



# SEISMIC DESIGN OF WATERLINES

*Bay Area pipeline Users Group  
February 8, 2024*

# Seismic Design of Water Systems

- **Doug DeVries, PE WA CA**

40 years of experience *as a contractor, consulting engineer and municipal engineer.*

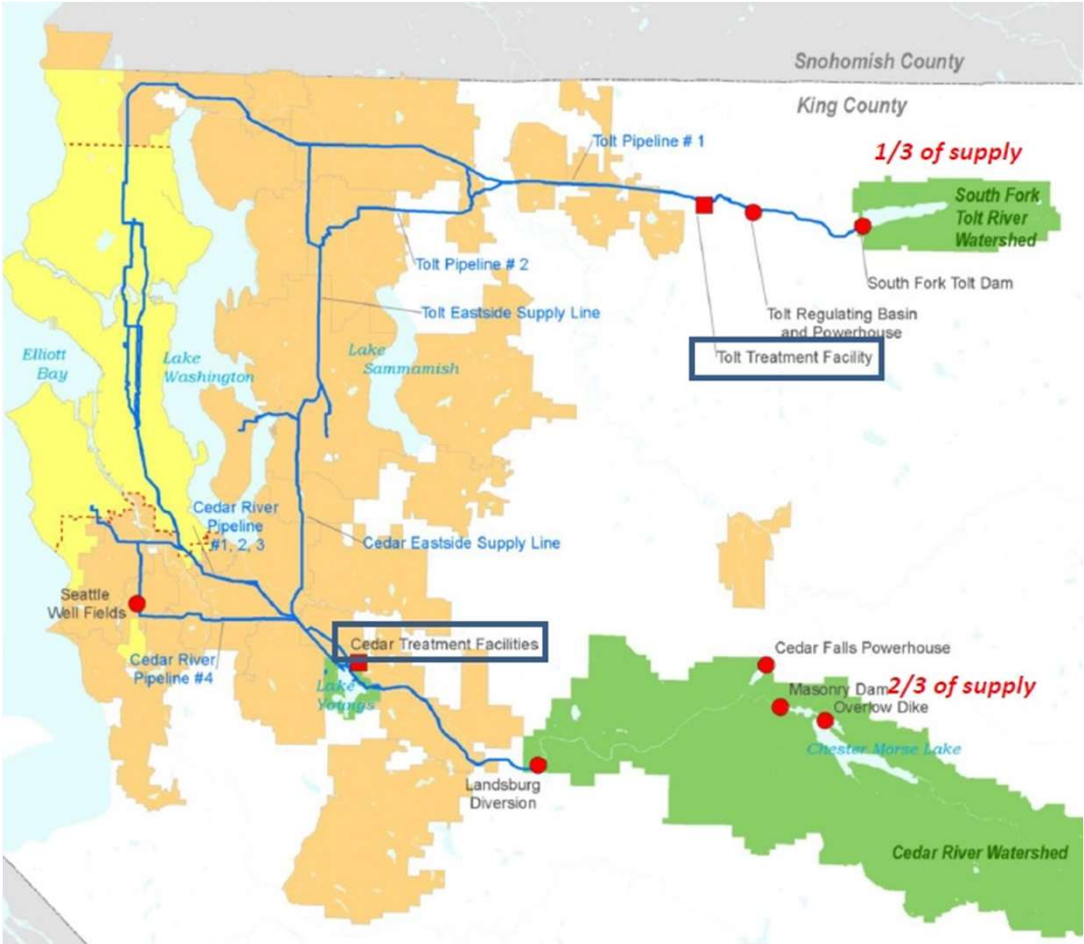


- **Sarah Merrill, PE**

5 years of experience as a civil engineer working with both public/private clients and in manufacturing. Designed two seismic waterlines.



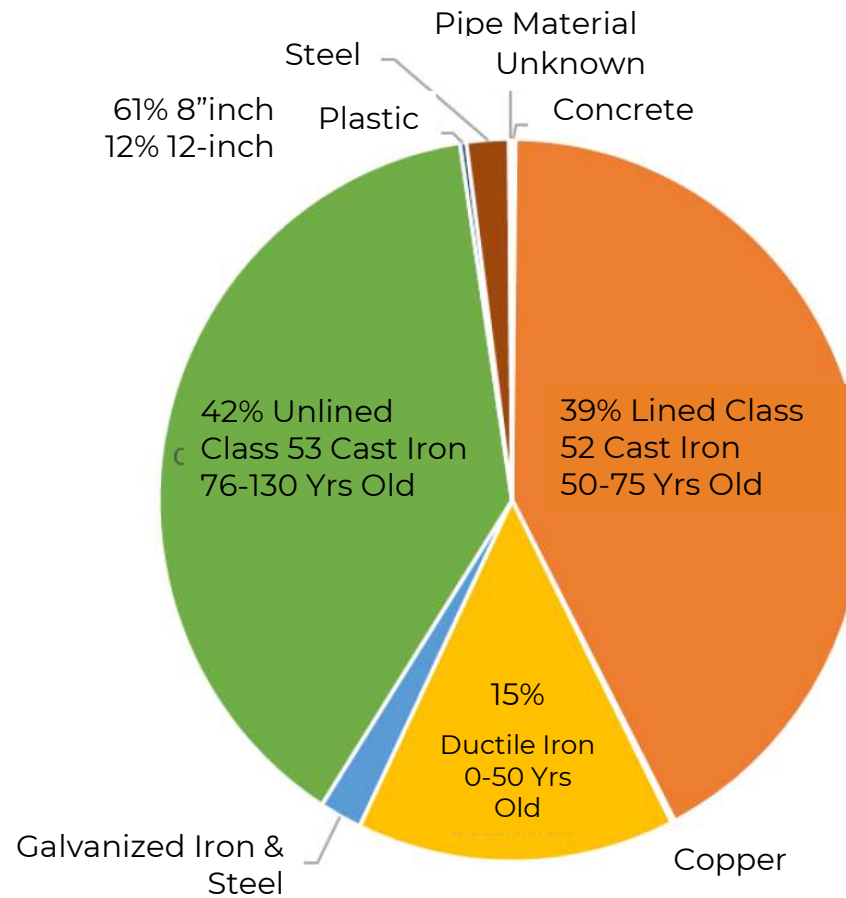
# SPU Water Transmission System



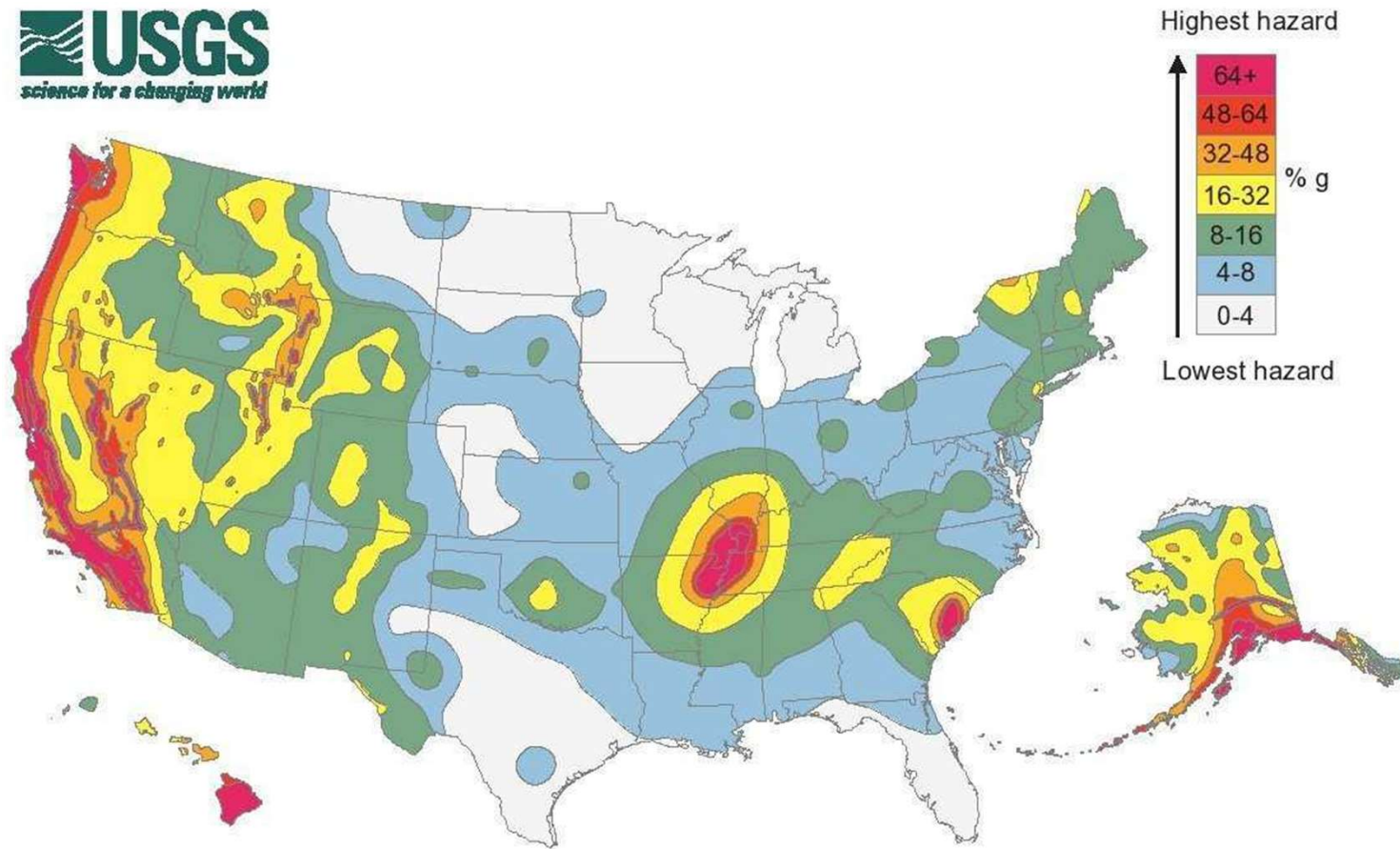
- Seattle Retail Service Area
- Wholesale Customers
- Watersheds



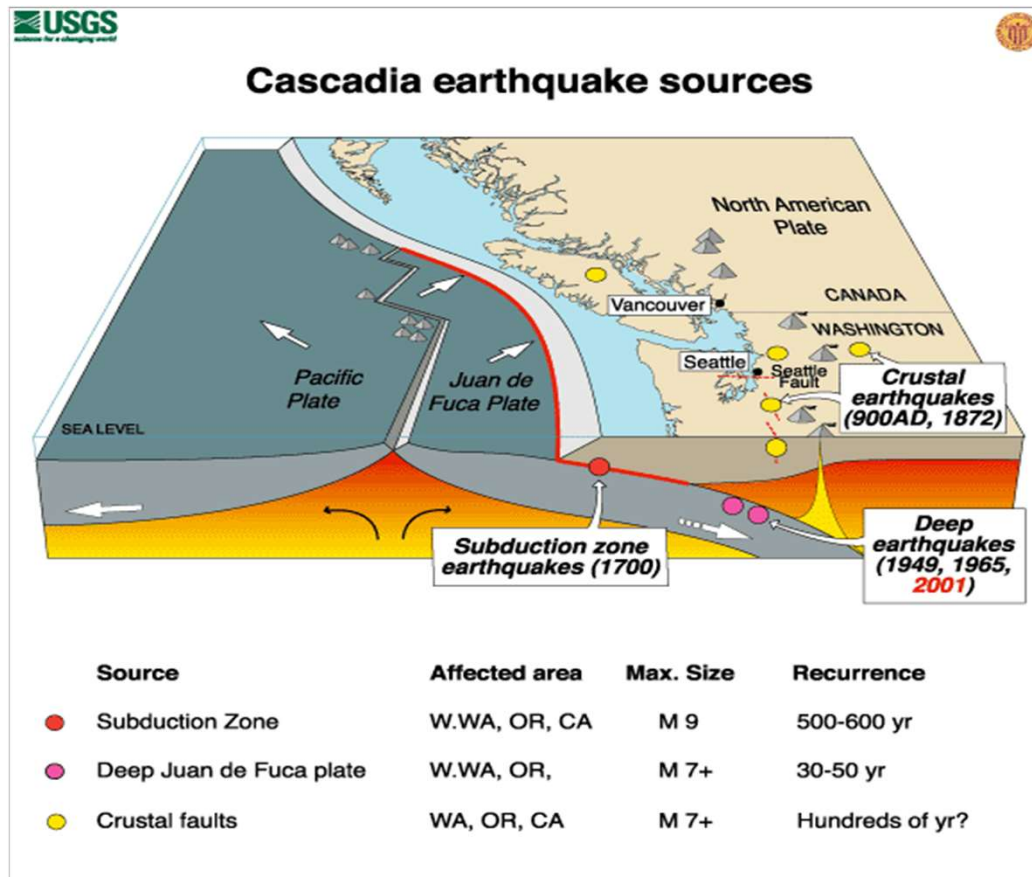
# Pipe Material in SPU Water System



# US Peak Ground Acceleration in the US



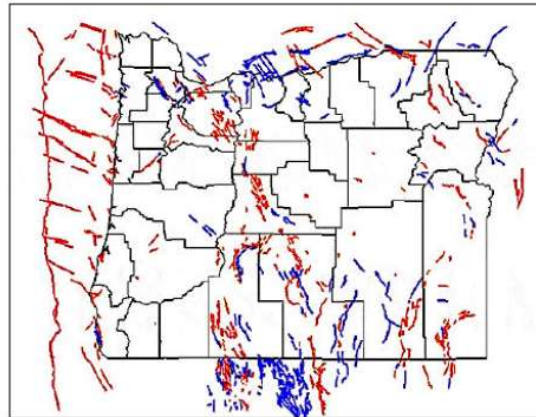
# Seismic Hazards



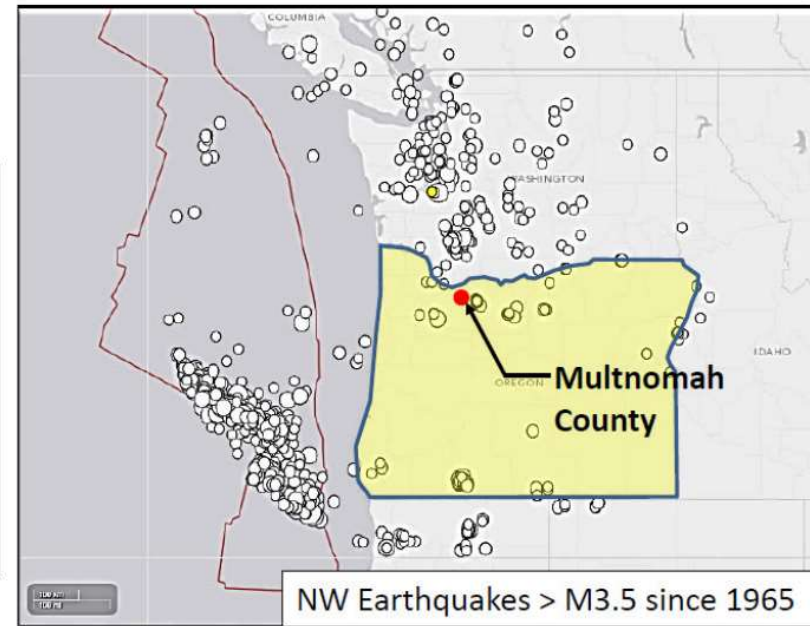
# NW Earthquake Activity

Source	Magnitude	Frequency	Latest Occurrence
Crustal	M < 5.5	Every 15–20 years	Annually
	M ≥ 5.5	???	1993: Scotts Mills & Klamath-Falls
CSZ*	M ≥ 8.0	Every 350–500 years	January, 1700
Intraplate	M = 4–7	Every 30–50 years	Feb., 2009 M4.1, Grants Pass, OR

