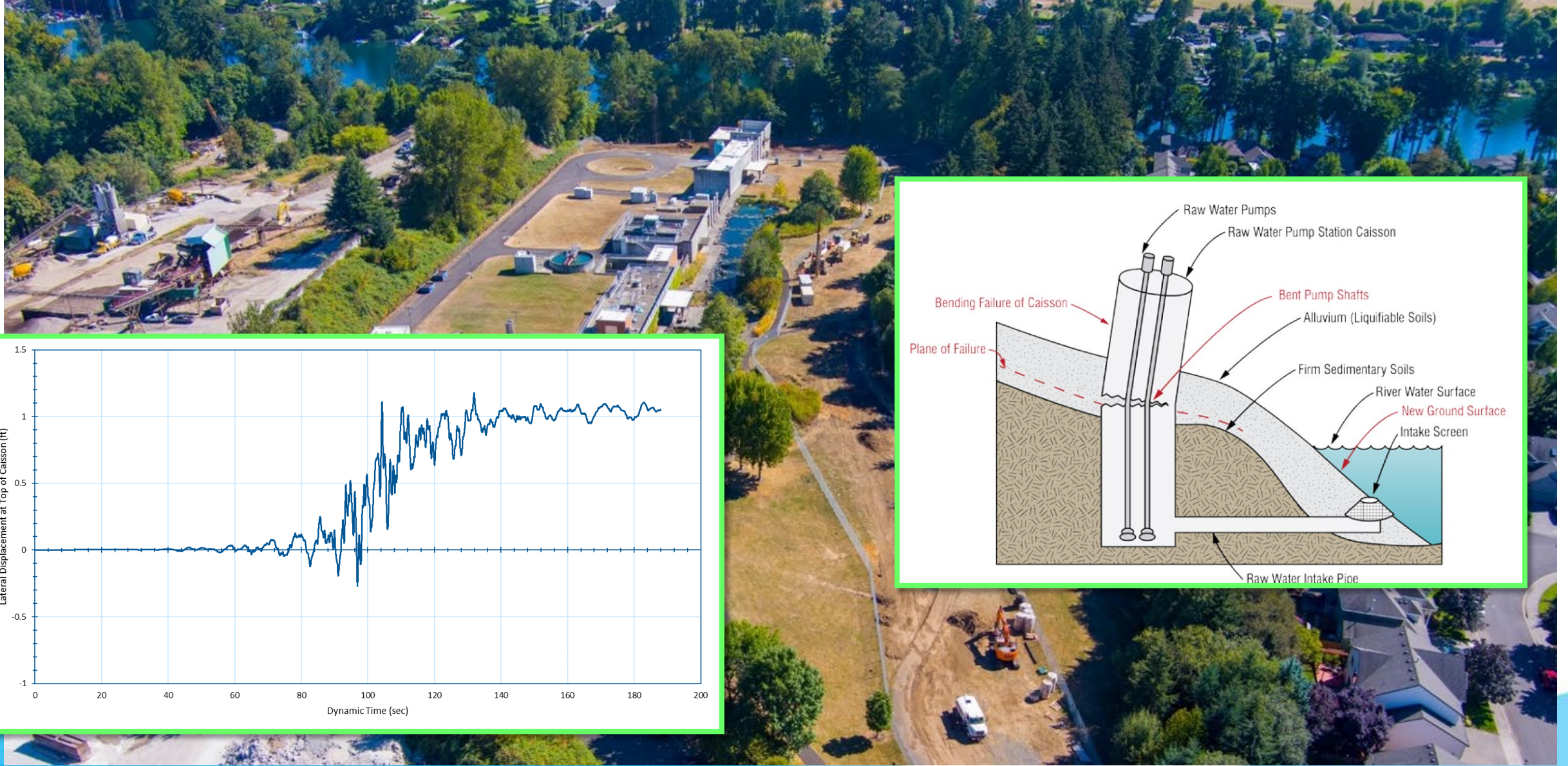


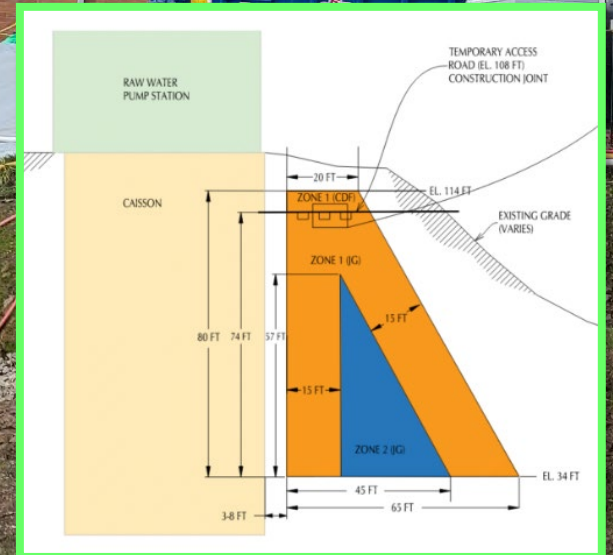
Figure 2. River Bank Post Liquefaction Stability Analysis

