Seismic Design of Waterlines on Bridges

By: Kenton Alldritt, PE, SE

May 8, 2025



DOWL



“

the pictures that had been broadcast did not prepare me for the devastating reality of the situation.

Andy Clarke
Cheshire Fire and Rescue Service
Gaziantep, Turkey
February 2023



7.8 Mag. Turkey Earthquake
Antakya, Turkey. February 20, 2023
Photo credit: Reuters

Agenda



- Seismic Risks
- Performance Targets
- Seismic Risk Mitigations
- Roles

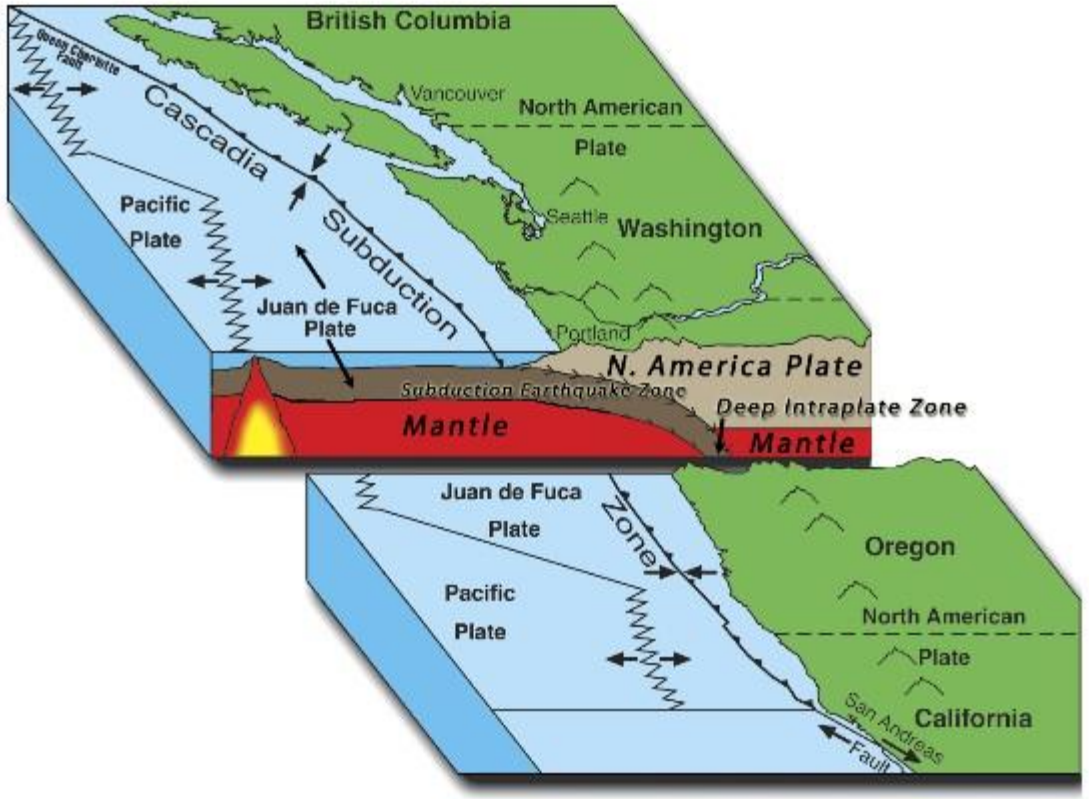






Seismic Risks

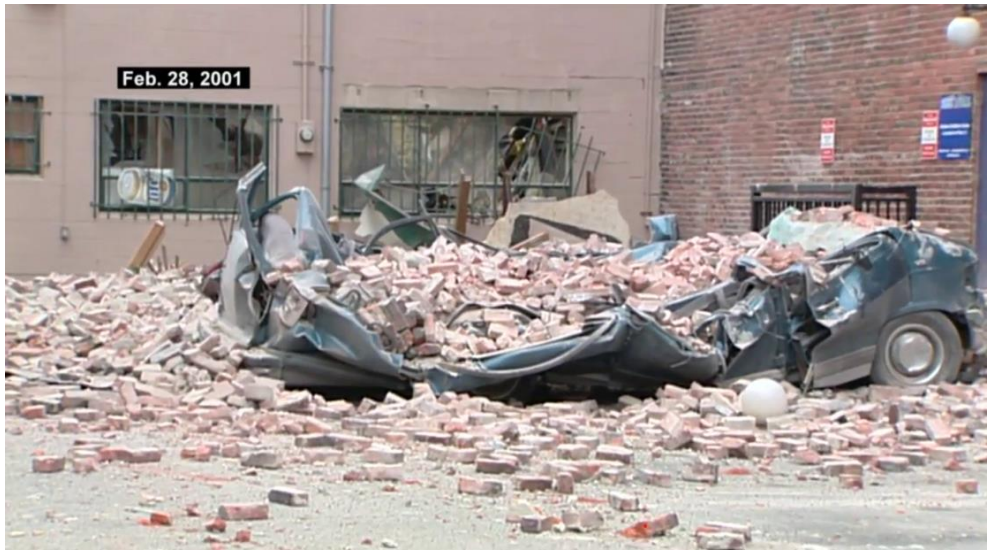
Seismic Risks



Source: https://www.oregon.gov/oem/hazardsprep/pages/cascadia-subduction-zone.aspx

Cascadia Subduction Zone

- 700-mile fault
- 70-100 miles off the Pacific coast shoreline
- 37% chance that an earthquake of 7.1+ magnitude in this fault zone will occur in the next 50 years
  - *Nisqually (2001) = 6.8 magnitude*



Source: https://komonews.com/news/local/gallery/seattle-earthquake-nisqually-quake-anniversary-pacific-northwest-fault-anniversary-preparing-and-remembering-nisqually-quake-risk-the-big-one?photo=3

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Seismic Risks - Bridges



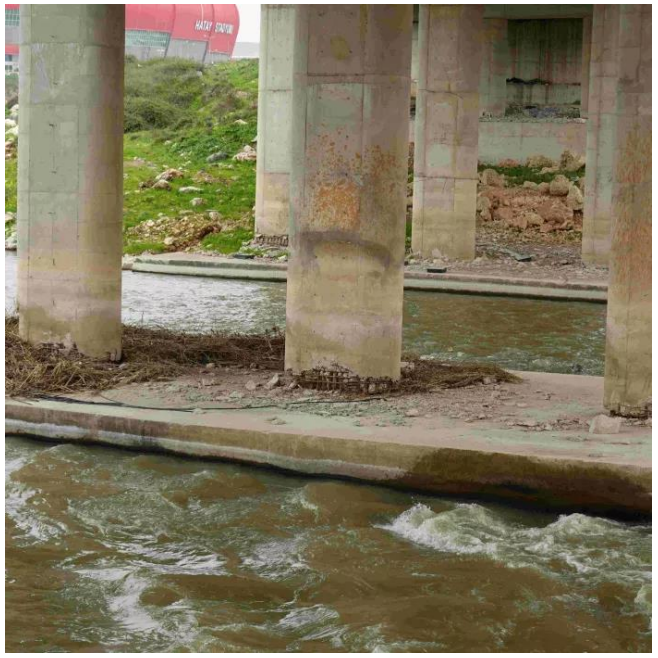


Source: https://thatoregonlife.com/2024/12/cascadia-subduction-zone-earthquake-the-big-one-oregon-highways-knocked-out/

Seismic Risks - Bridges



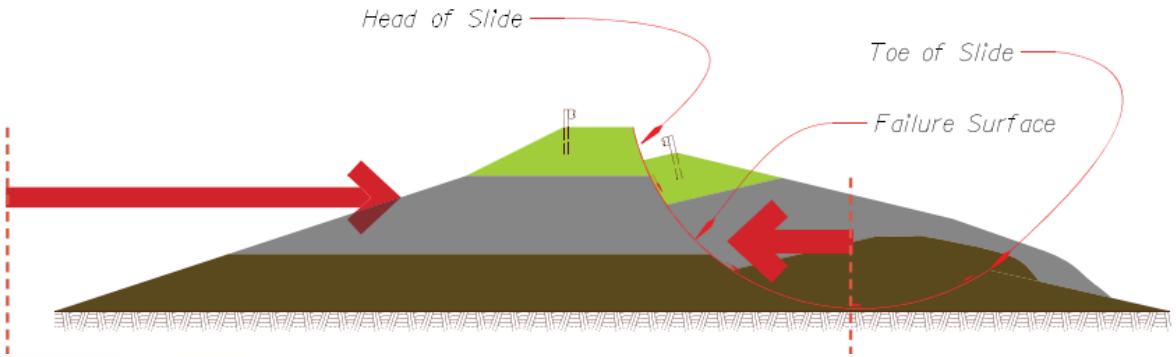




Source: https://www.exponent.com/article/modeling-earthquake-bridge-damage

Source: https://www.sdsu.edu/news/2023/05/sdsu-professor-among-first-assess-structural-damage-bridges-following-turkey-earthquake