**Note: M9.0 = 1000 x 2014 Napa EQ**



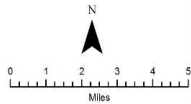
Known Oregon EQ Faults



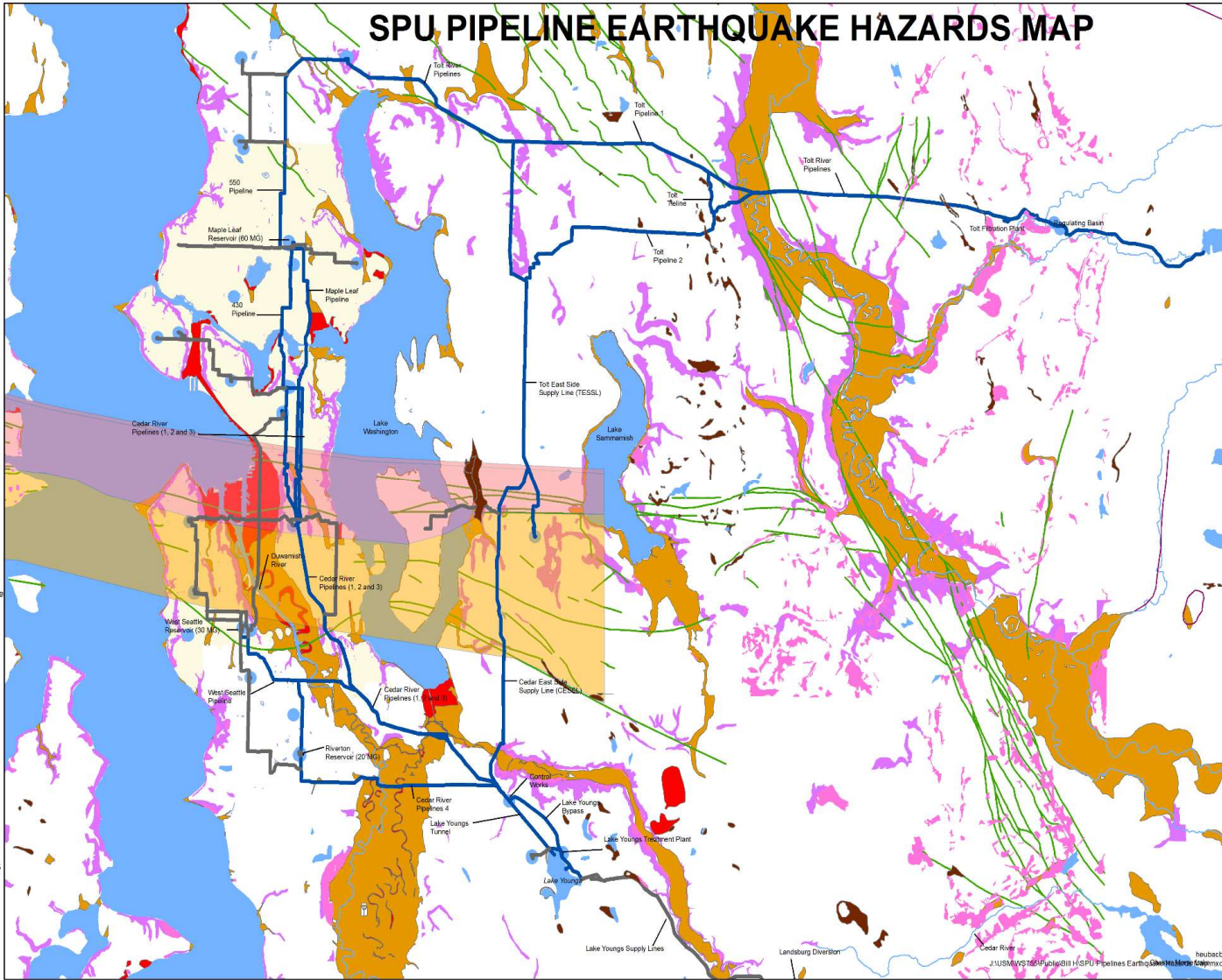
NW Earthquakes > M3.5 since 1965

# SPU PIPELINE EARTHQUAKE HAZARDS MAP

- Legend**
- Primary Backbone Pipelines
  - Secondary Backbone Pipelines
  - Seattle Fault Zone**
  - Zone A - Primary Seattle Fault Zone
  - Zone B - Back Thrusting
  - Liquefaction Susceptibility**
  - high
  - moderate
  - moderate to high
  - Known or Potential Landslide
  - Active Faults Lineaments
  - Peat



4/4/2018  
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 Coordinate System: State Plane, NAD83-91, Washington North Zone





# Portland Water Bureau Statistical Information



2 Dams



100+ miles of  
large pipe



2,300+ miles of  
Smaller dia. pipe



66 Tanks and  
Reservoirs



14,000+ hydrants



50,000+ valves



180,000 meters



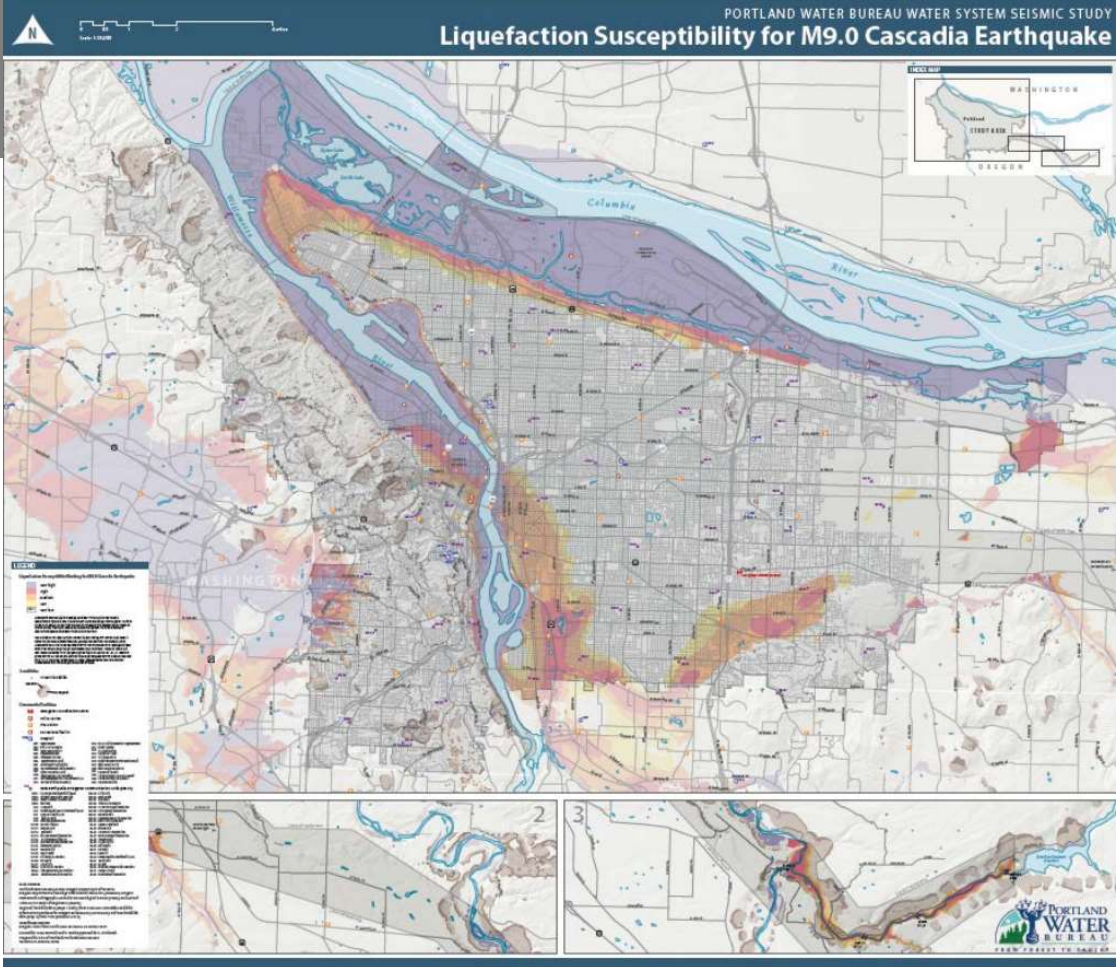
41 pump stations

## Portland Target Recovery Time

Target State of Recovery (TSoR) required as part of OHA-DWS, which require the water system backbone system to be 80% to 90% operational within 24 hours following a Cascadia Subduction Zone (CSZ) earthquake and the distribution system to be 80% to 90% operational within two weeks following a CSZ earthquake



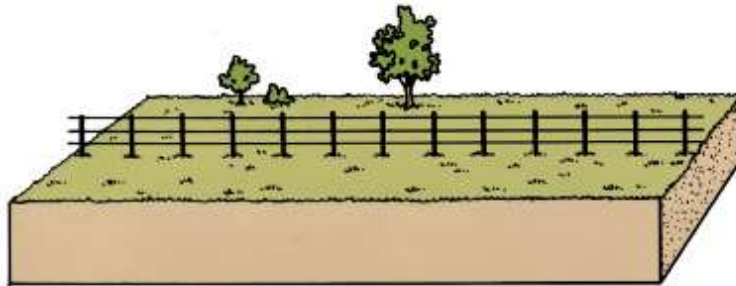
# Hazard Mapping



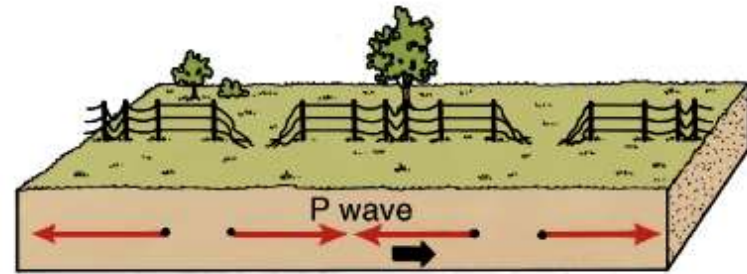
0:05



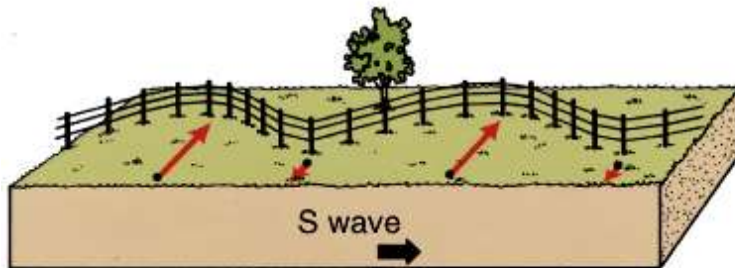
# Types of Seismic Waves



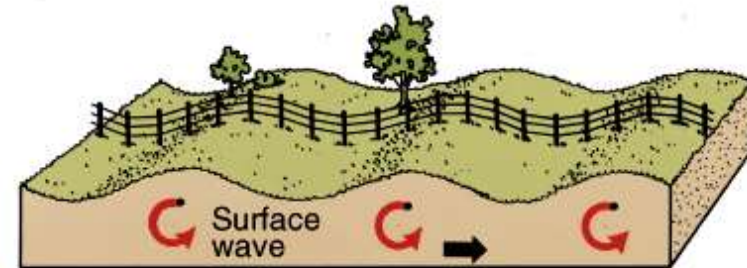
(A)



(B)



(C)



(D)

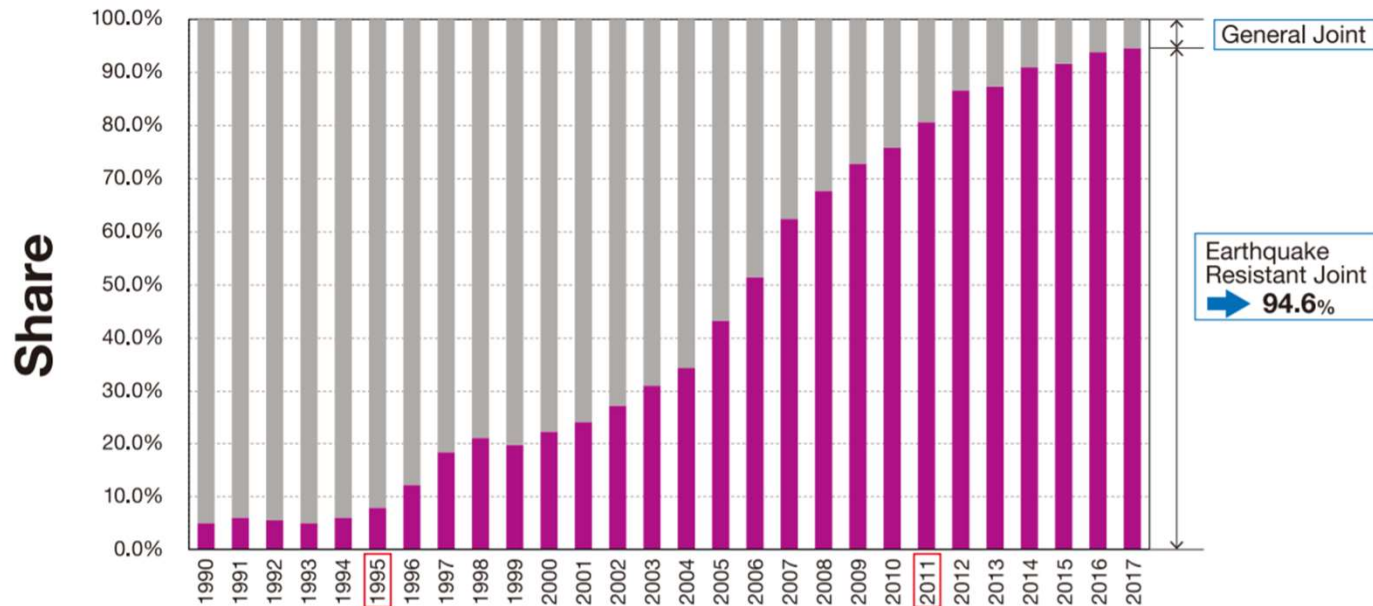
# Performance Philosophy

- Intended Performance Goal After Design Level Event
  - Greatly reduce (but not completely eliminate) number of water main breaks so they are manageable
  - Maximize probability that critical customers do not lose water pressure
    - Critical facilities such as hospitals
    - Fire fighting water
  - Reasonable restoration time to everyone

# HRDIP - Kubota

## Share of ERDIP in Japan

The amount of installed ERDIP has increased drastically in Japan after the 1995 Kobe Earthquake.



