# 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

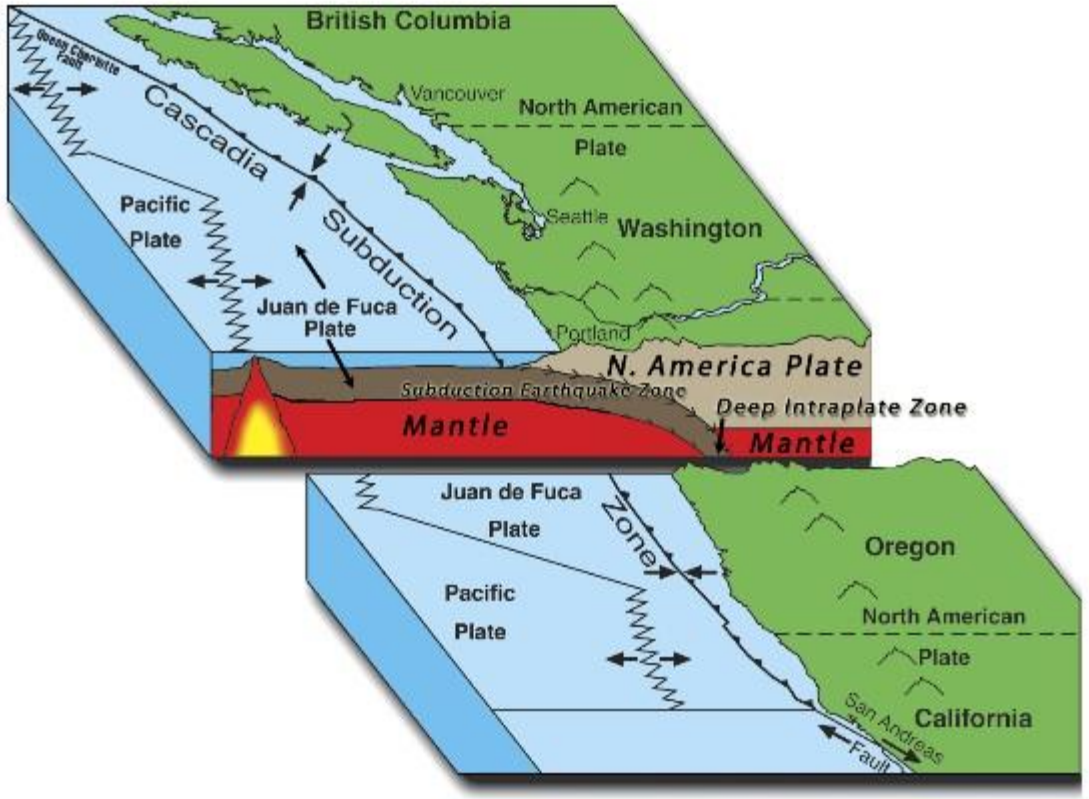






# Seismic Risks

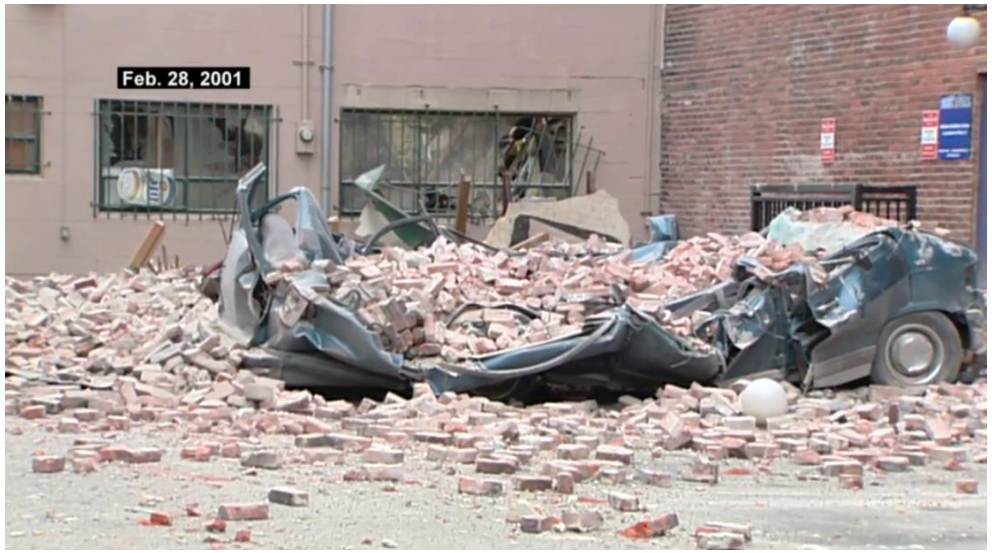
# Seismic Risks