Facilities – Peer Review

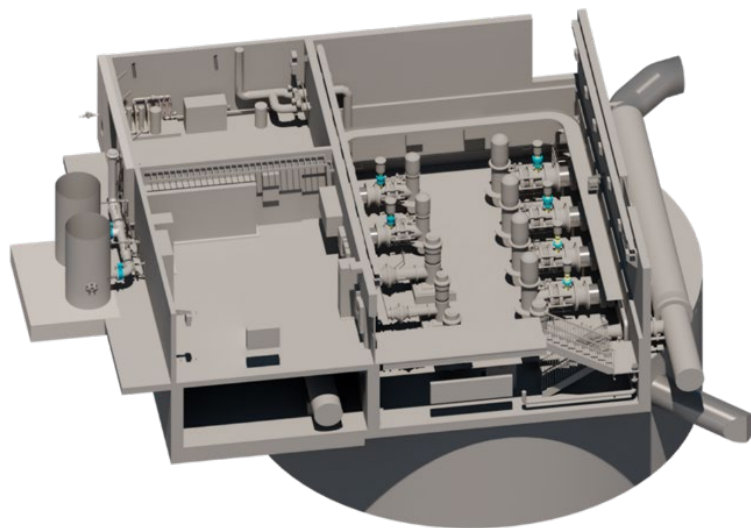


Raw Water Facilities (River Intake & Pump Station)

Angled Jet Grouting & Deep Soil Mixing (DSM)
Used to Improve the Ground along the Riverbank



Raw Water Facilities (River Intake & Pump Station)



Detailed analysis and structural modeling
of pump station building seismic
response

*ASCE 41¹ and ASCE 7
considerations for the
project*

*Pump verticality
governing criteria*

*(Less than 2-inch rotation
required for pump
operation)*

*Important for “Operational”
Performance Goal*

¹ Required for retrofitting existing structure
to our design requirements



New concrete seismic walls at RWPS

Seismic Certification Checklist

9.1.2 Critical System Identification

During preliminary design, the DC shall identify the critical systems and associated equipment, processes, controls, and other components critical to meeting the intended facility LOS goals and performance objectives. The DC shall also track and update components identified as part of the critical items through various design submittals.

Minimum Design Requirements:

MDR 9.1.2.1: Provide a complete list with a thorough description of the facility elements intended to be part of the critical systems.

MDR 9.1.2.2: Provide updates to the list through design development using various design submittals.

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Form completed by: _____
Firm worked for: _____

1.0 General

Project Name: _____ Date: _____

Equipment Description: _____

Equipment ID No.: _____

Equipment Location: _____

Equipment designation (Critical/Non-Critical Equipment)

Required Acceleration: _____ Required Importance Factor: _____

Required Additional Loading: _____
(Provide description/supporting information)

2.0 Existing Seismic Qualification (Certification Method)

1. Shake Table Testing ☐
2. Finite Element Analysis ☐
3. Experience Data (proof of "Ruggedness") ☐
4. Existing Seismic Certification (attach test information)
[Certified at full operating condition? (Y/N) If no, what condition: _____]

Date: _____

Location: _____

Acceleration: _____

Identify/describe any potential modifications desired/required for tested equipment:

_____ (Implement: Y/N)

5. None available ☐

3.0 Approach to Confirming Seismic Acceptance

- Require 1, 2, or 3 in Section 2 ☐
- Base or Vibration Isolation (may be combined with 3 if Experience Data exists for lower acceleration installations) ☐
- Acceptable downtime determined (includes repair plan/procedures, required spare parts, and storage requirements) ☐
- Implement 1 or 2 on parts of the equipment ☐