Kobe Earthquake

Fiscal Year

East Japan Earthquake

$$\text{Share} = \frac{\text{Earthquake Resistant DIP shipment}}{\text{All DIP shipment}} \quad (\text{in length})$$

Source: Japan Ductile Iron Pipe Association



## 5.10.1.2 SPU Watermain Seismic Design and Construction Requirements

The level of analysis and performance required for watermain design and construction shall be in accordance with the watermain criticality and earthquake hazard exposure as defined in Table 5-11. Primary and secondary backbone pipelines, hospital/critical facility and fire fighting mains are identified in Figures 5-23 and 5-24. For any pipeline, if a site-specific analysis shows a lesser level of design than that stipulated by Table 5-11 is adequate, then that pipeline need only be designed in accordance with the design indicated by the site-specific analysis.

**Table 5-11  
Minimum Watermain Design & Construction Analysis & Performance Requirements**

Watermain Class/Criticality	PGD Area	Seattle Fault Zone or SPU Intense Ground Shaking Region	All Other Areas
Ordinary	Performance Specification 1	Performance Specification 2	No seismic requirements
Hospital/Critical Facility and Fire Fighting Mains	Performance Specification 1	Performance Specification 1	Performance Specification 1
Secondary Backbone	Site-specific analysis	Site-specific analysis	Performance Specification 1
Primary Backbone	Site-specific analysis	Site-specific analysis	Site-specific analysis



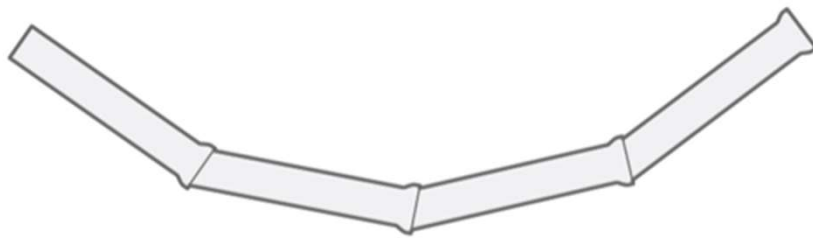
# ISO 16134

	CLASS	COMPONENT PERFORMANCE
Expansion/Contraction Performance (Elongation)	S1	$\pm 1\% L$ or more
	S2	$\pm 0.5\% L$ to $\pm 1\%$ of $L$
	S3	Less than $\pm 0.5\%$ of $L$
Pull Apart Resistance	A	17,000 $d$ lbs +
	B	8,500 $d$ lbs–17,000 $d$ lbs
	C	4,250 $d$ lbs–8,500 $d$ lbs
	D	Less than 4,250 $d$ lbs
Joint Deflection Angle	M1	15° or more
	M2	7.5° < 15°
	M3	Less than 7.5°

"L" is the component length in inches

"d" is the nominal pipe diameter in inches

# SPU Design Standard



**Segmented**

Earthquake Resistance  
Ductile Iron Pipe (ERDIP)

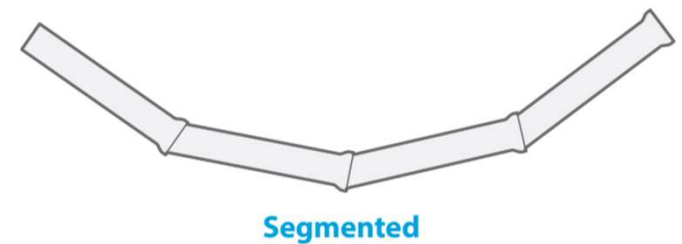


**Continuous**

Welded Steel, HDPE, CIPP,  
Primus

# SPU Design Standard Performance Level I

- Segmented Pipelines (maximum segment length is 30 feet)
- ISO 16134
- Axial Elongation (at each joint): 1% Minimum Axial Elongation or Shortening.
- Axial Pullout Strength (of each joint): 17,100 pounds per inch of nominal diameter
- Deflection (at each joint): 8 degrees of deflection per 20-foot segment. Prorate for shorter or longer segment lengths.
- Segmented pipeline systems that meet the Performance Specification 1 requirements include, but are not limited to:
  - Kubota Genex Earthquake Resistant Ductile Iron Pipe
  - American Pipe Earthquake Joint Pipe
  - Modified US Pipe TR-Extreme
  - McWane Seismic Coupling



# SPU Design Standard

- Continuous Pipelines
  - Welded Steel Pipelines with Butt-Welded Joints Meet the requirements of AWWA C200 and  $D \leq 100t$  Where D = the pipe nominal diameter in inches and t = the pipe wall thickness in inches (minimum thickness = 0.25 inches)
  - HDPE Pipelines – Meet the requirements of MAB-3-2017, AWWA C906 and ASTM F2620. Joints shall be butt-fused.
  - CIPP
  - Primus Liner



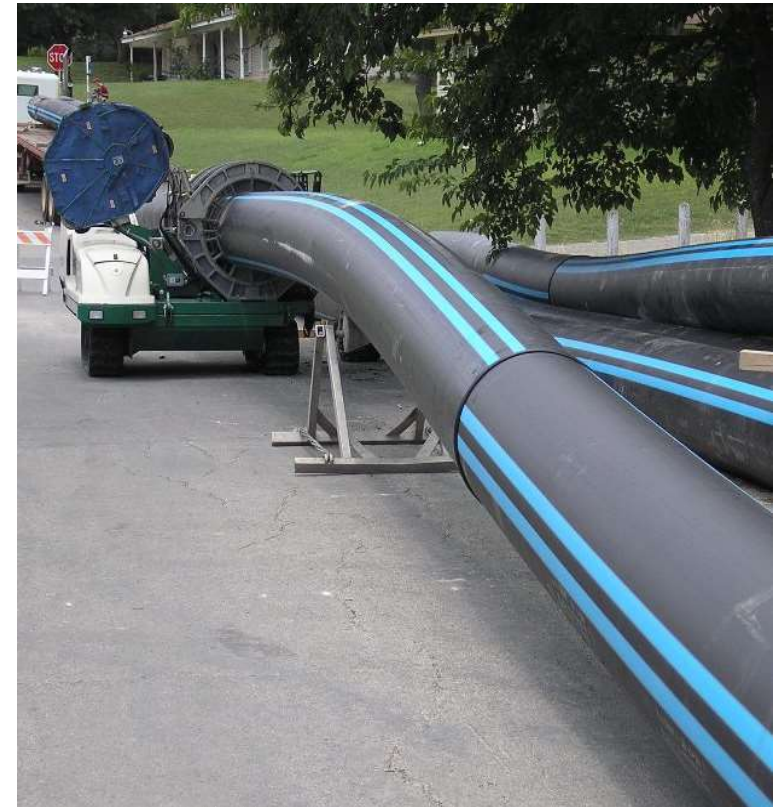
Continuous

# Hazard Resistant Options

- HDPE
  - Steel
  - CIPP
  - Primus Liner
- HRDIP
    - US Pipe
    - American Pipe
    - Kubota
    - McWane

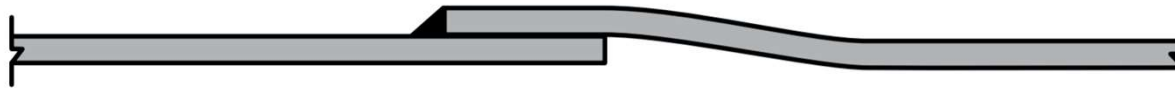
# HDPE

- Extremely Flexible and Resilient
- Cheaper
- Design
  - Profile not required
  - Simplifies fittings
- Services need saddles
- Service life similar to DIP
- Needs large staging area for fusing.
- Maintenance Crew Training

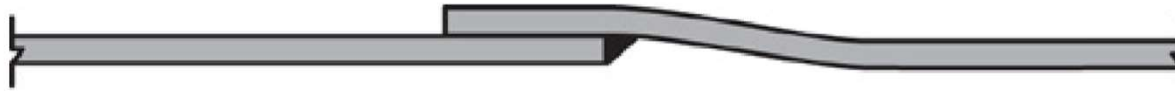


# Welded Steel

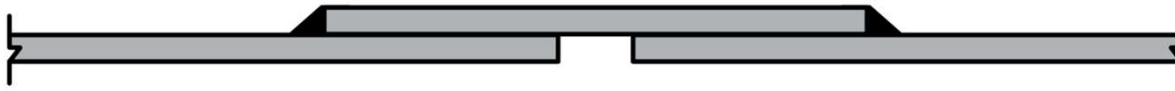
Outside Lap-welded Joint



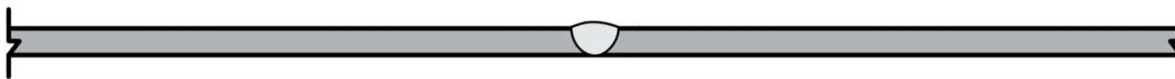
Inside Lap-welded Joint



Butt-strap Joint



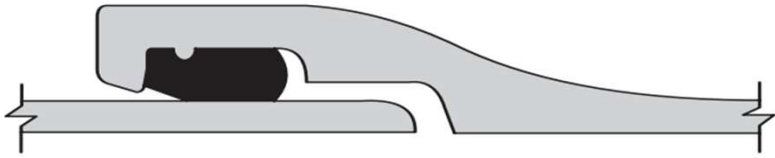
Butt-welded Joint Favored by SPU



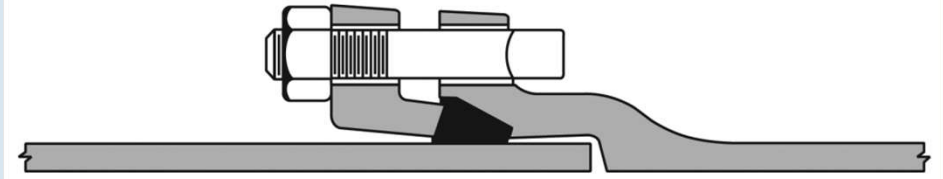
# Ductile Iron Pipe Joint Types

— Unrestrained

**Push-on Joints**



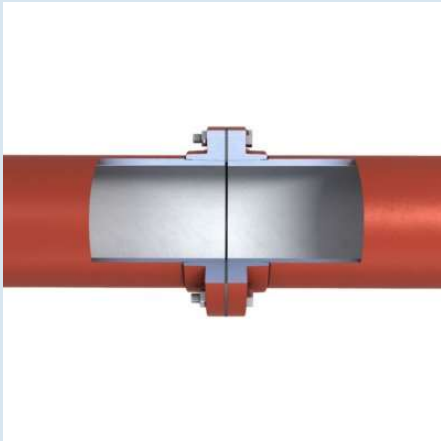
**Mechanical Joint**



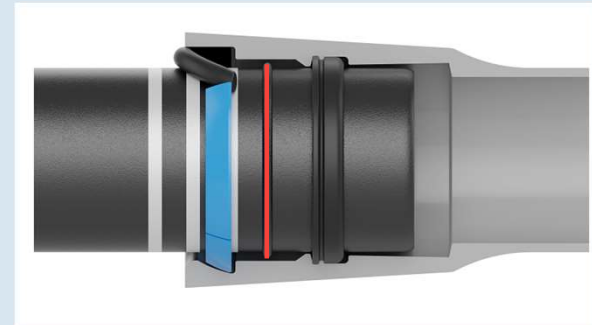
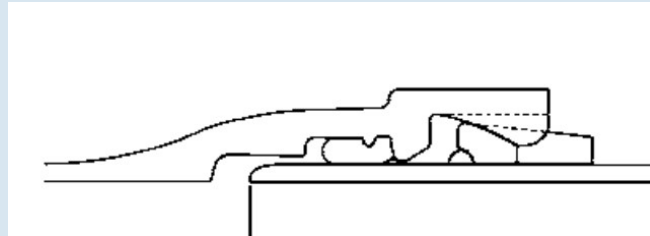
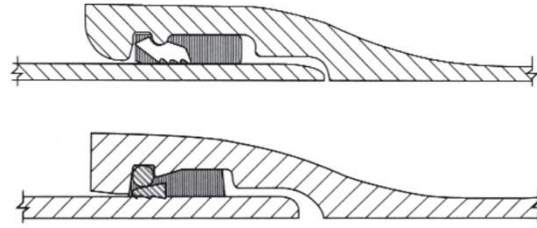


# Ductile Iron Pipe Joint Types

— Restrained



**Restrained Push-On Gasket Joints**



## HRDIP – US Pipe TR Xtreme S-1

- 2.9" of expansion/contraction
- Joint deflection
  - 5° for 6", 8", 12" and 16"
  - 4° for 20"
  - 3° for 24"
- Half-size pipe lengths, ~9'
- Expansion, contraction and deflection in single joint



# Specialty Designed Push-On Restrained Joint



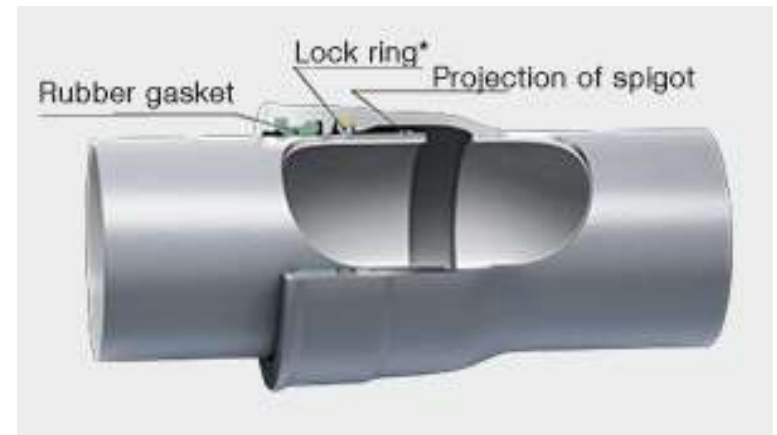
# HRDIP – US Pipe TR Xtreme S-1



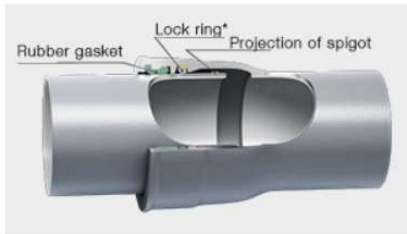
wsp

## HRDIP - Kubota

- Kubota has several different products
- $1\% \pm$  of expansion/contraction
- Joint deflection
  - $8^\circ$  for 3"-16"
- NS Type and S Type for larger sizes up to 104"
- Proven record



# ERDIP - Kubota

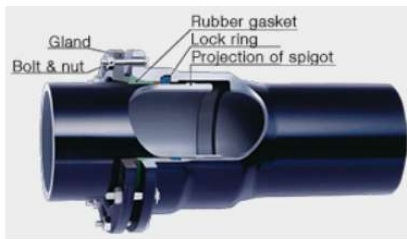


## GX-type

DN75-DN400 (3" - 16")

\*External coating: C-protect

\*Lock ring is preset.