*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



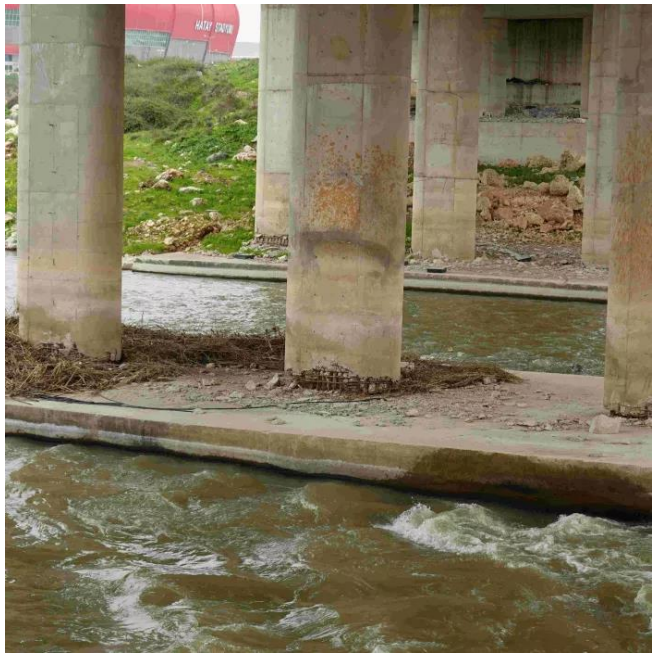


*Source: https://thatoregonlife.com/2024/12/cascadia-subduction-zone-earthquake-the-big-one-oregon-highways-knocked-out/*