Seismic Risks - Bridges





Source: https://www.oregon.gov/oem/documents/oregon_resilience_plan_final.pdf

Seismic Risks - Waterlines





Source: https://ebaa.com/files/pdf/connections /Connections.FT-05.pdf

Seismic Risks - Waterlines











Performance Targets

Performance Targets - Bridges



2000 to 2016 – Several reports and studies relating to resiliency

2021 ODOT Seismic Implementation: Policies and Design Guidelines

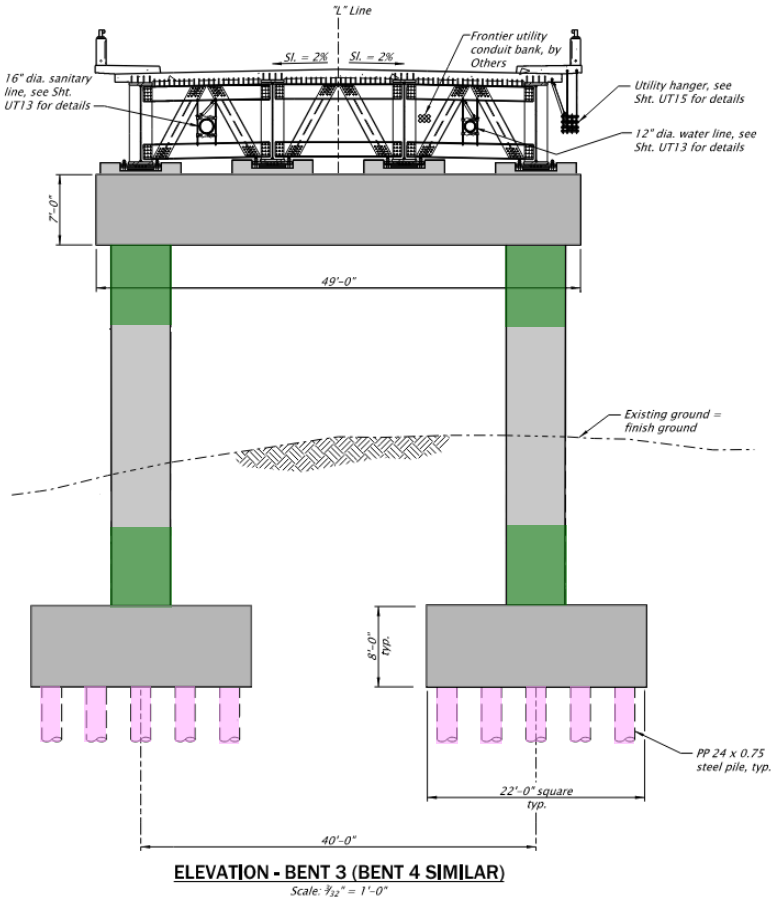
- Sets goals and criteria for transportation system hardening
- Guidelines for replace or retrofit

Retrofit and rehab. versus replace considerations		Ratio Retro+Rehab Costs / Replacement (R_c)		
AGE in CN Year	**RSL, yrs**	**R_c<0.35**	**0.35≤ R_c ≤0.65**	**R_c>0.65**
NA	<16	Replace	Replace	Replace
≤ 50	16 ≤ RSL ≤30	Add'l Analysis	Add'l Analysis	Replace
≤ 50	> 30	Retro+Rehab	Add'l Analysis	Replace
> 50	16 ≤ RSL ≤30	Add'l Analysis	Replace	Replace
> 50	>30	Add'l Analysis	Add'l Analysis	Replace

Source:https://www.oregon.gov/odot/Bridge/Docs_Seismic/ODOT%20Seismic%20Implementation%20-%20April%202021.pdf

Performance Targets - Bridges





PL1: Life Safety	PL2: Operational	PL3: Fully Operational
Significant damage is sustained during an earthquake and service is significantly disrupted, but the potential for collapse is minimized. The bridge may need to be replaced after a large earthquake.	Damage sustained is minimal and access for emergency vehicles is available after inspection and clearance of debris. The bridge should be reparable with or without restrictions on traffic flow.	No damage (or very minor damage that does not require immediate attention) is sustained and full service is available for all vehicles immediately after the earthquake.

Source: ODOT BDM

Performance Targets - Bridges

ODOT BDM Tbl 1.17.2.3-2

Case No.	Engineering Design Parameters	PL1: Life Safety	PL2: Operational	PL3: Fully Operational
1	Superstructure-to-abutment permanent vertical offset	No Limits	≤ 6 inches	≤ 1inch
2	Superstructure-to-abutment permanent horizontal offset	No Limits	≤ 6 inches	≤ 1 inch
3	Approach fill settlement limit of approach slab (longitudinal differential settlement)	≤ 1/20	≤ 1/50	≤ 1/250
4	Approach fill settlement without an approach slab	≤ 12 inches	≤ 6 inches	≤ 1 inch
5	Lateral soil movement	≤ 36 inches	≤ 12 inches	≤ 6 inches

Performance Targets - Waterlines



2013 Oregon Resilience Plan

2012 Resilient Washington State Framework

- Set goals for:
  - Critical and Essential Buildings
  - Transportation
  - Water and Waste Water
  - Energy
  - Communications

Performance Targets - Waterlines

TARGET STATES OF RECOVERY: WATER & WASTEWATER SECTOR (VALLEY)

	Event occurs	0–24 hours	1–3 days	3–7 days	1–2 weeks	2 weeks–1 month	1–3 months	3–6 months	6 months –1 year	1–3 years	3 + years
Domestic Water Supply											
Potable water available at supply source (WTP, wells, impoundment)		R	Y		G			X			
Main transmission facilities, pipes, pump stations, and reservoirs (backbone) operational		G					X				
Water supply to critical facilities available		Y	G				X				
Water for fire suppression—at key supply points		G		X							
Water for fire suppression—at fire hydrants				R	Y	G			X		
Water available at community distribution centers/points			Y	G	X						
Distribution system operational			R	Y	G				X		

KEY TO THE TABLE

TARGET TIMEFRAME FOR RECOVERY:

Desired time to restore component to 80–90% operational	G
Desired time to restore component to 50–60% operational	Y
Desired time to restore component to 20–30% operational	R
Current state (90% operational)	X

Source: https://www.oregon.gov/oem/documents/oregon_resilience_plan_final.pdf

Performance Targets - Waterlines

Resiliency Checklist

Failure Analysis and Resiliency Mitigation Checklist



Subtask 4.4.9 Resiliency, Reliability, Redundancy, and Recovery
Failure Analysis and Resiliency Mitigation Checklist

Name: **Overstress: Connection Failure Between the Walls and Floor**

Category (e.g., Feature, System, Sub-System)

Storage Tanks	■	Site and Facility Access	___	Electrical / I&C	___
Pipelines and Valves	___	Site and Facility Security	___	Operations	___
Process Mech / HVAC	___	Structural/Architectural	___	Other	___

Hazard

Cyber Attack	___	Permanent Ground Deformation	___	Extended Power Outage	___
Chemical Spill	___	Ground Shaking	■	Loss of Communications	___
Terrorist Attack	___	Loss of Access to Site	___	Loss of Internet / WiFi	___
Vandalism	___	Water Quality Issue	___	Failure of Other Infrastructure	___
Looting	___	Fire	___		___

Description of Failure	Consequence of Failure	Probability
During ground shaking, the tank walls slide laterally relative to the underlying foundation slab; if overstressed, the wall-to-slab connection could fail.	Wall-to-slab connection has a water stop and failure constitutes structural damage resulting in leakage, loss of storage, and loss of operation.	High

Analysis	Yes	No	Remarks
Is there a redundancy requirement prescribed by the current SGMDR?		■	
Is there a risk of failure identified?	■		
Does it affect the performance objective?	■		
Is mitigation of the risk already addressed by the current design criteria?		■	
Are new or additional mitigation strategies needed to address the risk?	■		
Is effort required to access the equipment after failure?	■		Post-EQ inspection

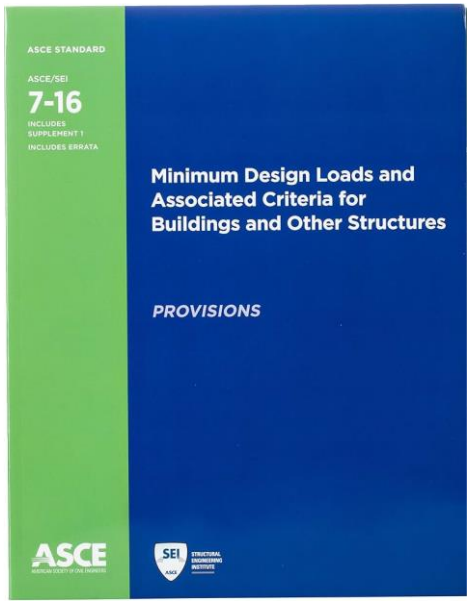
Description of Proposed Mitigations	What are Labor / Cost/ Material Requirements for Mitigation?	Building Inspection or Other Skill Set is Needed (Y/N)?
Connection failure between the walls and foundation slab will be mitigated by installing more seismic cables as part of the enhanced design required per SGMDR. SOP: Perform post-seismic inspection.	Structural inspection involved.	Y