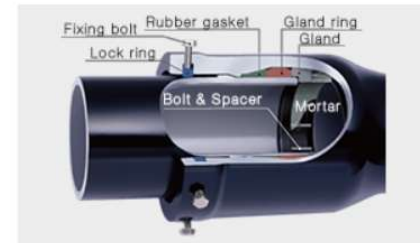
## NS-type

DN500-DN1000 (20" - 40")



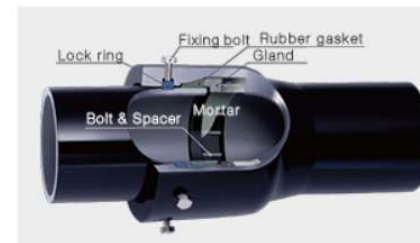
## S-type

Pipe: DN1100-DN2600 (44" - 104")



## US-type

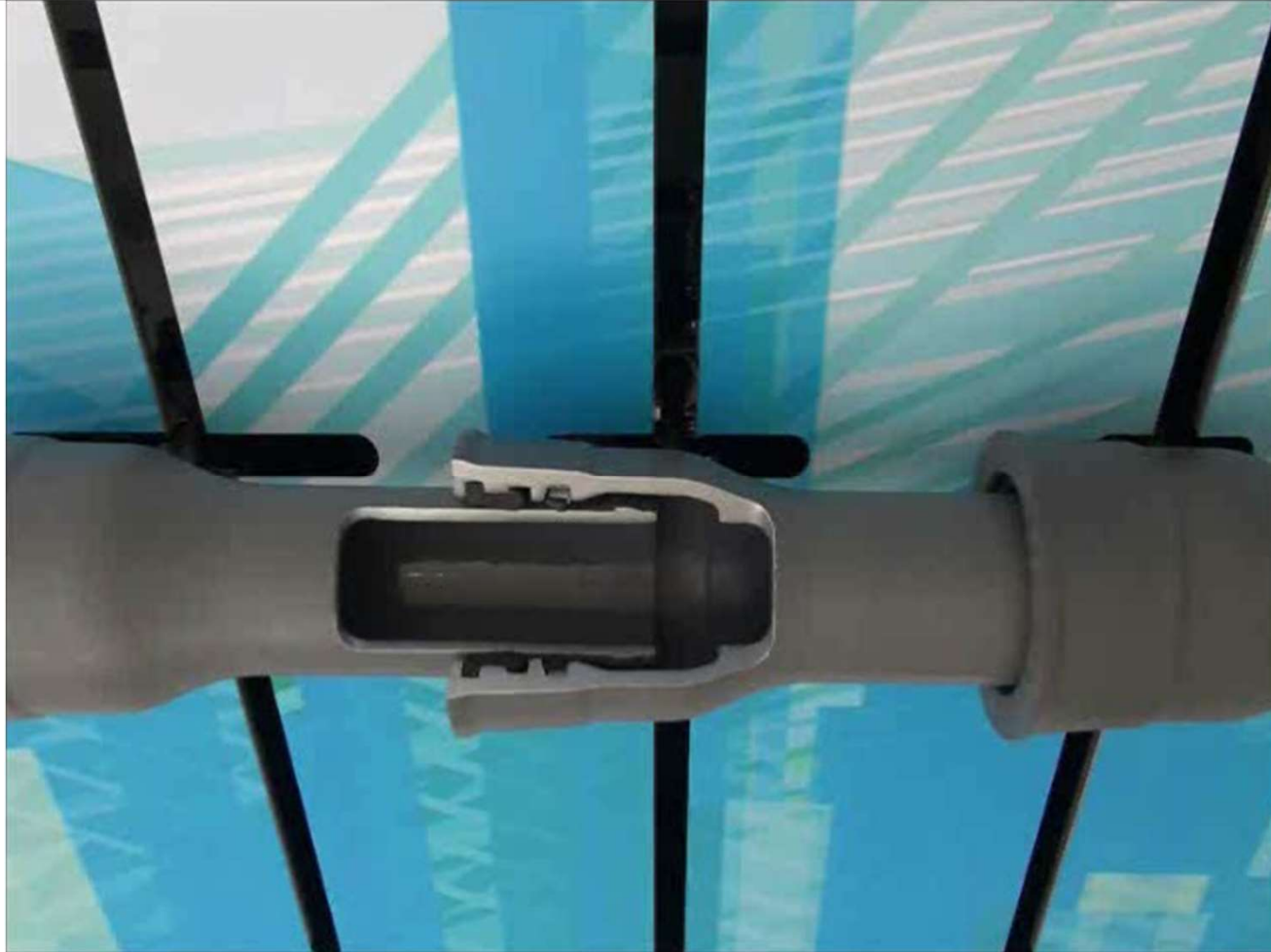
Pipe: DN800-DN2600 (32" - 104")



## UF-type

Fitting: DN800-DN2600 (32" - 104")

# HRDIP - Kubota

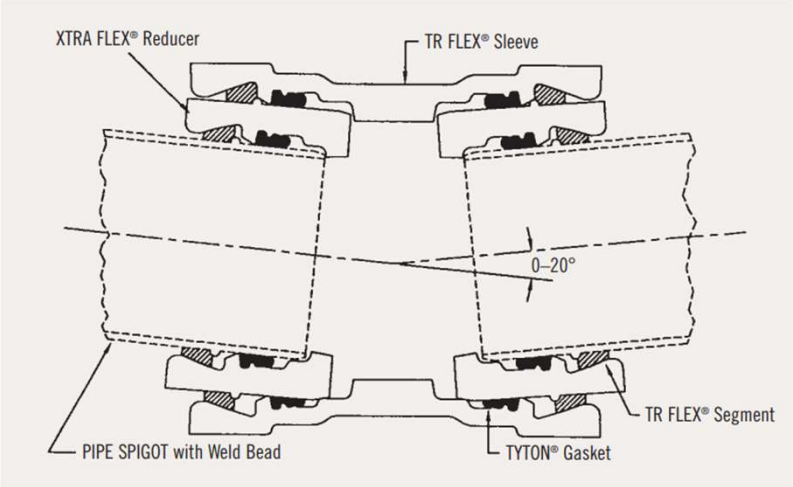


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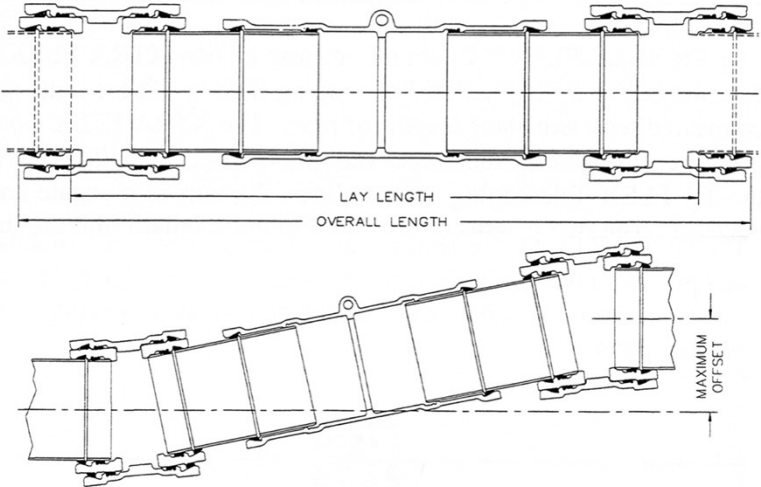
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# HRDIP – US Pipe Additional Fittings

## Xtra Flex Couplings



## Tele Flex Coupling



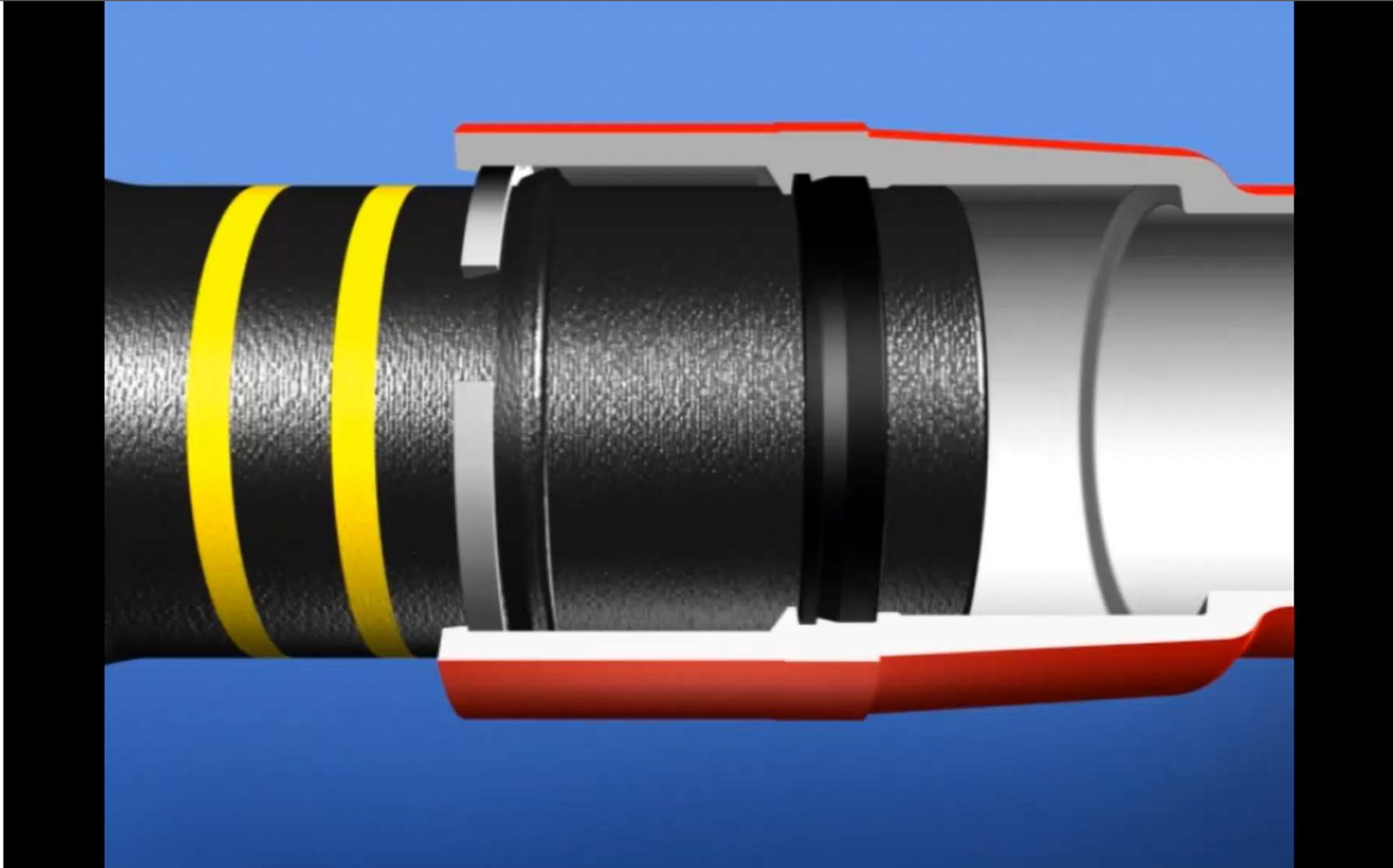


# HRDIP – American Earthquake Joint System

- 4.8" of expansion/contraction
- Joint deflection
  - 8° for 6", 8" and 12"
  - 7° for 16"
  - 6° for 20" and 24"
- Full length pipe
- Center the joint - do NOT fully extend



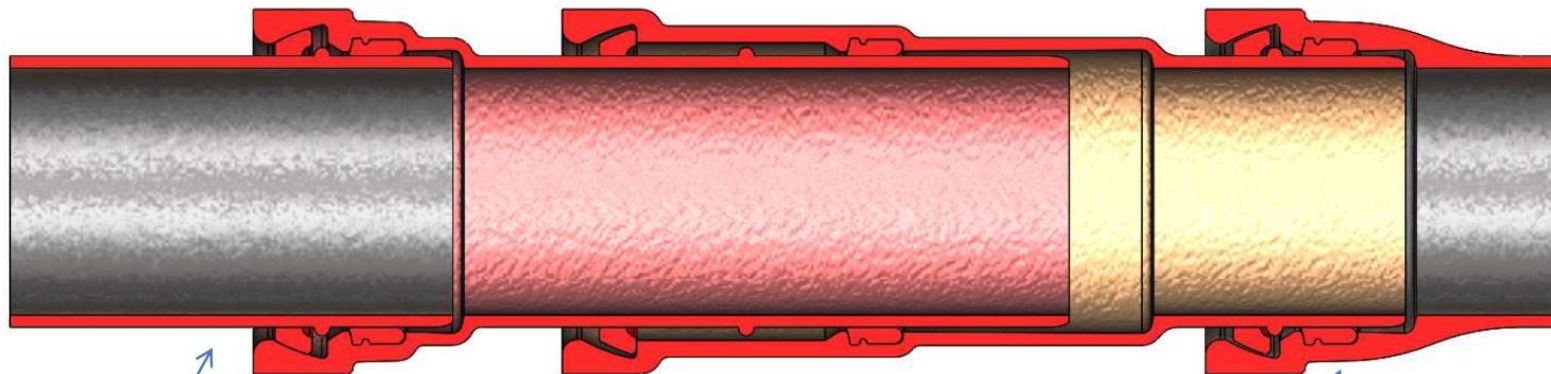
# ERDIP – American Earthquake Joint System