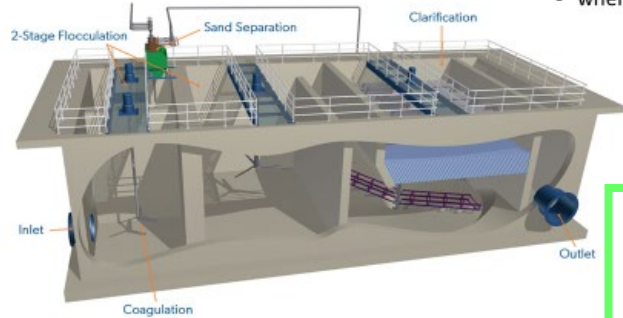
December 31, 2019

Page 3

Seismic Qualifications Checklist
and Mitigation Strategies – Version 1

Water Treatment Plant

Ballasted Flocculation

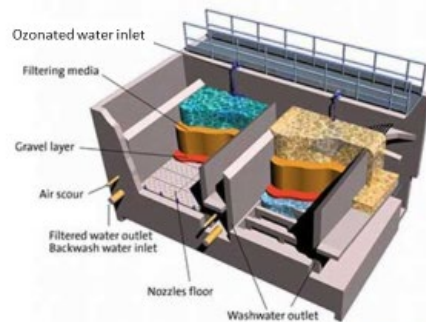


- Physical-chemical process
- Turbidity/particle removal
- Algal toxins
 - when contained in intact cells

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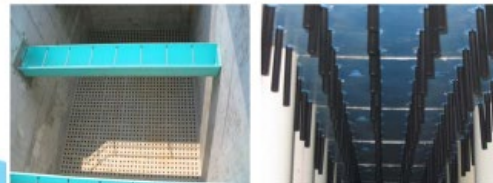
Classified as **“Critical”**
Systems (seismic
certification required)

Filtration



- Physical and biological process
- Turbidity/particle removal
- Simple organics removal (biofiltration)
- Complex organics removal (activated carbon)

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Ozonation

Liquid Oxygen Tank



- Chemical process
- Primary role: break down complex organics
 - Taste and odor
 - Algal toxins
 - Emerging contaminants (pharmaceuticals)
- Secondary role: disinfection (cyst-type organisms)



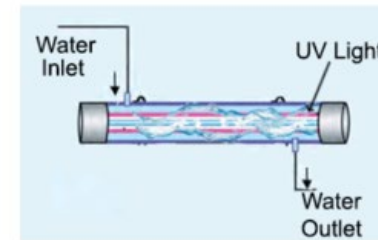
Ozonator

Continuing UST Dome Center Tank

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UV Disinfection

- Physical process
- *Giardia* and *Cryptosporidium* inactivation
- Emerging contaminant destruction when combined with hydrogen peroxide



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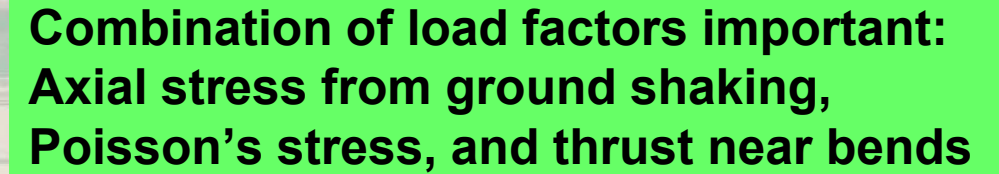
Classified as **“Semi-Critical”**
Systems
(impractical to
get seismic
certification/not
needed for
primary water
quality needs)

Raw Water Facilities Physical Model Witness Test



Seismic Hazard: *Transient Ground Shaking & Associated Joint Efficiency*

Seismic Hazard: *Transient Ground Shaking & Associated Joint Efficiency*



Site Class	Description	Shear Wave Velocity (feet/sec.)		
		NEHRP (2020)	PSHA (2017)	Weighted Average along PLM 4.3
A	Hard Rock	>5,000	-	-
B	Medium Hard Rock	3,000 – 5,000	-	-
BC	Soft Rock	2,100 – 3,000	2,500	-
C	Very Dense Sand or Hard Clay	1,450 – 2,100	1,750	-
CD	Dense Sand or Very Stiff Clay	1,000 – 1,450	1,200	-
D	Medium Dense Sand or Stiff Clay	700 – 1,000	350	496 – 852
DE	Loose Sand or Medium Stiff Clay	500 – 700	-	
E	Very Loose Sand or Soft Clay	<500	500	
F	Soils Requiring Site Response	-	-	-

Site Class DE Important Change from NEHRP (2020)