Performance Targets - Waterlines

Waterlines in **Buildings** >> ASCE 7

Chpt 13 – Nonstructural Components

- Default Target is to reduce risk of:
  - components falling
  - blocking exits
- Major damage sustained
- Likely loss of functionally (ASCE 7-16 C13.1.3)





2010 New Zealand Earthquake – University of Canterbury

Graphic Citation: https://www.chronicle.com/article/2-universities-in-new-zealand-cope-with-earthquake-damage/

Performance Targets - Waterlines

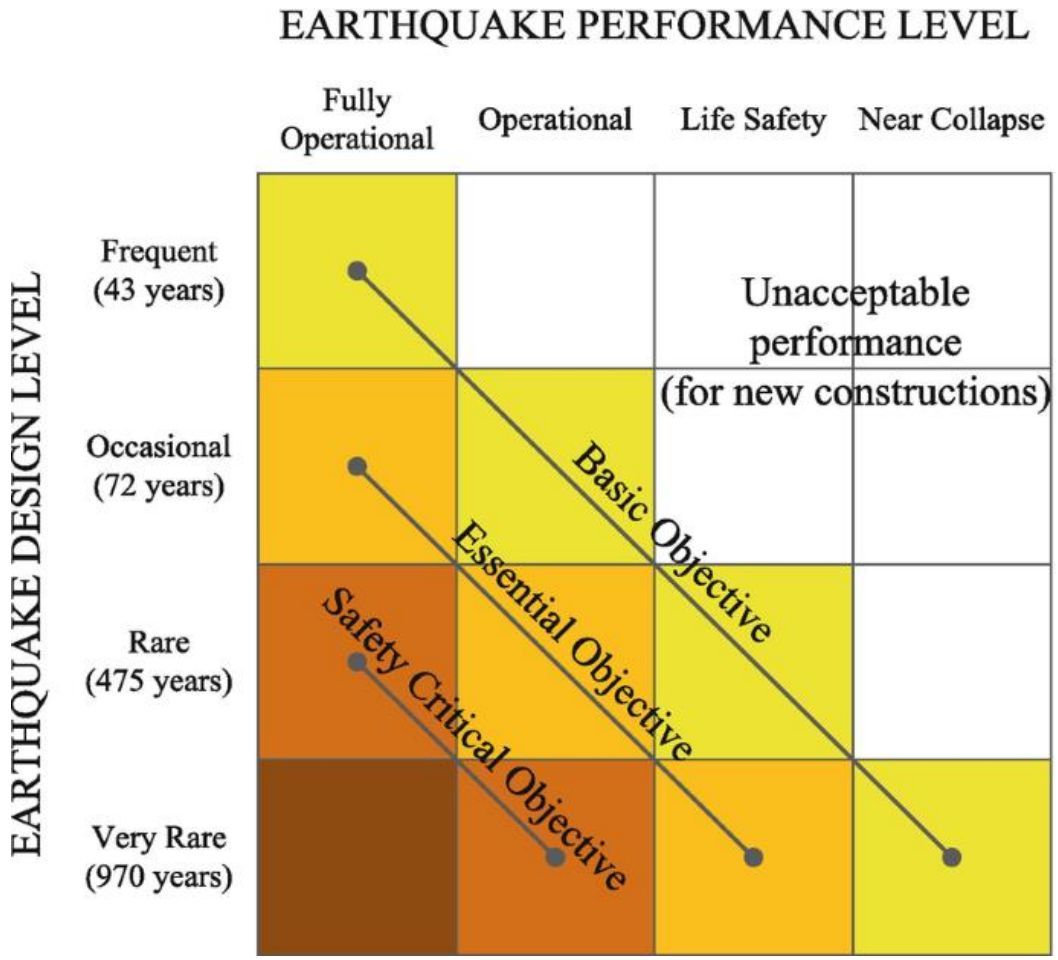
ASCE 7 Enhanced Performance Target

Increase the Important ace Factor (ASCE 7-16 C13.1.3)

- 1.0 – (typical utilities)
  - major damage
  - No significant falling hazards
- 1.5 – (Risk IV, toxic, fire sprinklers and egress)
  - Limited damage
  - Remain in place

$$F_p = \frac{0.4 a_p S_{DS} W_p}{\left(\frac{R_p}{I_p}\right)} \left(1 + 2\frac{z}{h}\right)$$

C13.2.4 – "In many cases, flexibility is more important than strength in the performance of a distributed systems, such as piping or ductwork. A good understanding of the displacement demand on the system, as well as its displacement capacity is required."



Graphic Citation: Saouma, V.E., Hariri-Ardebili, M.A. (2021). Performance Based Earthquake Engineering. In: Aging, Shaking, and Cracking of Infrastructures. Springer, Cham. https://doi.org/10.1007/978-3-030-57434-5_21

Performance Targets - Waterlines

What about waterlines on **Bridges?**

Bridge Code > AASHTO LRFD Bridge Design Specifications

2.5.2.5—Utilities

Where required, provisions shall be made to support and maintain the conveyance for utilities.

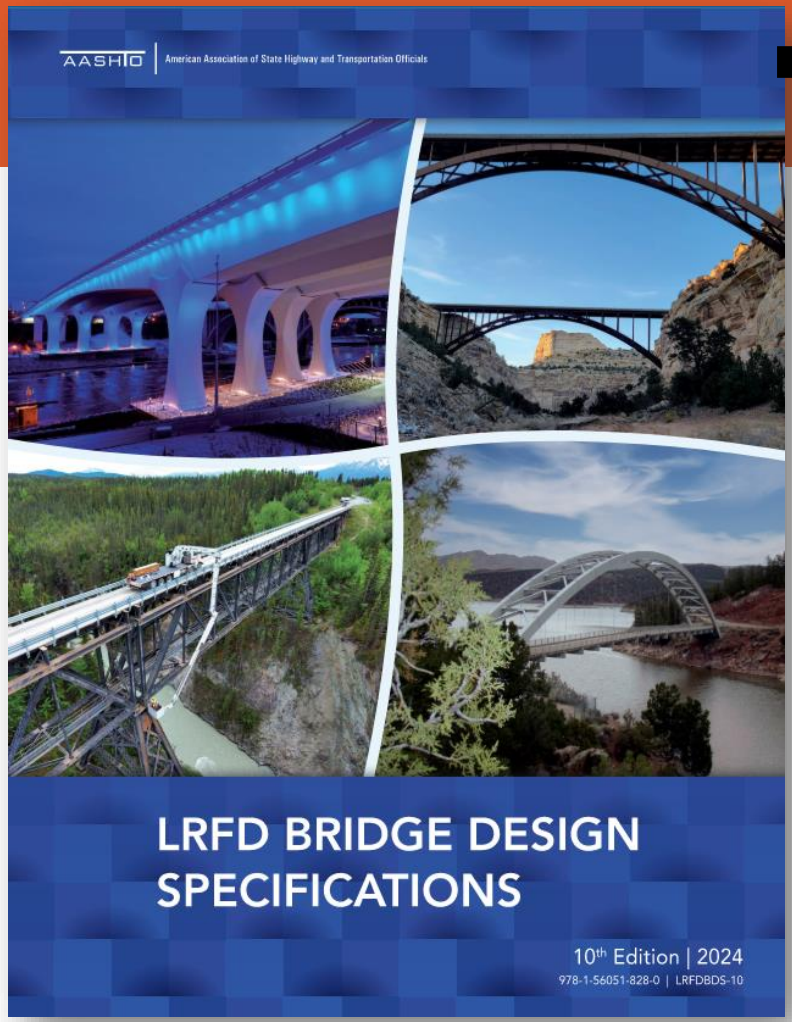
ODOT > Bridge Design Manual 1.12.6.2

Provide transverse supports near each coupling for lines and line thrust blocks as required.

WSDOT > Bridge Design Manual 18.8.2.F

10.8.2.F Water Lines

Transverse support or bracing shall be provided for all water lines to carry Strength and Extreme Event Lateral Loading. Fire control piping is a special case where unusual care must be taken to handle the inertial loads and associated deflections. The Utility Engineer shall be involved in the design of supports resisting dynamic action loads and deflections.