# ERDIP – McWane Seismic Flex Coupling

Plain End Adaptor

Bell End Adaptor



TR Flex Plain End

TR Flex Bell

# EBAA – Flexible Expansion Joints



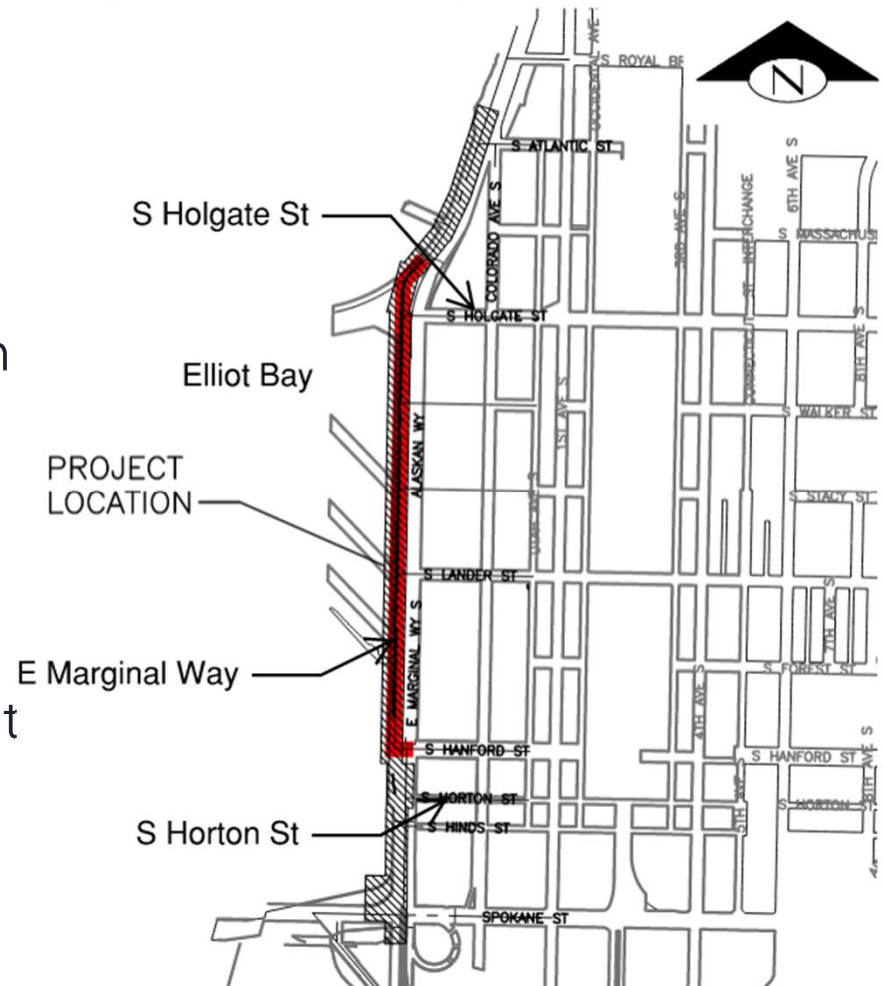
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# Victaulic

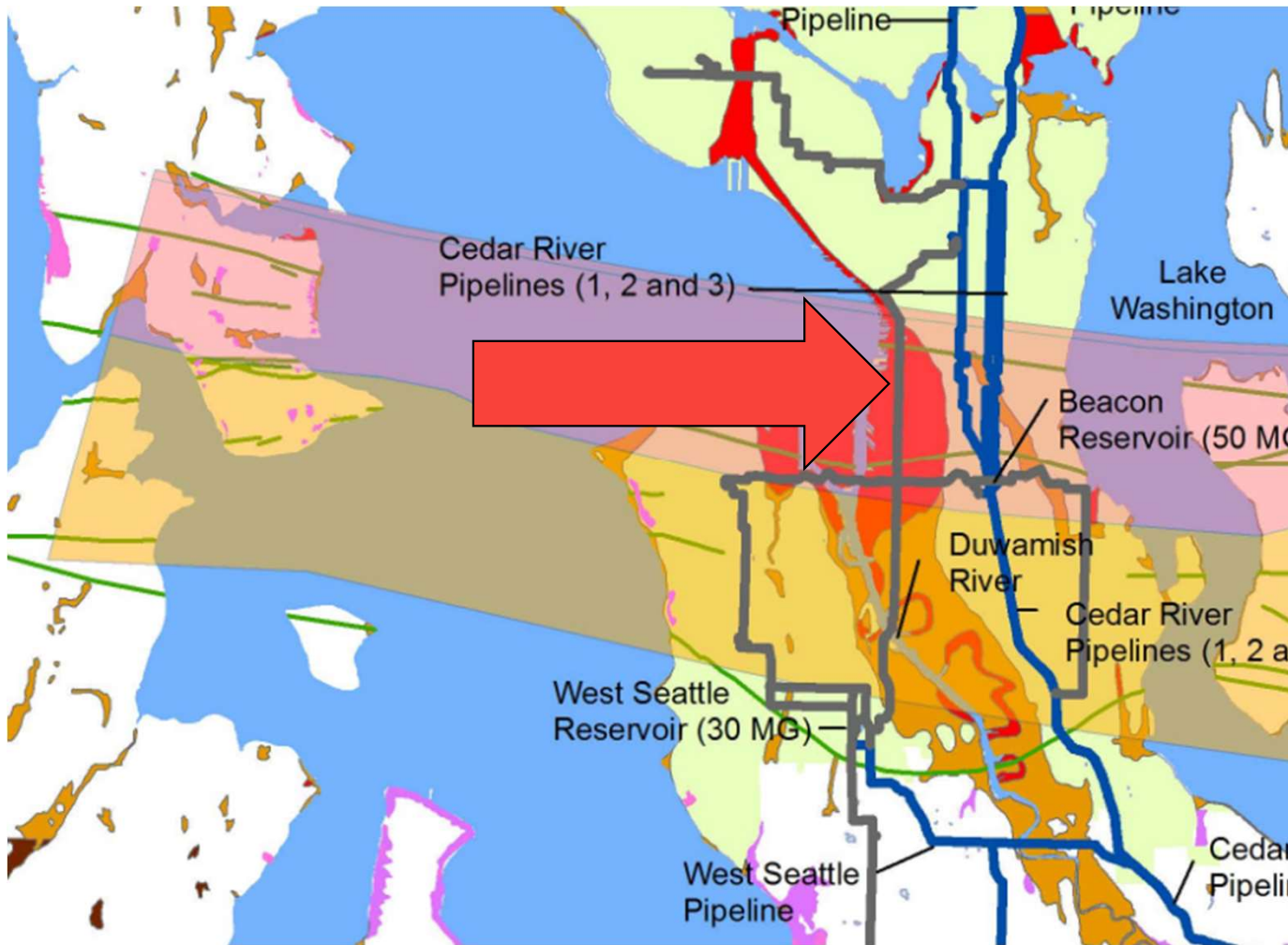


# Projects – East Marginal Way (EMW)

- Earthquake Zone
  - Seattle Fault Zone: <7.3 magnitude earthquakes
  - Cascadia Subduction Zone: 9.3 magnitude earthquakes
- Ground Response - Liquefaction
  - Projected permanent ground deformation of 10-25 feet

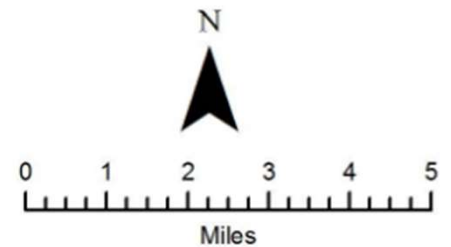


# East Marginal Way



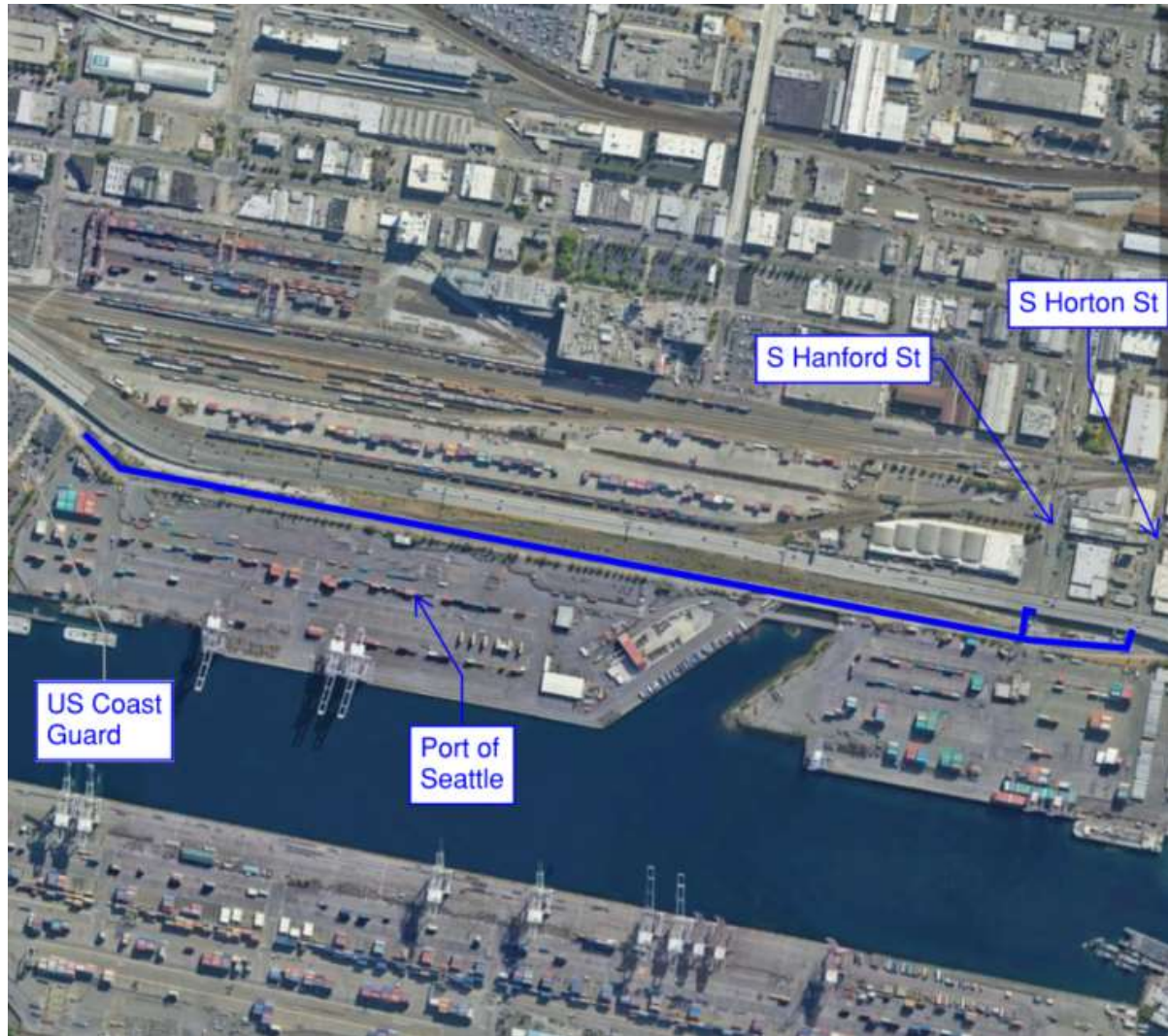
## Legend

- Primary Transmission Pipelines
- Secondary Transmission Pipelines
- Seattle Fault Zone**
  - Zone A - Primary Seattle Fault Zone
  - Zone B - Back Thrusting
- Liquefaction Susceptibility**
  - high
  - moderate
  - moderate to high
  - Known or Potential Landslide
  - Active Faults Lineaments
  - Peat





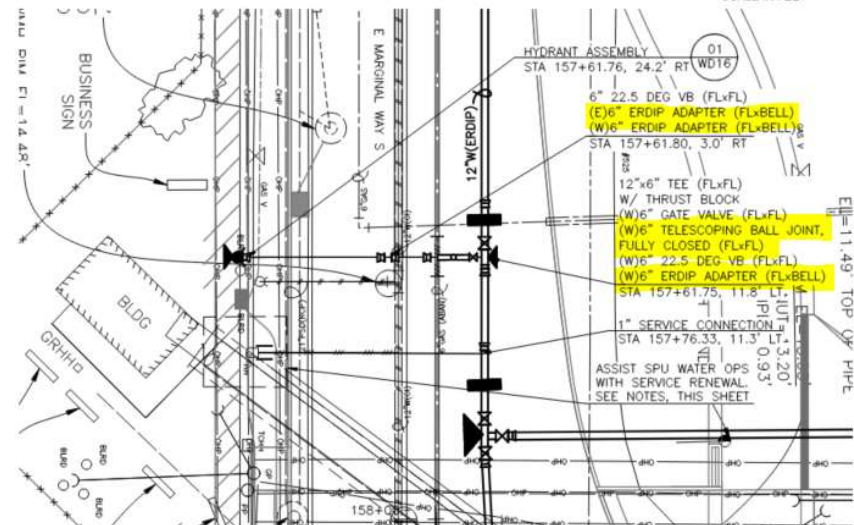
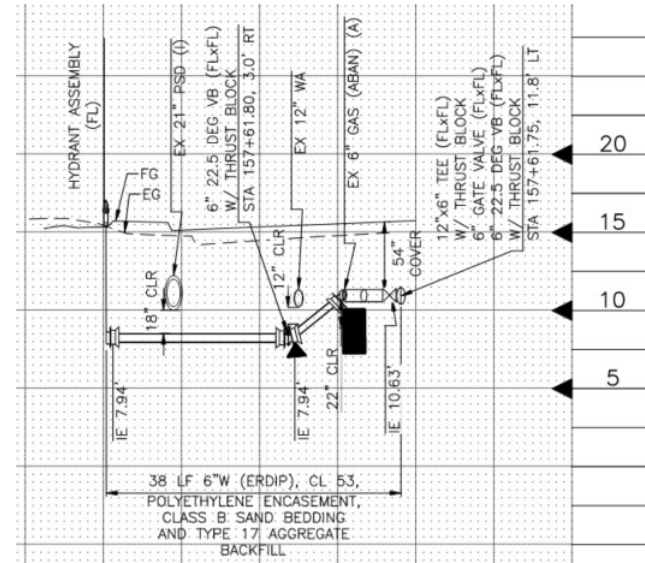




- Watermain serves primary distribution main along the waterfront, is a critical loop for the Port of Seattle and US Coast Guard

# EMW Project Details

- Federally funded: Buy-America
- Over a mile of 12" HRDIP replacing 12" cast iron pipe
- Replaced all hydrants and laterals with HRDIP pipe
- Transitioned to MJ as close to meters as possible
- Designed main and services off original alignment to prevent long shut-down periods and provide required fire flow
- Designed hydrant legs to be fully compressed
- Helped SPU fine tune their seismic standards



# HRDIP - Design Considerations

- Different approaches by each manufacturer
- No weak links
- Treat as unrestrained system
  - Thrust Blocks at bends
  - Thrust Collars at valves
- Hydrants
- Provide flexibility
  - Spare parts
  - Closures
  - Telescoping fittings
- Lay Plan
- Allow for future extension of HRDIP

## Questions & Discussion

Please reach out to us with  
questions!