Developed Spreadsheet Tool to Assess Joint Efficiency *NEW PRACTICAL APPROACH*

Approach: Change joint type where capacity of double lap weld is exceeded

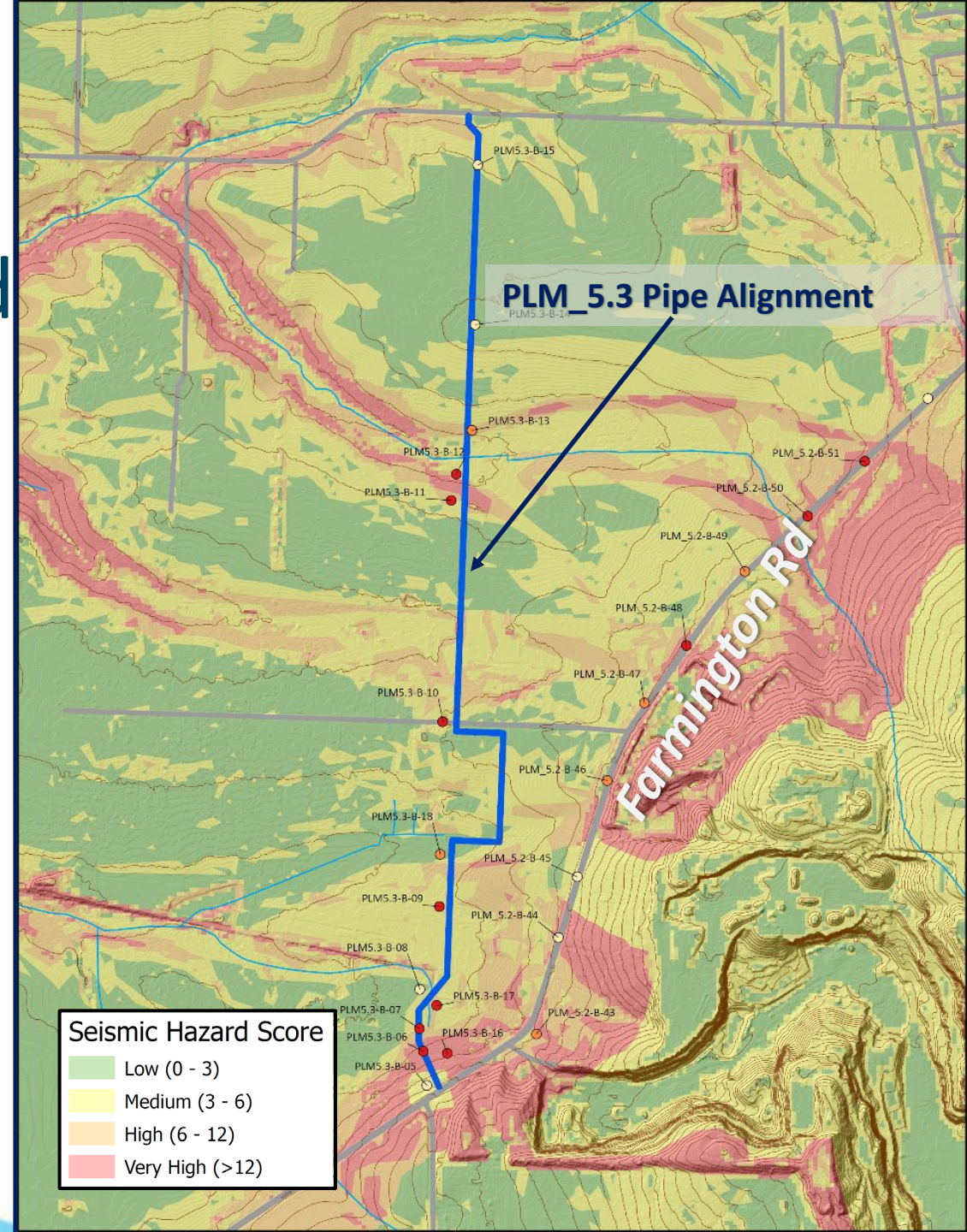
Pipeline Section PLM_5.3 – Rural Area N. of Farmington Rd

Seismic Hazard: *Liquefaction, Lateral Spreading,
Slope Failure, Soil Amplification*

O'Rourke and Lui (2012) indicate that lateral spreading can occur for distances up to 1,000 ft (300 m) away from a “free face” at slopes as little as 1.5%
ALA (2005) similar recommendations for lateral spreading within 1,000 ft from a “free face” at slopes as little as 1%

Seismic Hazard	Slope ≤ 3%	Slope > 3% - 6%	Slope > 6% - 9%	Slope > 9% - 12%	Slope > 12%
LDI ≤ 2 ft	Low	Low	Low	Medium	Medium
LDI 2 to 6 ft	Low	Medium	High	High	Very High
LDI ≥ 6 ft	Medium	High	Very High	Very High	Very High

(LDI – Lateral Displacement Index)



Concluding Remarks

- Quality control is essential for optimizing seismic resilience in the design of infrastructure
- Checklists are:
 - Effective tools to help address complex problems like resiliency
 - Support consistency across different project designs
 - Make design consultant more accountable and requires them to incorporate seismic resiliency throughout the design
- Outside experts, internal teams, and peer review are valued additions to project seismic design development
- Leadership is a fundamental underpinning for resiliency

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