# Seismic Risks - Bridges



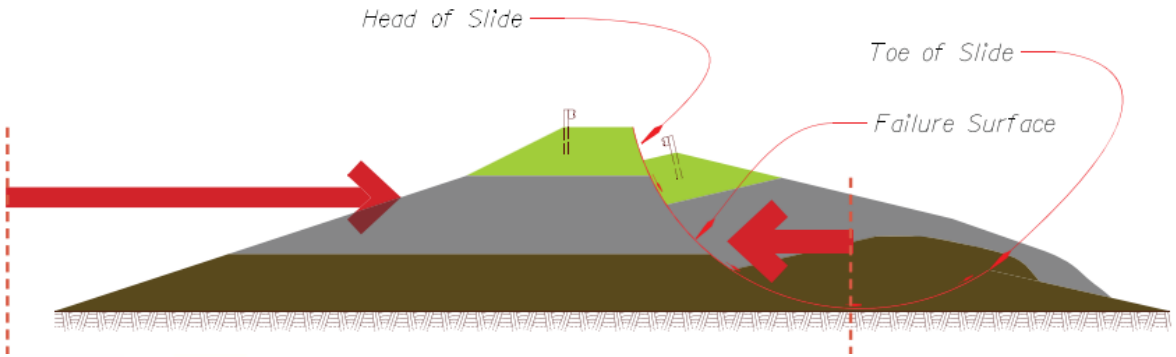




*Source: https://www.exponent.com/article/modeling-earthquake-bridge-damage*

*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

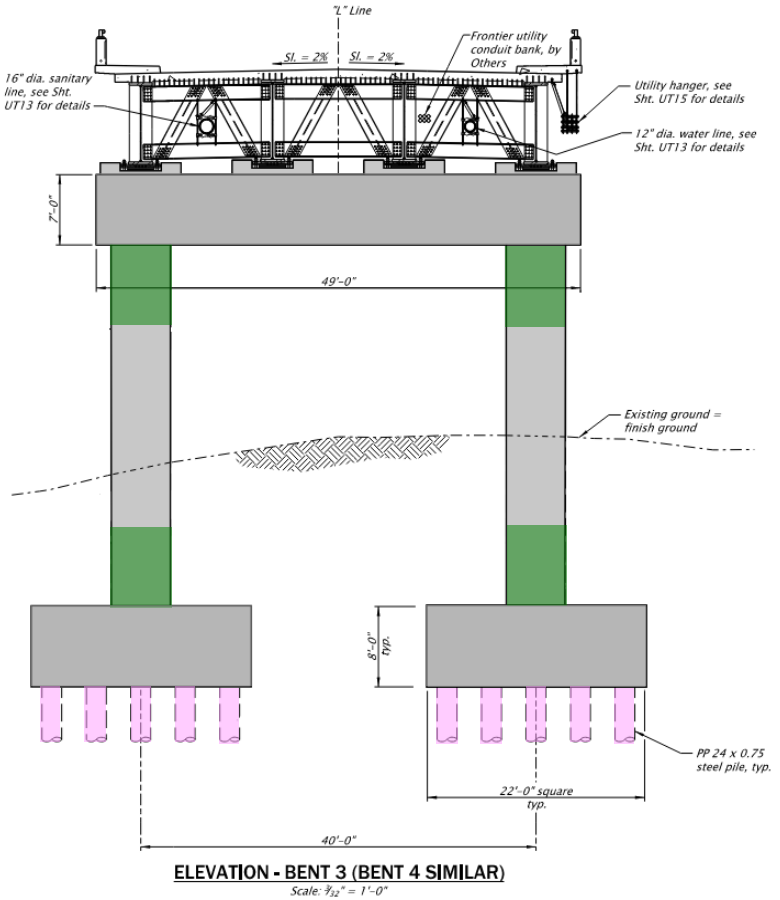
- Sets goals and criteria for transportation system hardening
- Guidelines for replace or retrofit

| 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 |

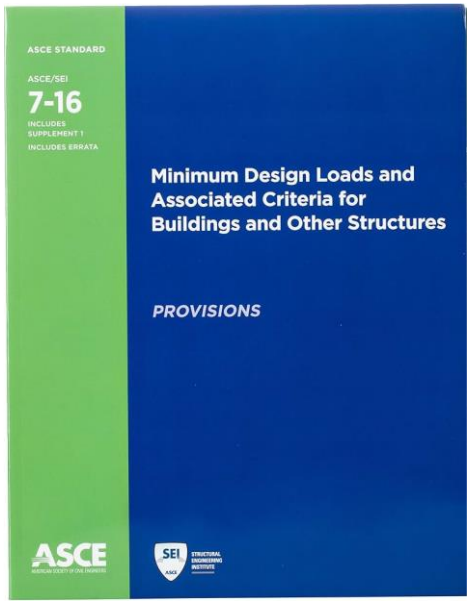
| Description of Proposed Mitigations | What are Labor / Cost/ Material Requirements for Mitigation? | Building Inspection or Other Skill Set is Needed (Y/N)? |
|---|---|---|
| Connection failure between the walls and foundation slab will be mitigated by installing more seismic cables as part of the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