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WSP

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**Sarah Merrill, PE**

WSP

[Sarah.Merrill@wsp.com](mailto:Sarah.Merrill@wsp.com)



# Seismic Pipe Testing

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- Cornell University
    - [Testing Bed Setup](#)
    - [Testing Bed Test](#)
-

# Projects – Factoria Stormwater Improvement

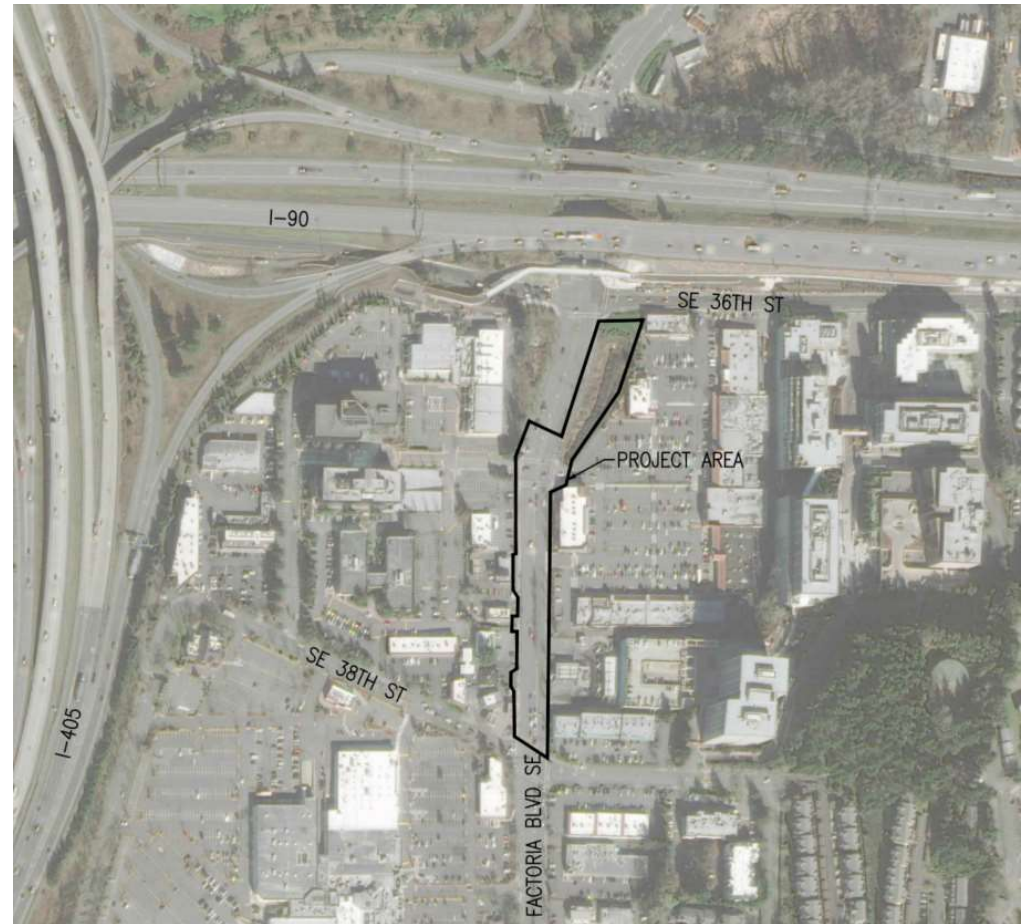
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## Earthquake Zones






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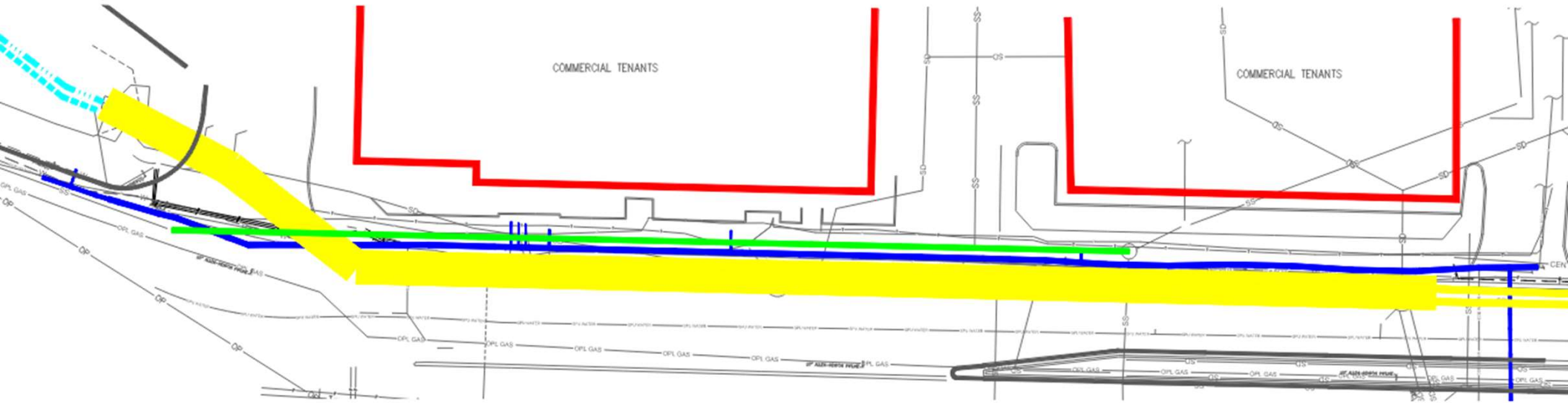
## Ground Response

- Liquefaction
- 





STORMWATER	
SEWER	
WATER	
BUILDING	
CREEK	

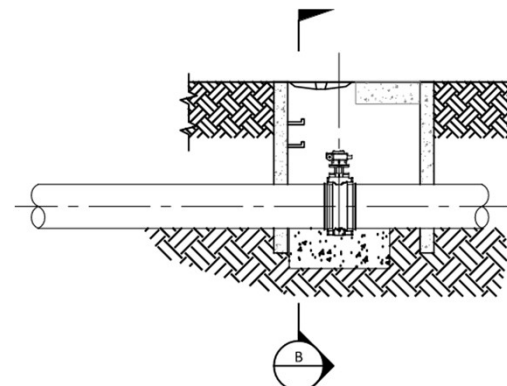
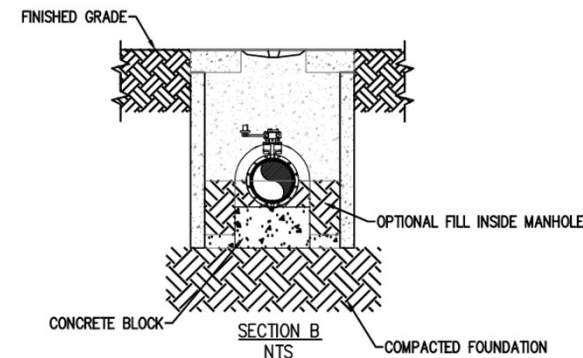
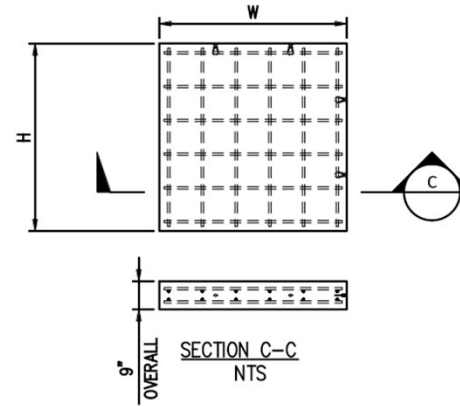


- Watermain serves the strip mall and is a main conveyance pipe from the water reservoir



# Factoria Project Details

- Locally funded
- 16" ERDIP replacing 12" cast iron pipe
- Watermain lies between proposed 9'x4' storm box and 16" existing sewer pipe
- Pre-cast thrust blocks due to horizontal constraints
- Bottomless appurtenance structures to reduce damage during liquefaction



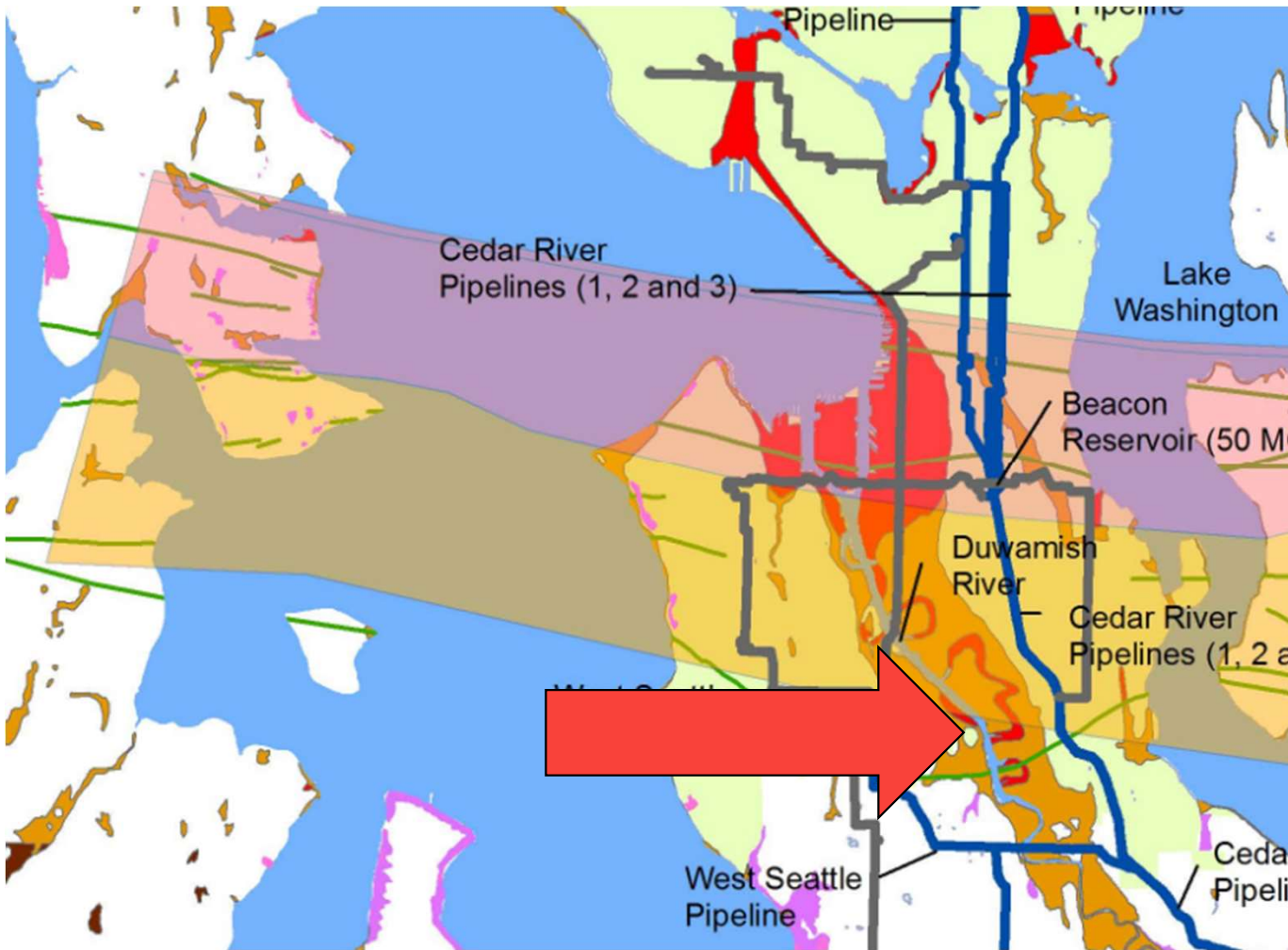


## Projects – South Park

- Locally Funded
- 1,300 LF of 12” ERDIP replacing 8” cast iron pipe
- Design nearly complete
- Construction in 2024
- Kubota Pipe



# South Park



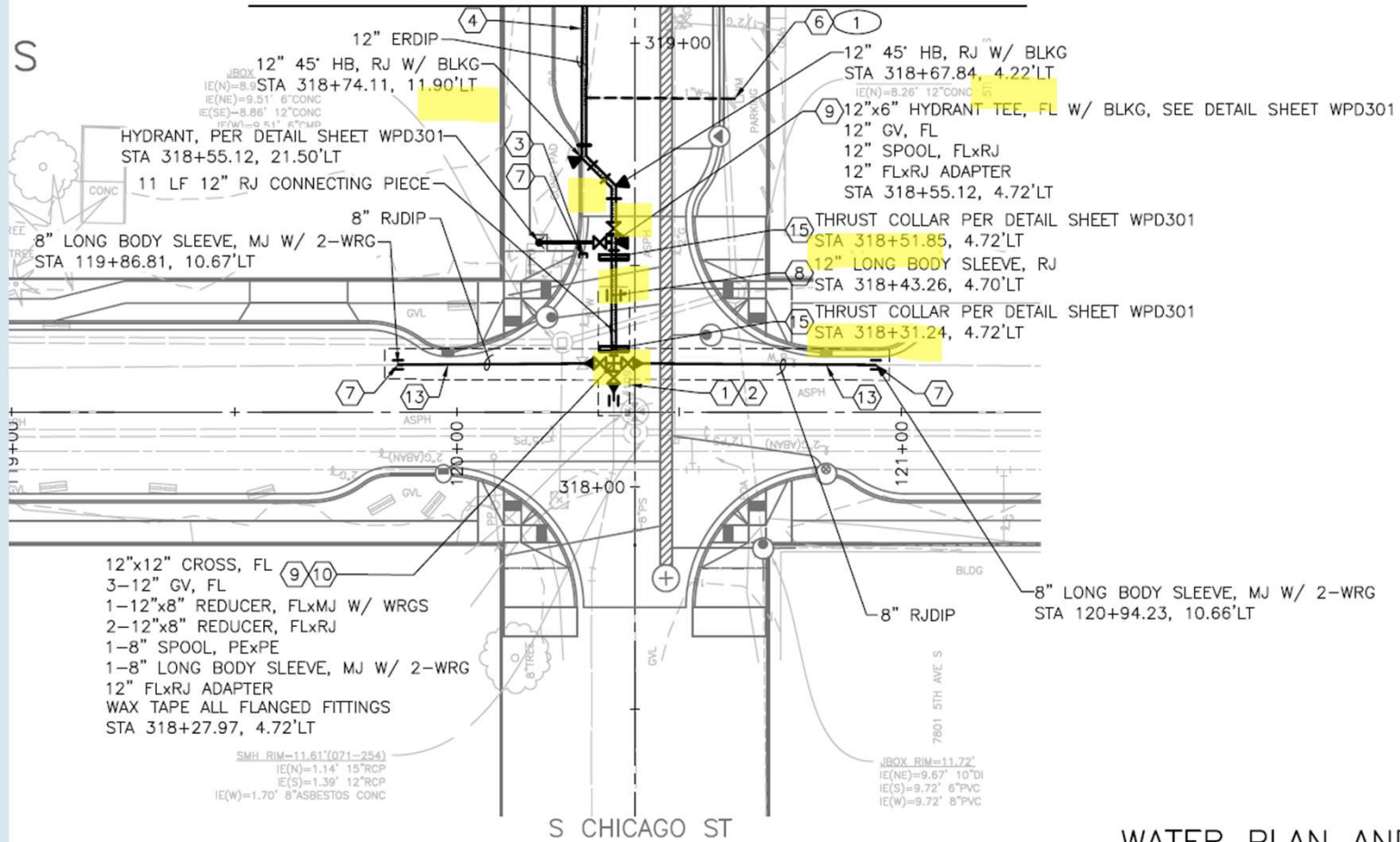
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# South Park Project