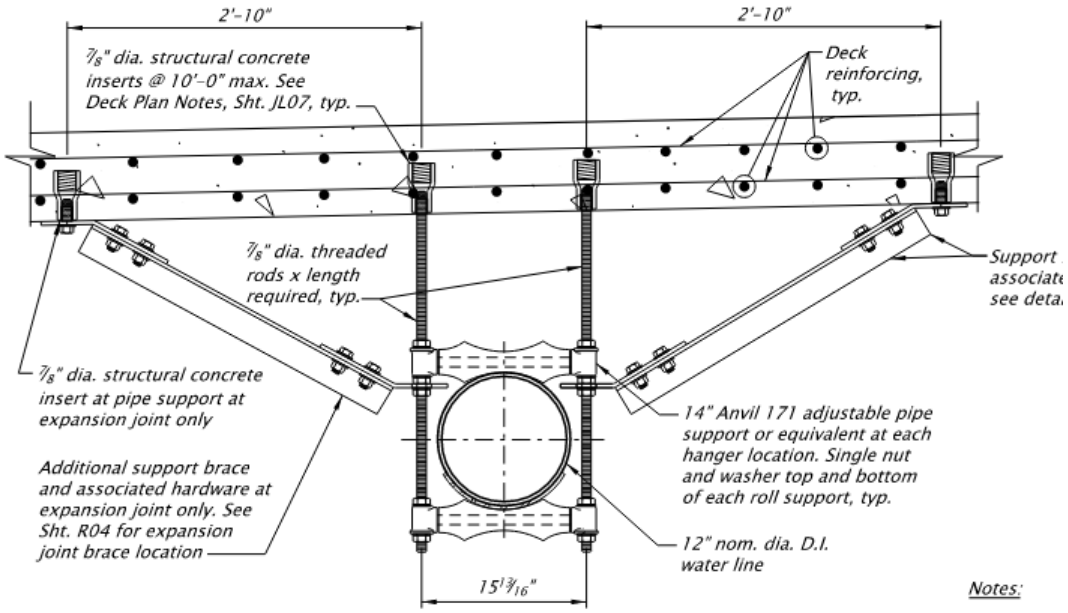




Seismic Risk Mitigations

Seismic Risk Mitigations

Seismic Bracing



PIPE SUPPORT ALONG DECK

Scale: 3/4"=1'-0"



Source: https://ebaa.com/files/pdf/connections/Connections.FT-05.pdf

Seismic Risk Mitigations

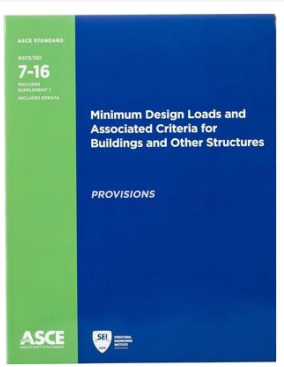
Seismic Bracing Design

Which code??

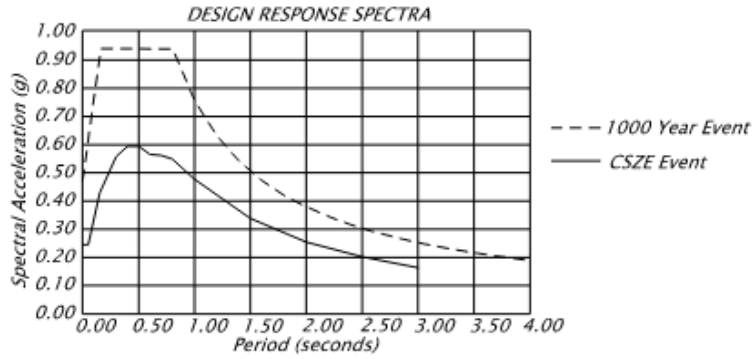
- *Engineer to meet the **performance target** selected.*
- *May be a mix of codes*
  - ASCE 7 – Chapter 13
  - AASHTO –
    - Use period of bridge, distribute seismic mass
    - Model bracing in bridge model
  - DIPRAA – pipe stress limits

dipra
Ductile Iron Pipe Research Association

$$F_p = \frac{0.4 a_p S_{DS} W_p}{\left(\frac{R_p}{I_p}\right)} \left(1 + 2\frac{z}{h}\right)$$



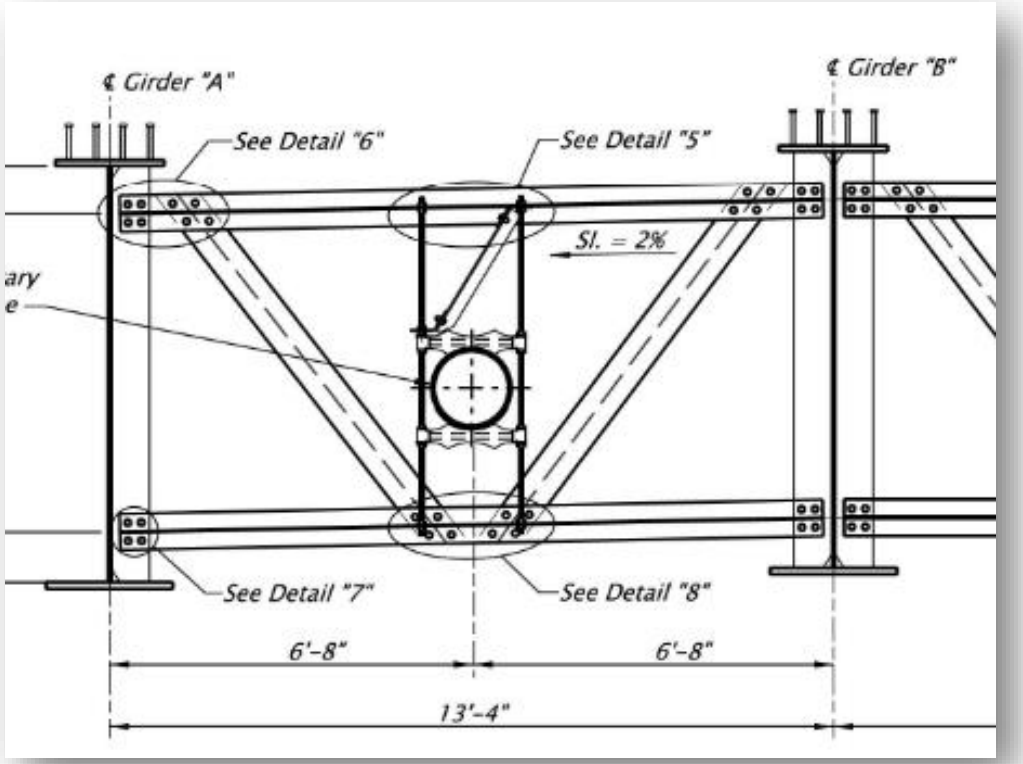
Seismic Performance Criteria	Earthquake	Mapped Hazard Values			Site Class	Design Hazard Values			Seismic Design Criteria
		PGA	S_S	S_1		A_S	S_{DS}	S_{D1}	
Life Safety	1000-Year Return	0.293	0.630	0.247	E	0.475	0.940	0.757	D
Operational	Cascadia Subduction Zone	0.195	0.380	0.195	E	0.245	0.476	0.477	C