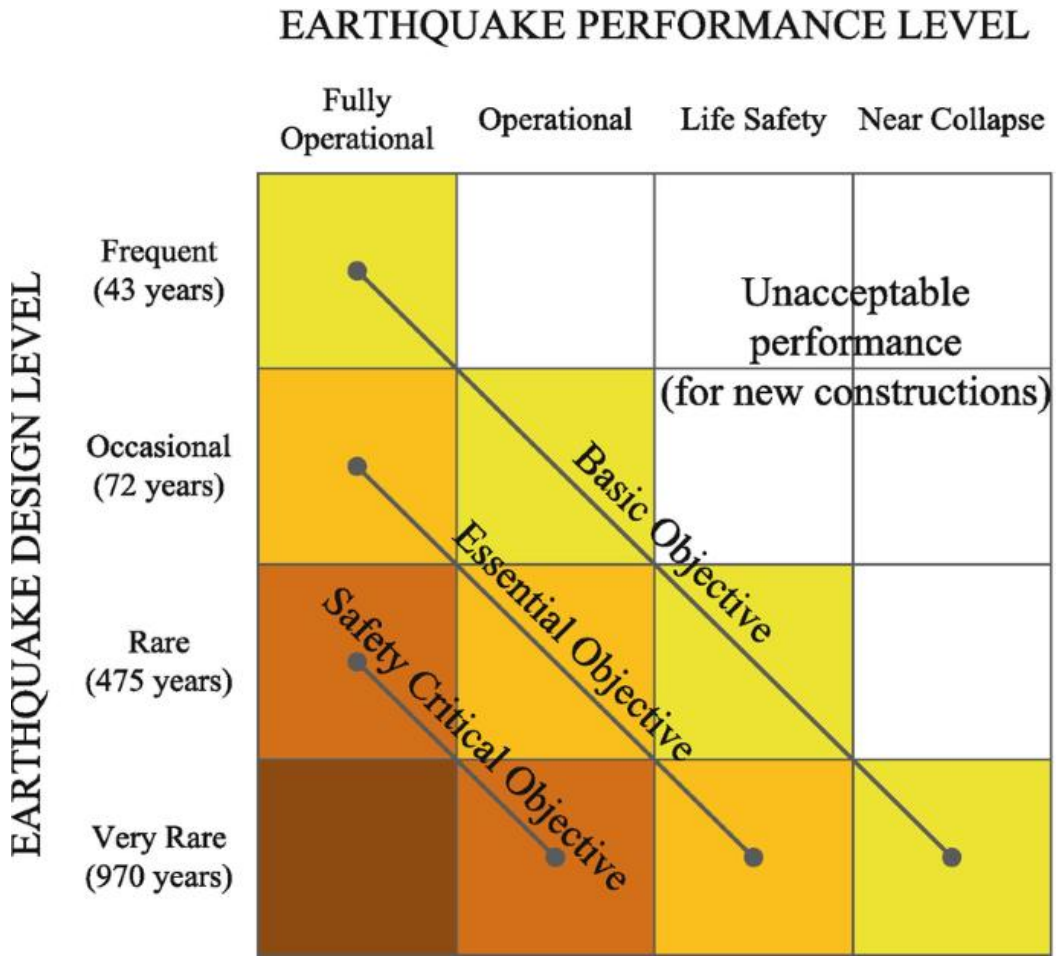
**ASCE 7 Enhanced Performance Target**

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.

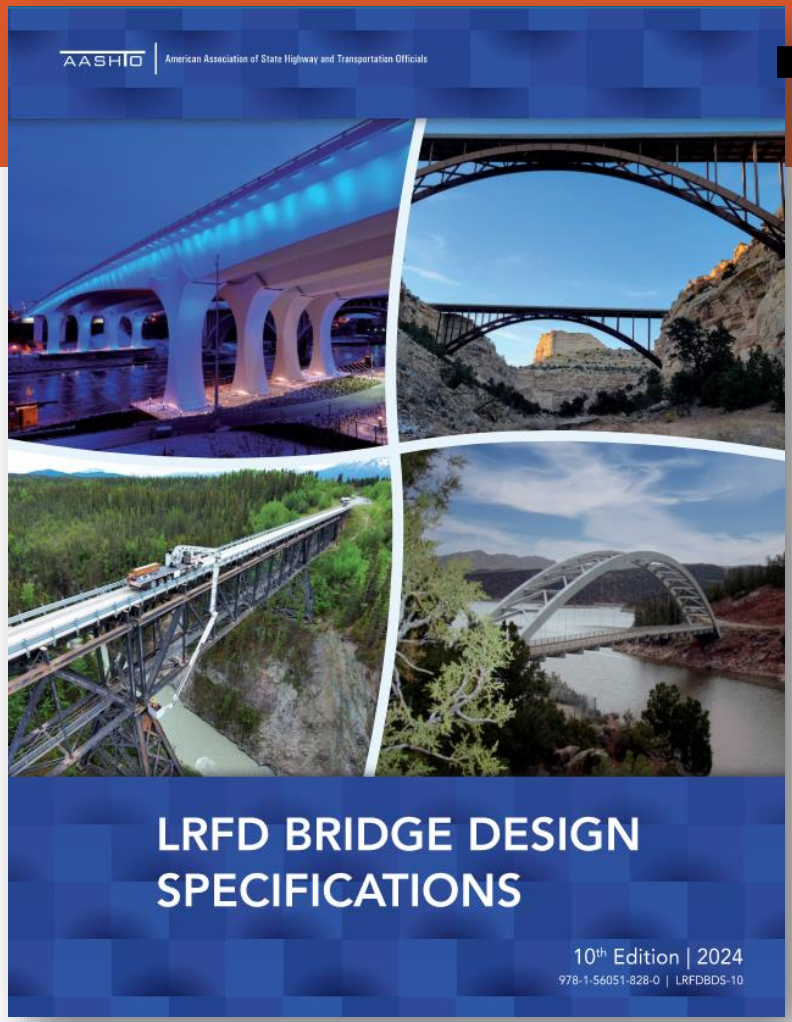
ODOT > Bridge Design Manual 1.12.6.2

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.