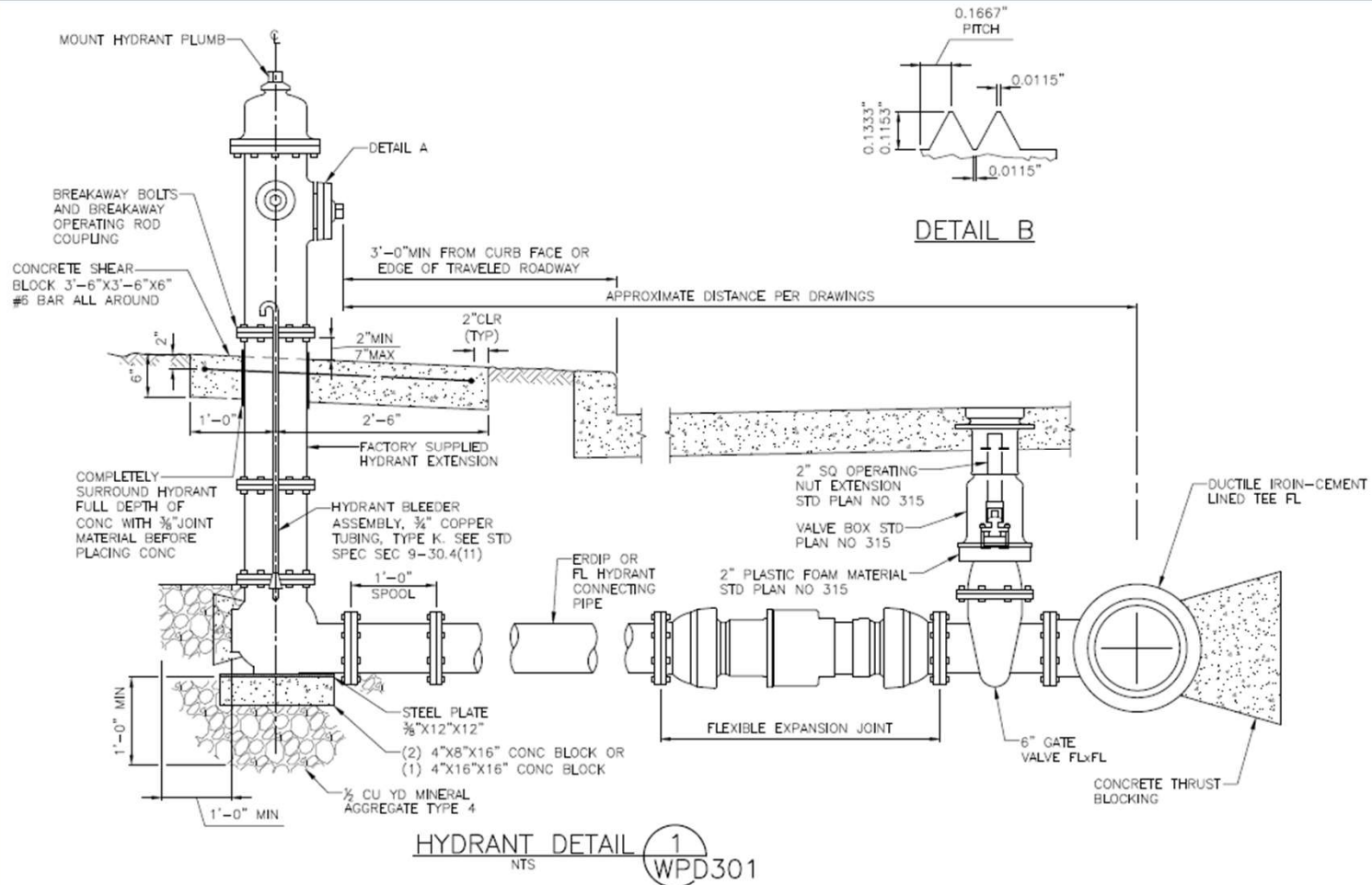
MATCH LINE STA 319+08 - SEE SHEET WP109



WATER PLAN AND



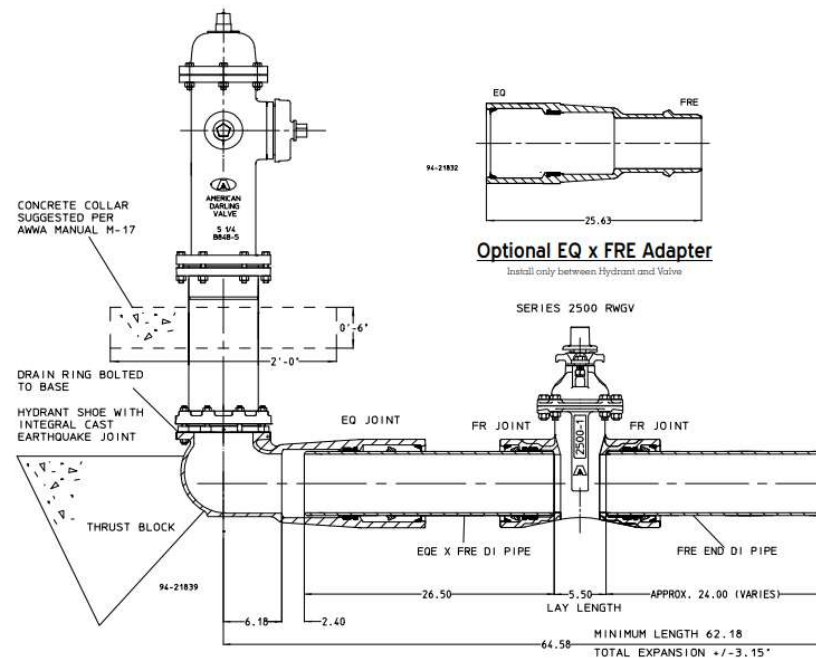
# South Park Project



# ERDIP – American Earthquake Joint System



## AMERICAN Flow Control Submittal Information 5-1/4 AMERICAN-DARLING® B-84-B-5 FIRE HYDRANT WITH INTEGRAL CAST EARTHQUAKE JOINT SYSTEM



### Optional EQ x FRE Adapter

Install only between Hydrant and Valve

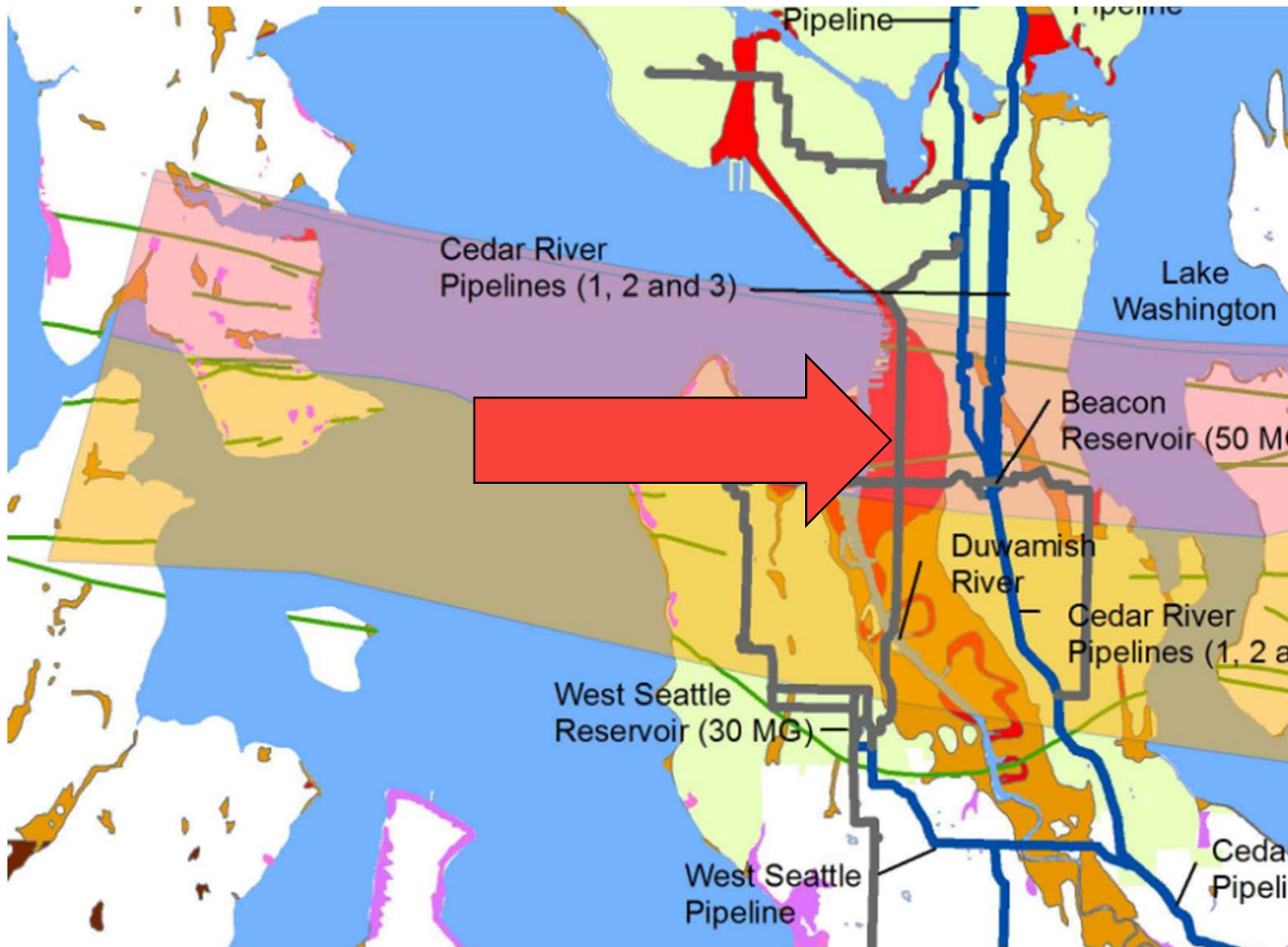
### Standard Earthquake Joint Configuration



# Projects – Lander Street Overpass



# Lander Street Overpass

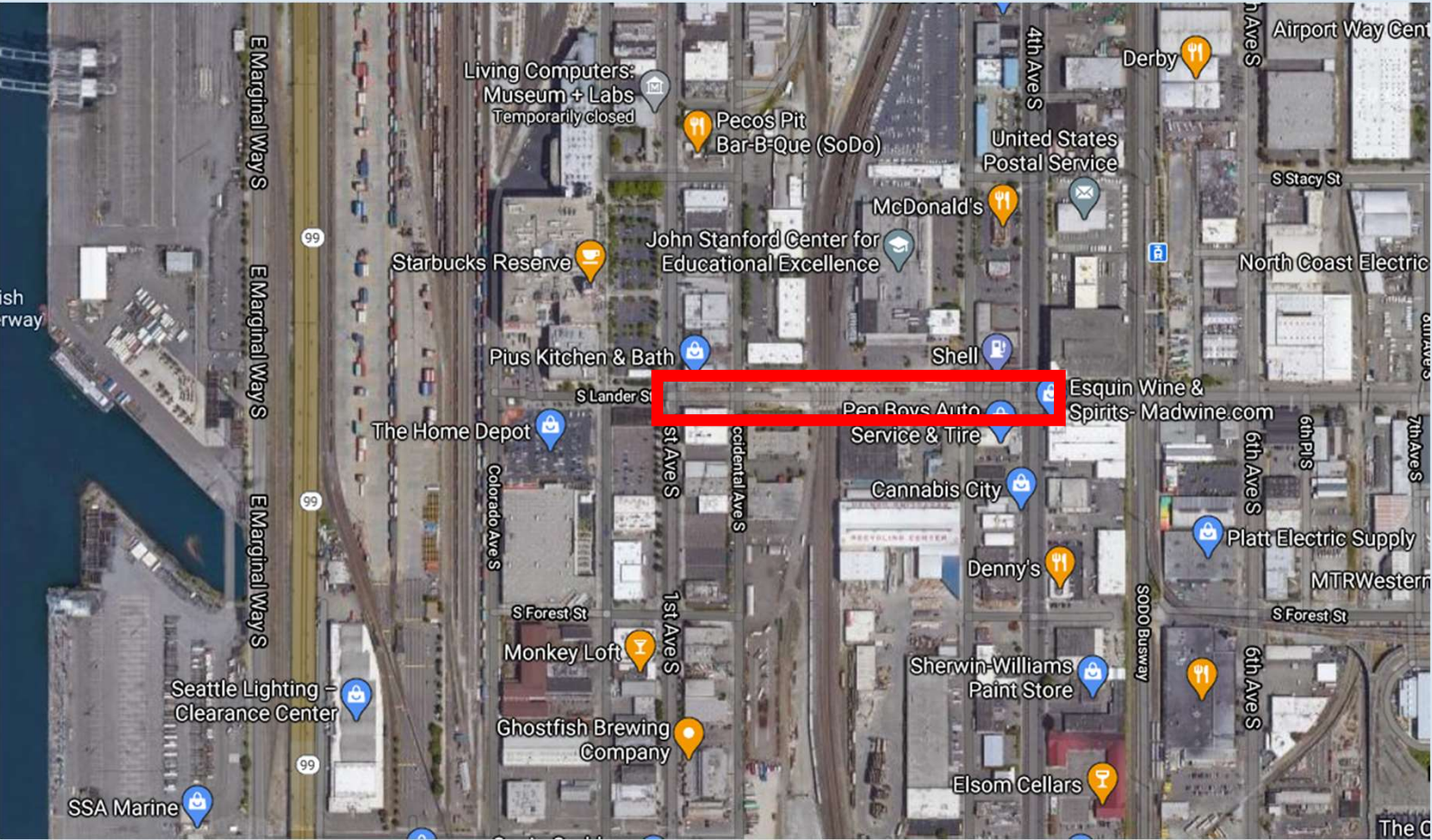


## Legend

- Primary Transmission Pipelines
- Secondary Transmission Pipelines
- Seattle Fault Zone**
  - Zone A - Primary Seattle Fault Zone
  - Zone B - Back Thrusting
- Liquefaction Susceptibility**
  - high
  - moderate
  - moderate to high
- Known or Potential Landslide
- Active Faults Lineaments
- Peat