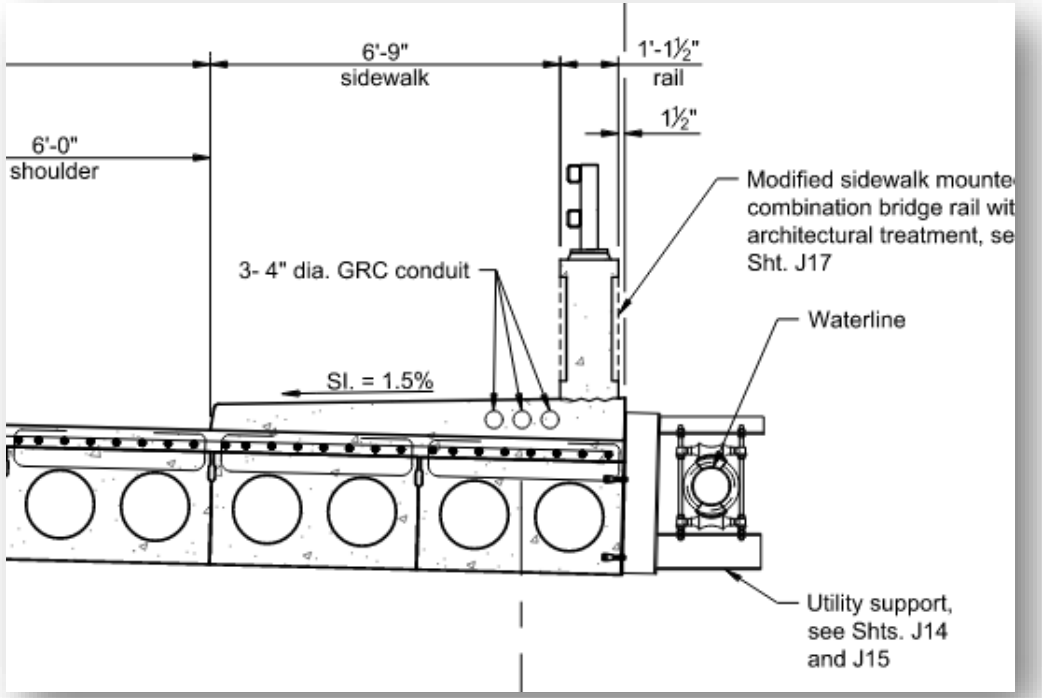


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Seismic Risk Mitigations

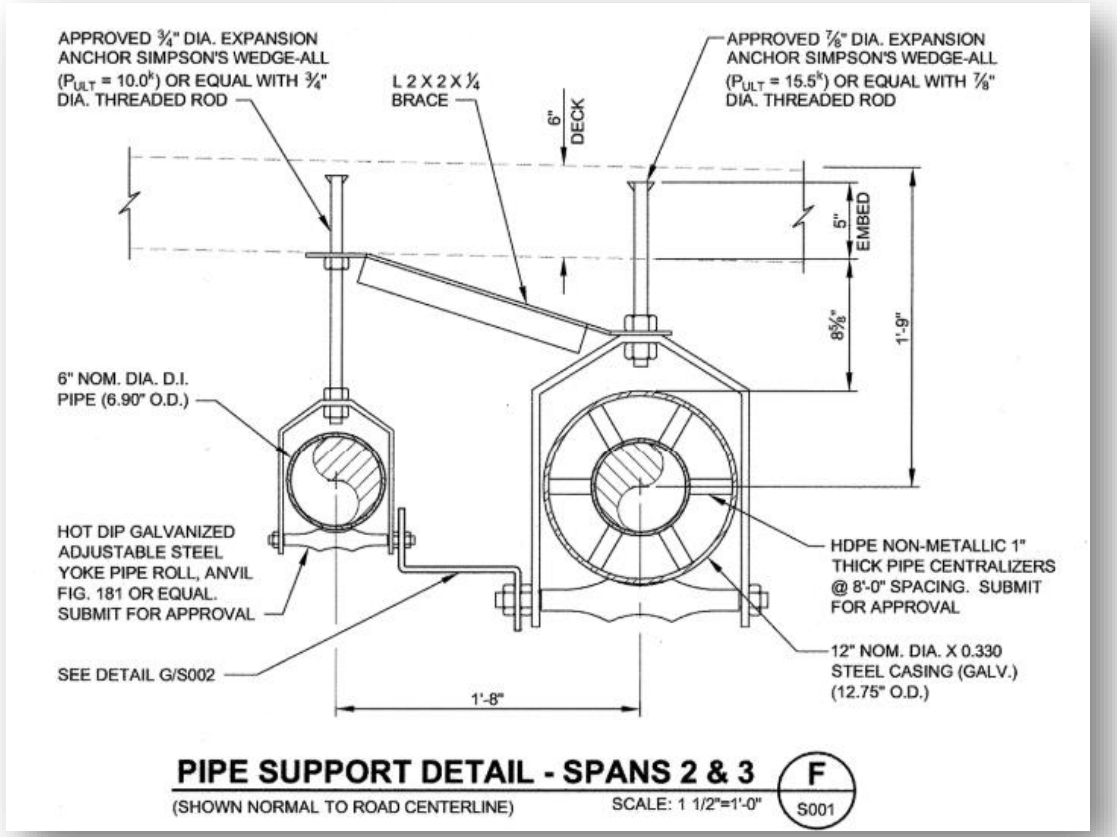
Seismic Bracing

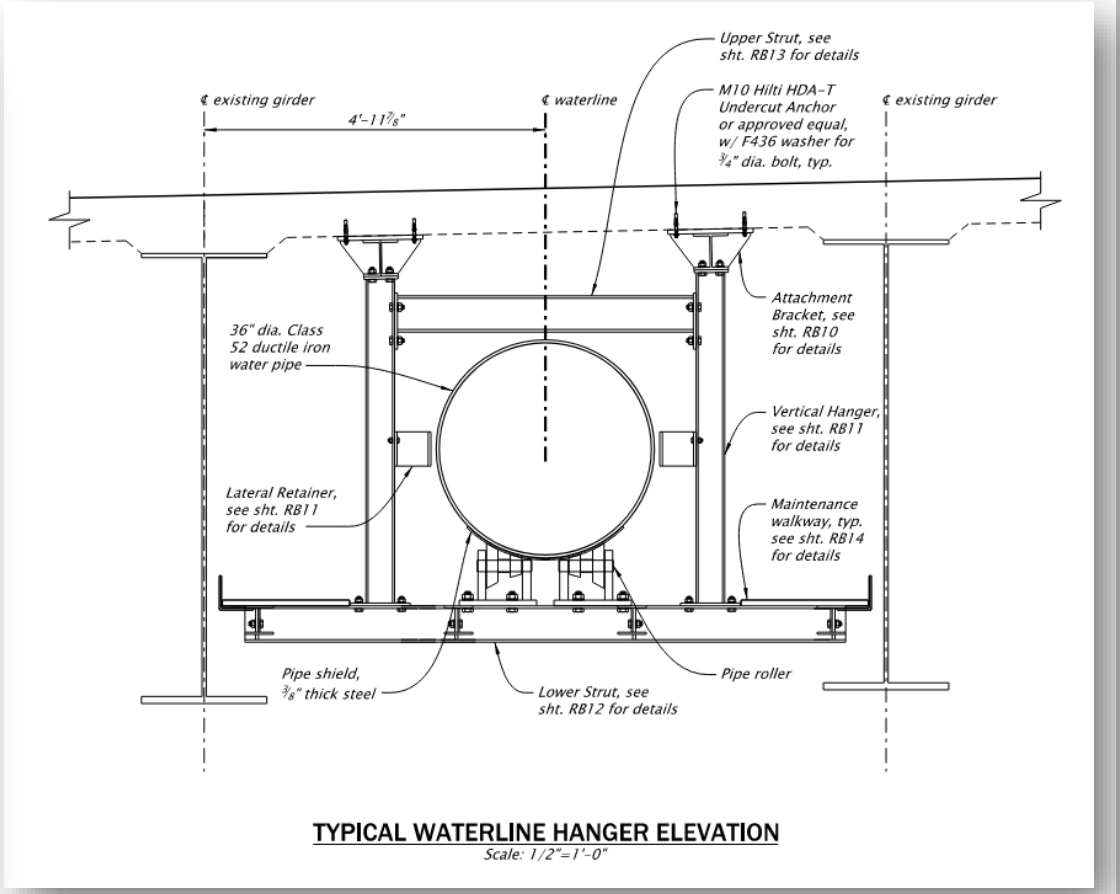




Seismic Risk Mitigations