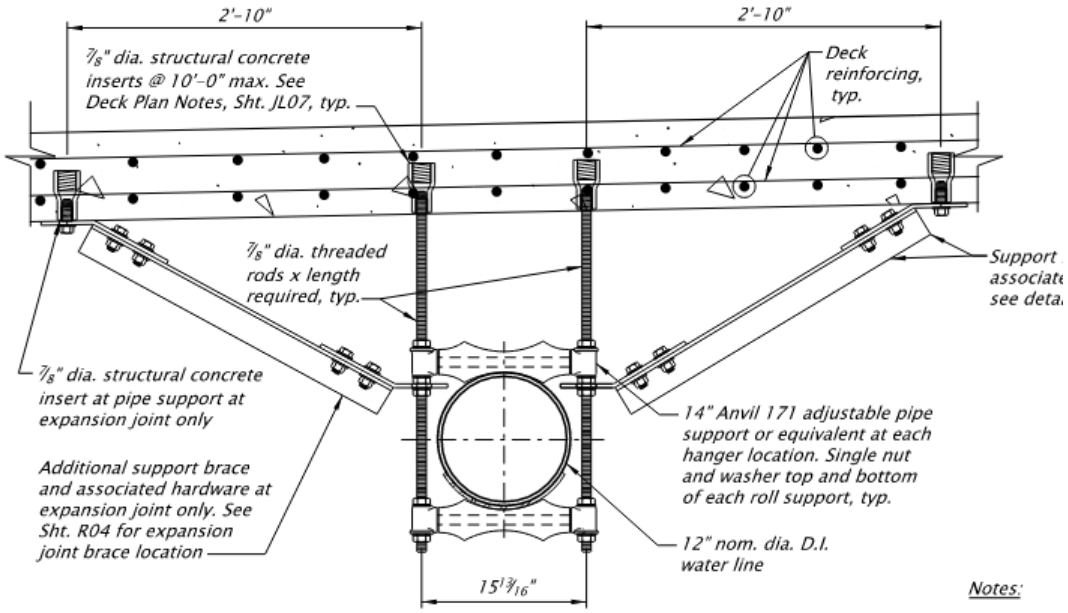




# Seismic Risk Mitigations

# 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

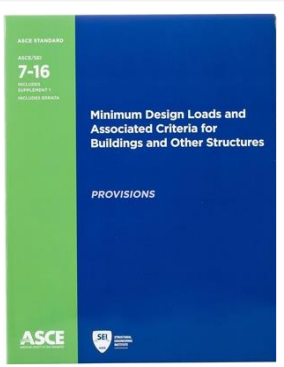
## Seismic Bracing Design

Which code??

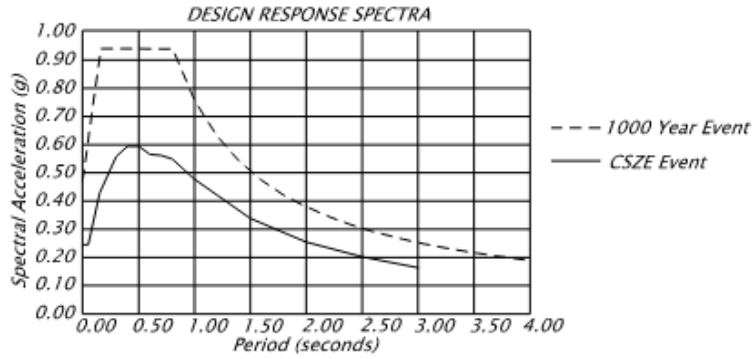
- *Engineer to meet the **performance target** selected.*
- *May be a mix of codes*
  - ASCE 7 – Chapter 13
  - AASHTO –
    - Use period of bridge, distribute seismic mass
    - Model bracing in bridge model
  - DIPRAA – pipe stress limits