# Lander Street Overpass





## Lander St Overpass

- Permanent Ground Displacement (PGD) Susceptible Area with liquefiable soils
- 1,600+ LF of 16" earthquake resistant ductile iron pipe (ERDIP)
- BNSF railroad crossing – 20" HDPE in jack and bored 24" steel casing
- 20" HDPE in 24" HDPE casing

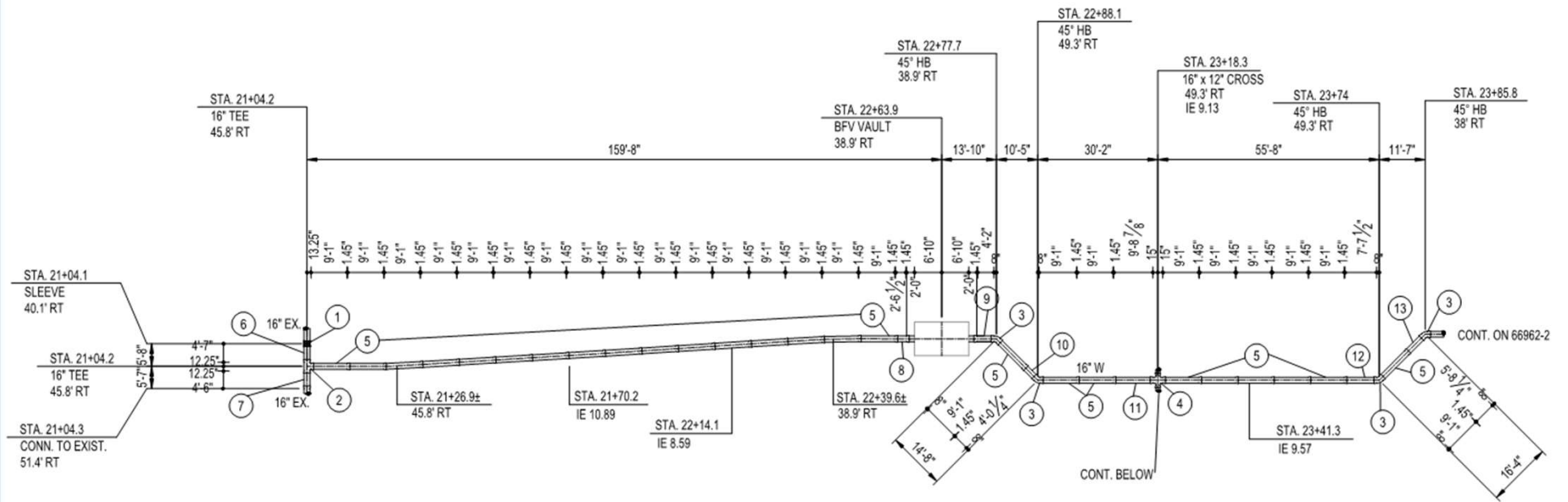
## Lander St Overpass - Challenges

- No mechanical joints or wedge restraint glands
- Interaction with geof foam
- Federally funded = Buy American

## Lander St Overpass - Challenges

- USPIPE TR-Extreme
- Approx. 9' length sticks of pipe
- Flange Adapters
- Spare parts
- Telescoping Sleeve for connections
- Hybrid System Connection with HDPE

# Lander Street Overpass – Lay Plan



**PLAN**  
 REFERENCE CONTRACT DWG(S)  
 WT01



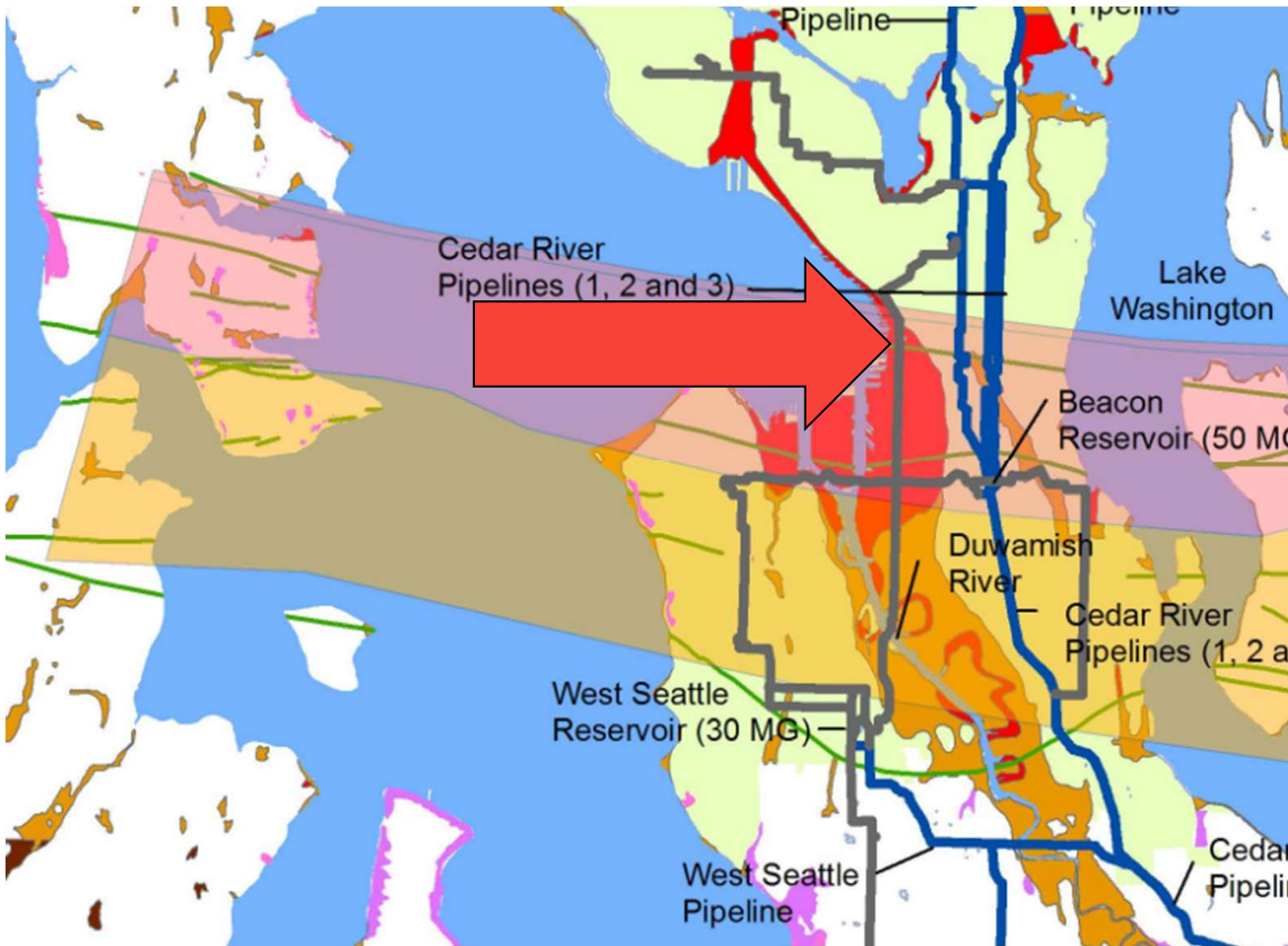




## Projects – C3 Utility Project

- Federally Funded
- American Earthquake Joint System, 8"-24"
- Learning curve on installation with larger pipe
- Smaller pipe relatively easy to install

# C3 Utility Project



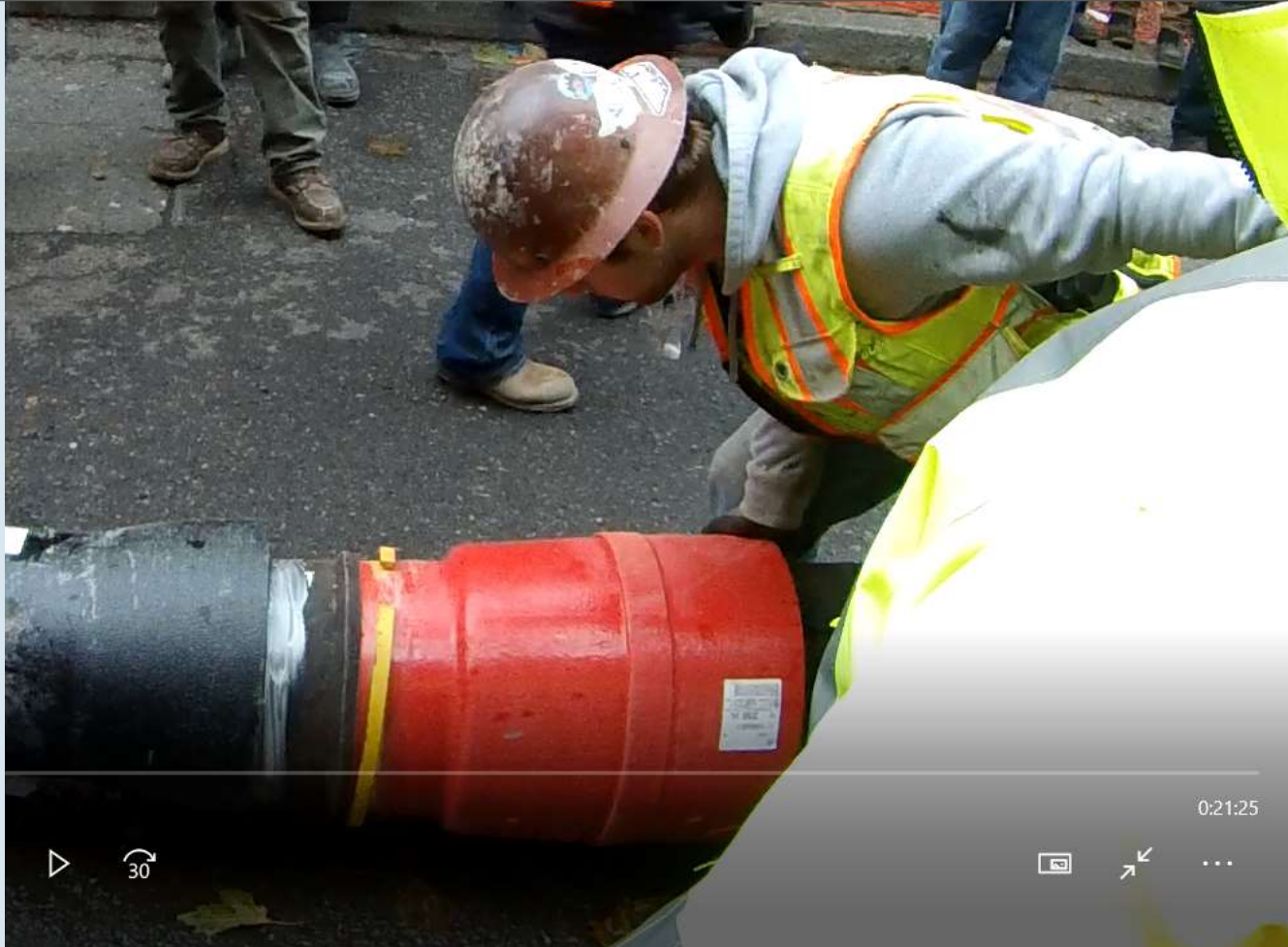
## Legend

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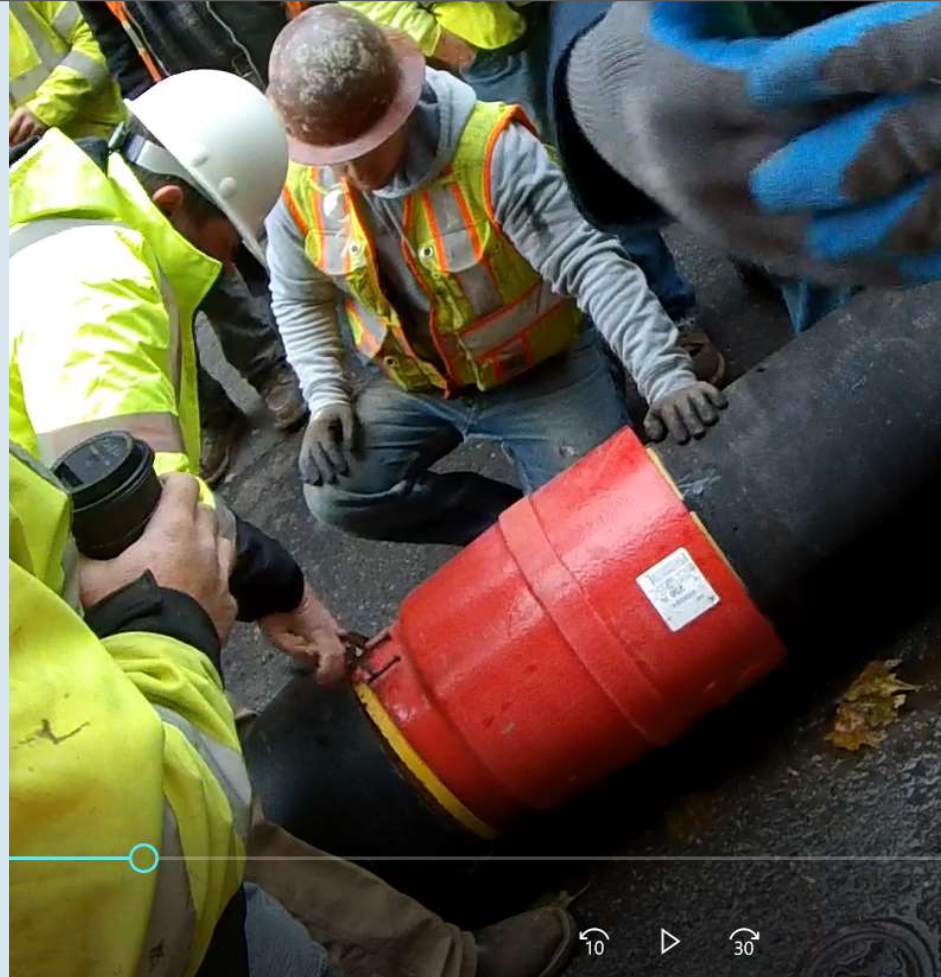




# C3 Utility Project - Installation



# C3 Utility Project – Locking Mechanism



# C3 Utility Project – Adjusting Stabbing Depth



# South Park Roadway & Drainage Project