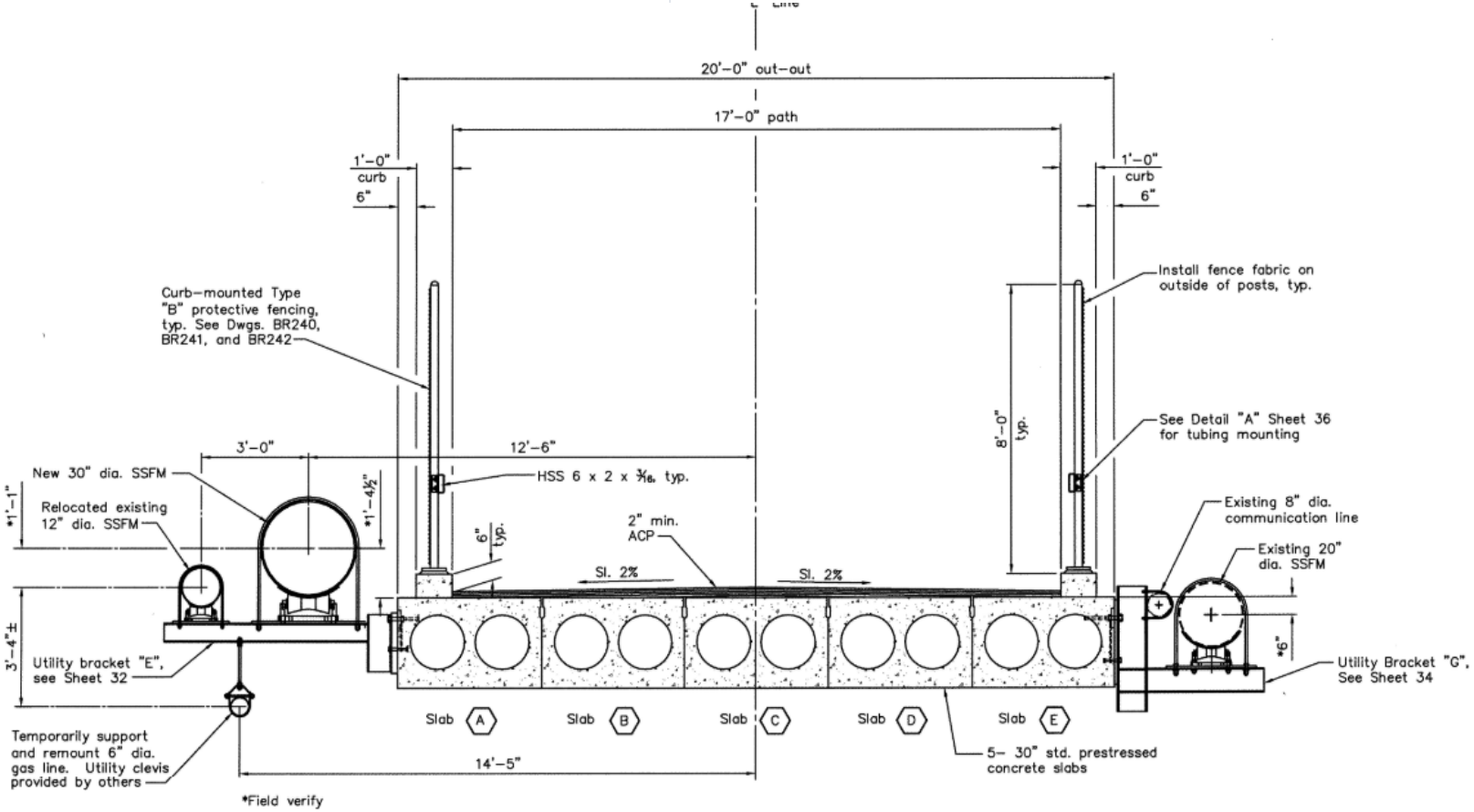
Seismic Bracing





Seismic Risk Mitigations

Seismic Bracing

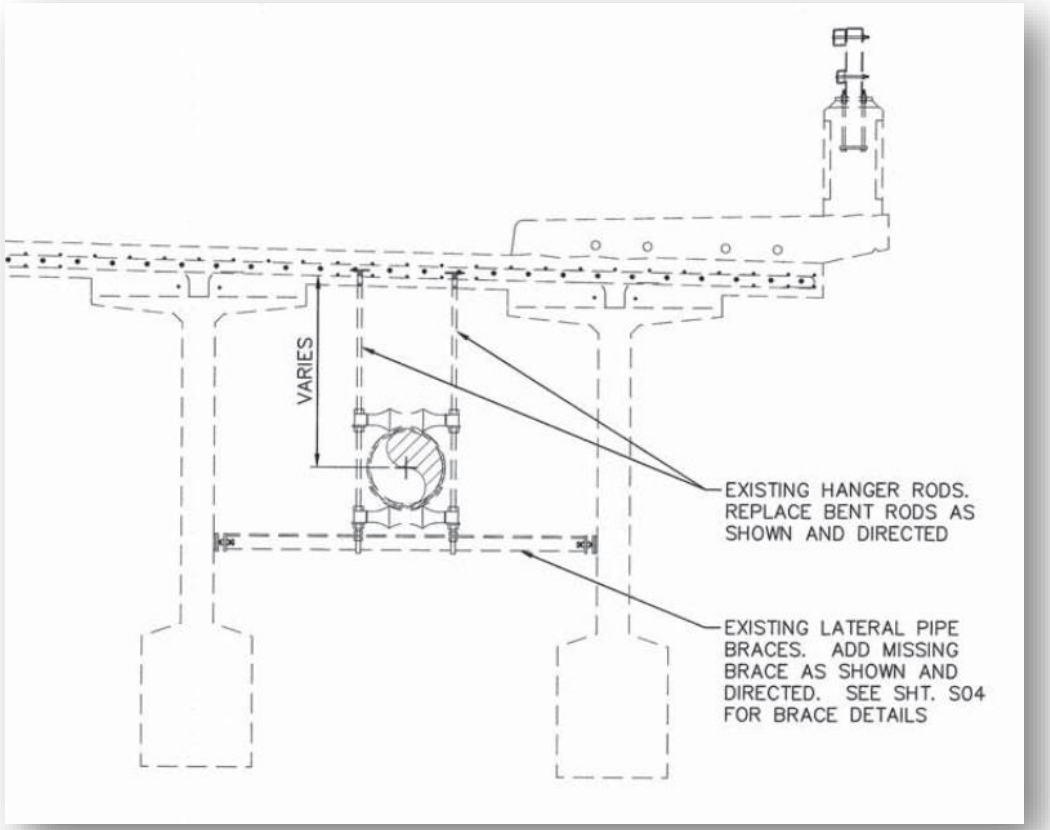


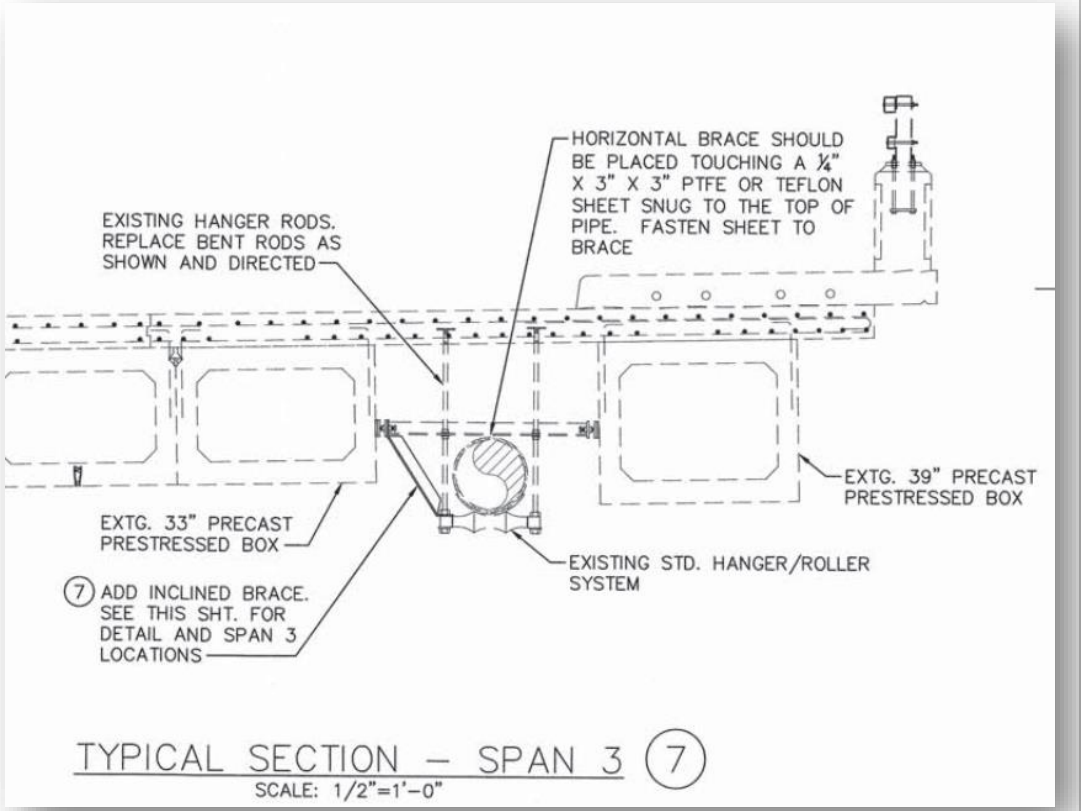
NORTH APPROACH TYPICAL SECTION (LOOKING NORTH)

Scale: ¼"=1'-0"

Seismic Risk Mitigations

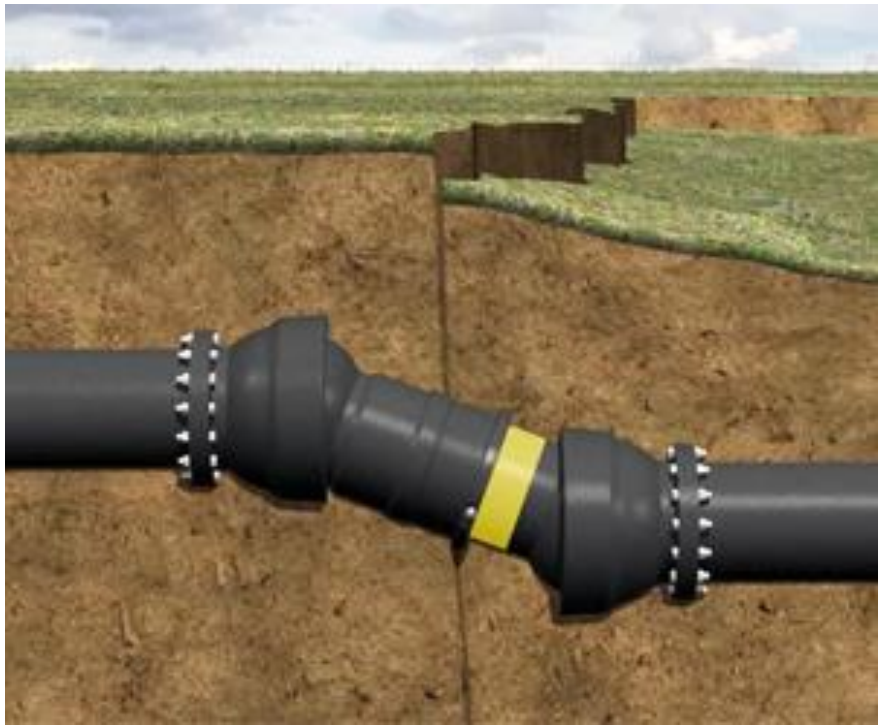
Seismic Bracing





Seismic Risk Mitigations

Flexible Joints







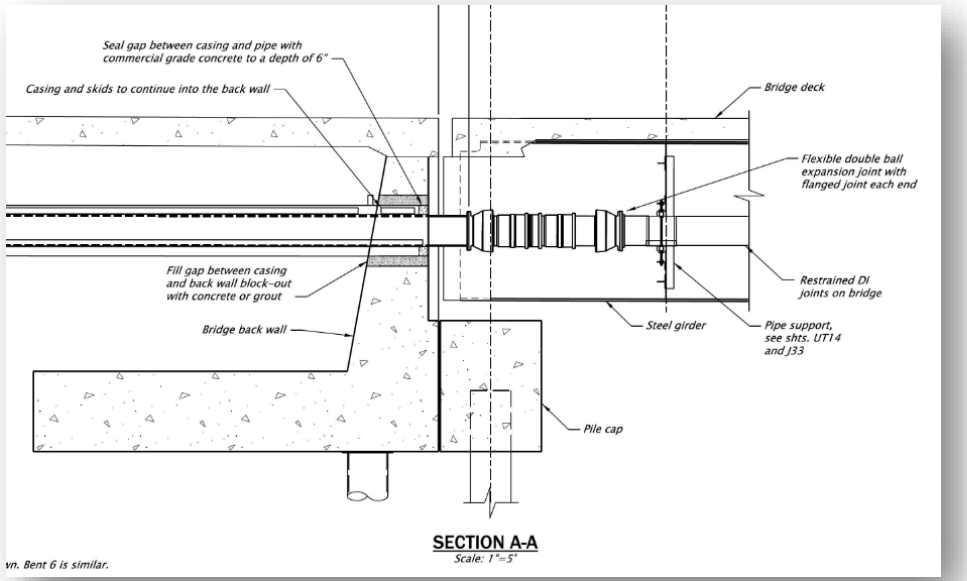
Source: https://ebaa.com/files/pdf/brochures/Brochure.FLEX-TEND%20Force%20Balanced.pdf

Source: https://www.uspipe.com/ductile-iron-pipe/seismic-earthquake-resistant-ductile-iron-pipe-erdip/

Seismic Risk Mitigations

Flexible Joints





C13.2.4 – “In many cases, flexibility is more important than strength in the performance of a distributed systems, such as piping or ductwork. A good understanding of the displacement demand on the system, as well as its displacement capacity is required.”

Seismic Risk Mitigations

Flexible Joint





Seismic Risk Mitigations

Flexible Joints





Seismic Risk Mitigations

Flexible Joints



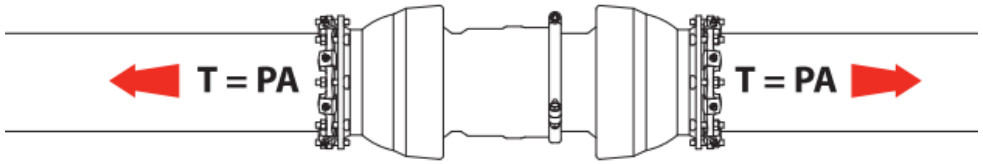
Force Balanced



Non-Force Balanced

Thrust Equation: $T = PA$

Where:
T = Thrust Force, lbs.
P = Hydrostatic Test Pressure (PSI), in^2
A = Area of Pipe, in^2



Source: https://ebaa.com/files/pdf/connections/Connections.FT-05.pdf

Seismic Risk Mitigations

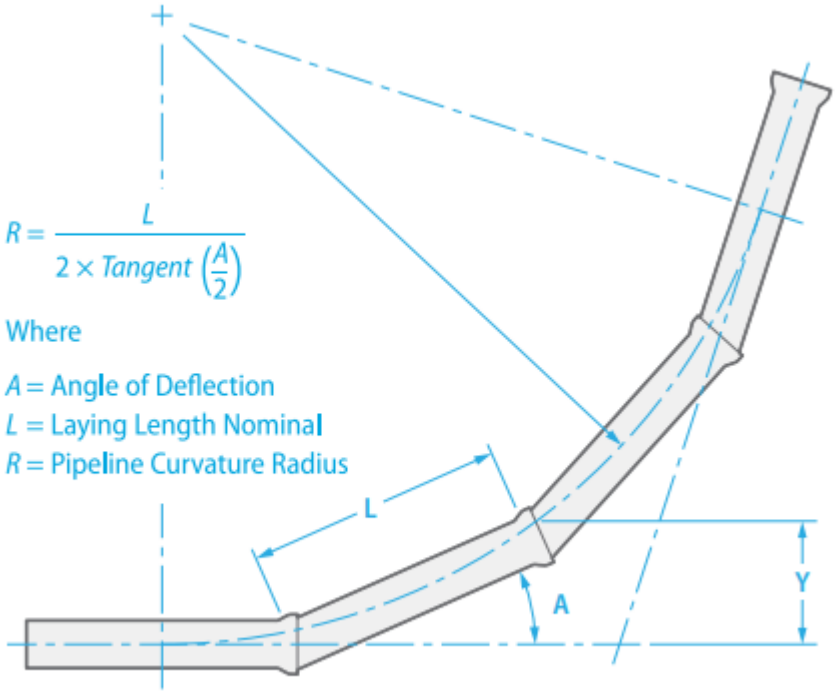


Buried spools

$$R = \frac{L}{2 \times Tangent\left(\frac{A}{2}\right)}$$

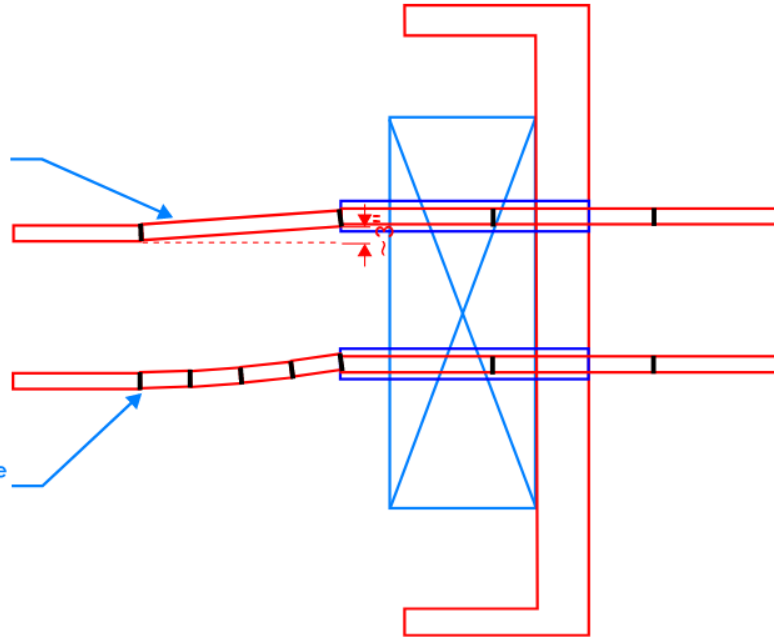
Where

A = Angle of Deflection
L = Laying Length Nominal
R = Pipeline Curvature Radius



One stick can handle deflection, but passive earth pressure over stresses pipe

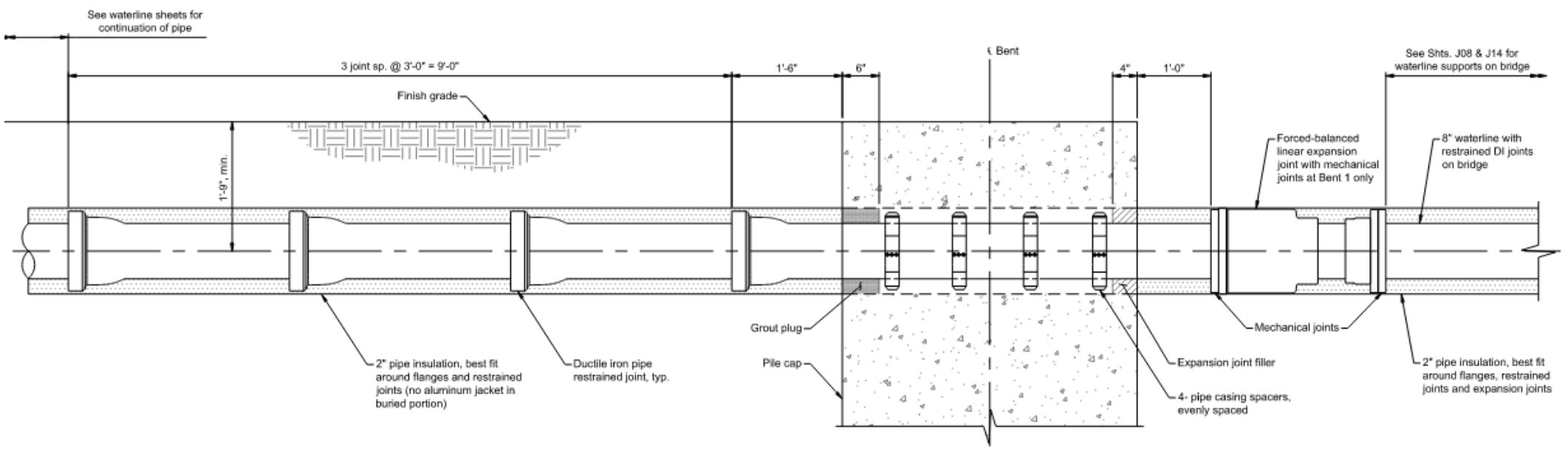
Each joint can handle 3 deg of deflections



Source: https://www.uspipe.com/wp-content/uploads/Seismic_Pipe_Submittal_2024_digital.pdf

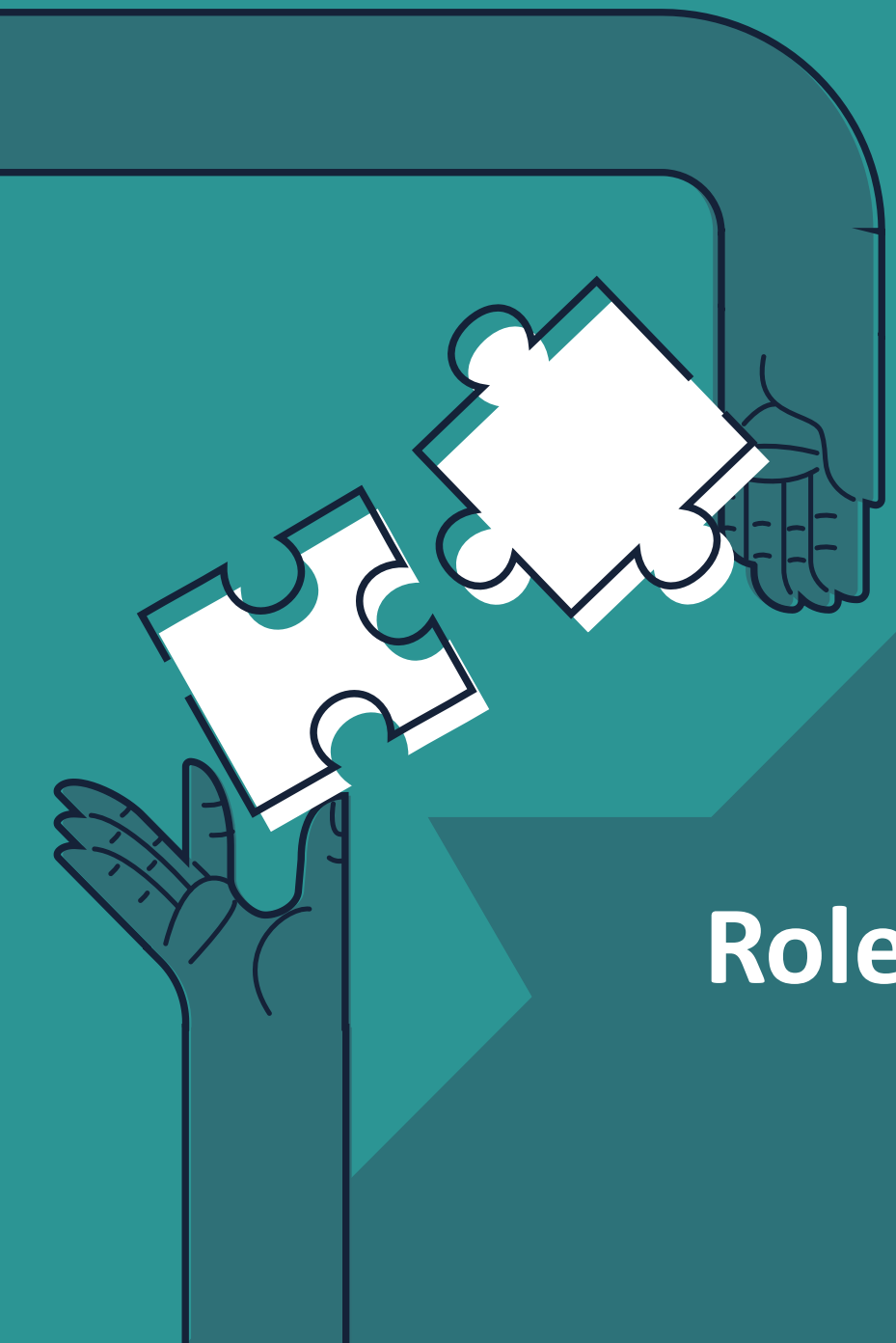
Seismic Risk Mitigations

Buried spools



WATERLINE SUPPORT AT BENTS 1 AND 3

SCALE: 3/4" = 1'-0"



Roles

Roles



Bridge Owner



Bridge Engineer

Waterline Owner

Waterline Engineer

Bridge Owner

- Selects seismic performance target for bridge
- Negotiates “accommodation”

Bridge Engineer

- Designs bridge for performance target
- Incorporates agreed upon “accommodation”
- Communicates bridge seismic behavior to waterline engineer

Roles

Bridge Owner



Waterline Owner

Bridge Engineer



Waterline Engineer

Waterline Owner

- Select seismic performance target for waterline
- Negotiates “accommodation”

Waterline Engineer

- Designs waterline bracing for performance targets
- Designs waterline flexibility for bridge deformations
- Remains within agreed upon “accommodation”

Roles



Bridge Owner





Waterline Owner

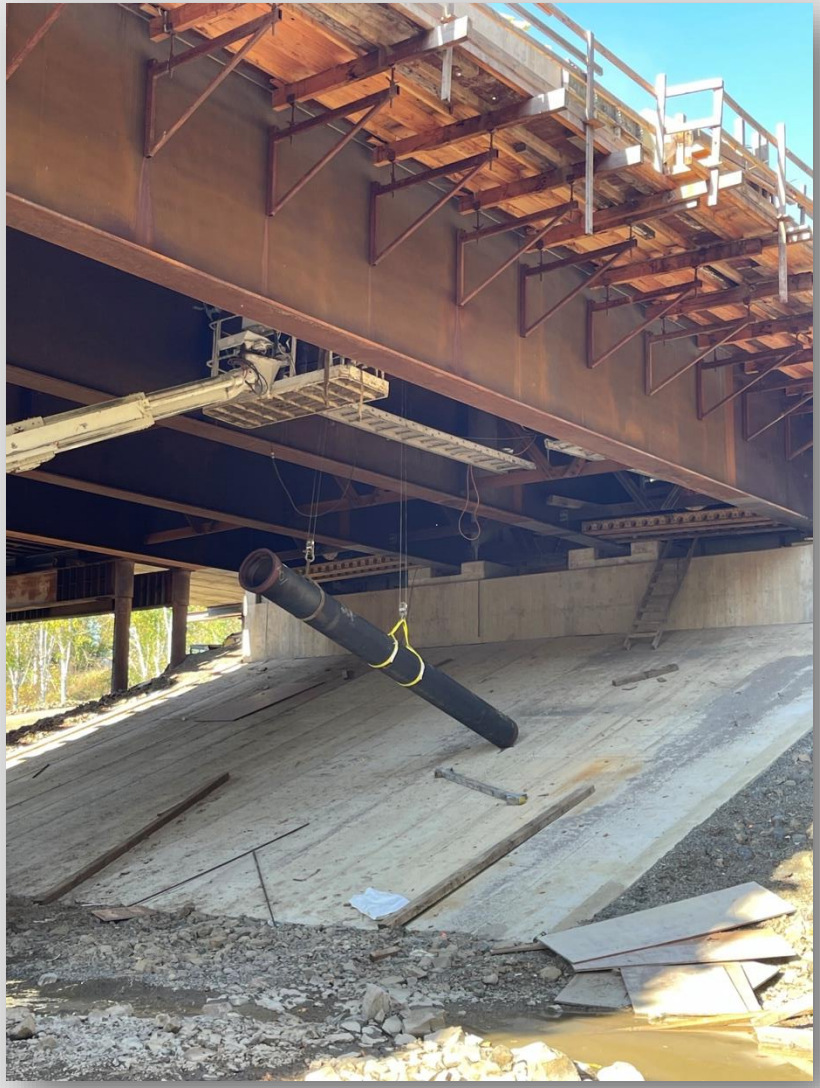


Bridge Engineer





Waterline Engineer





Take-aways

DOWL

Take-aways

- Seismic risk exist for **both bridges and waterlines**
- Bridge and utilities owners **both have seismic performance goals** *(may be the same or may be different)*
- Mitigations include **bracing, flexibility and/or armoring**
- More **coordination** between bridge and waterline engineer the better



Thank you

Questions?



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