dipra
Ductile Iron Pipe Research Association

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



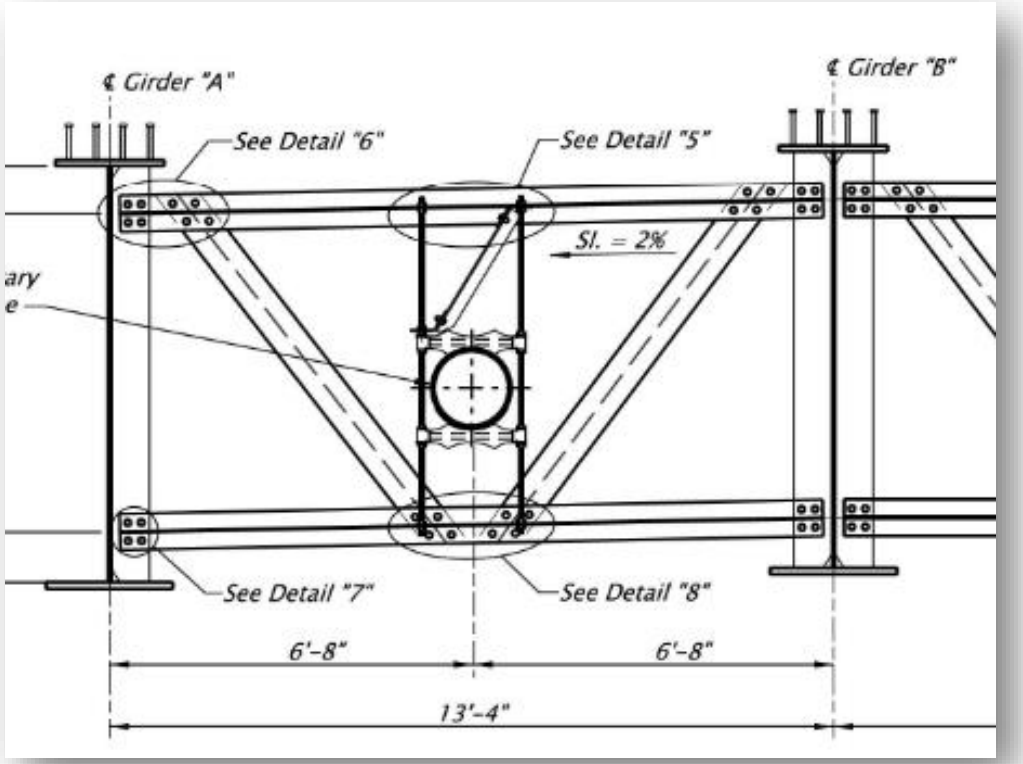

| Seismic Performance Criteria | Earthquake | Mapped Hazard Values | | | Site Class | Design Hazard Values | | | Seismic Design Criteria |
|---|---|---|---|---|---|---|---|---|---|
| | | PGA | $S_S$ | $S_1$ | | $A_S$ | $S_{DS}$ | $S_{D1}$ | |
| Life Safety | 1000-Year Return | 0.293 | 0.630 | 0.247 | 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 |

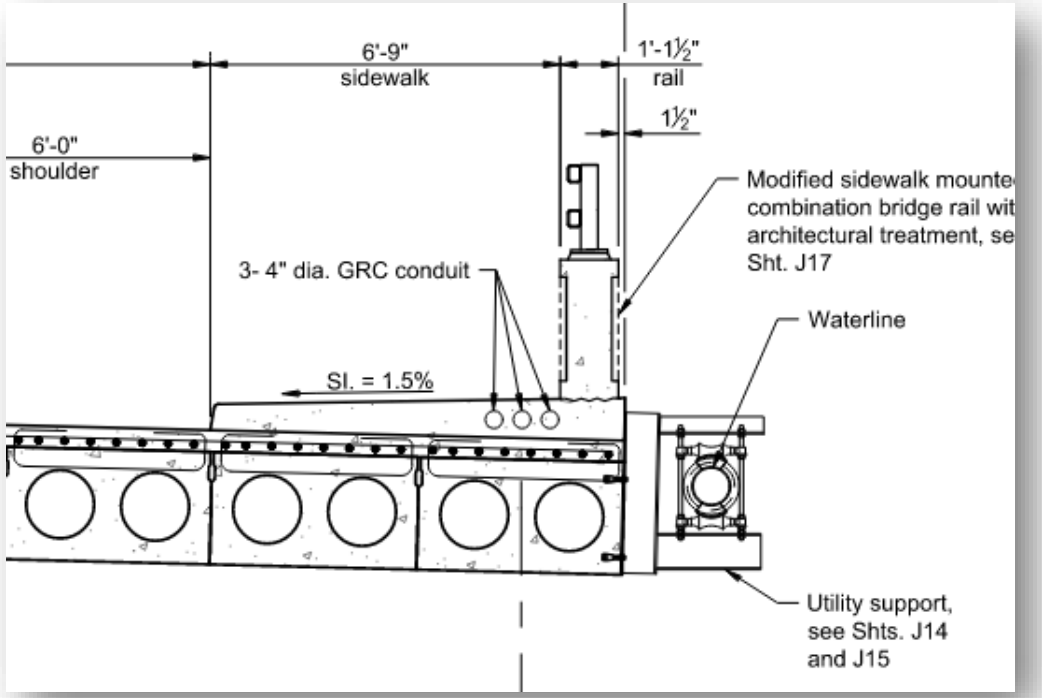



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# Seismic Risk Mitigations

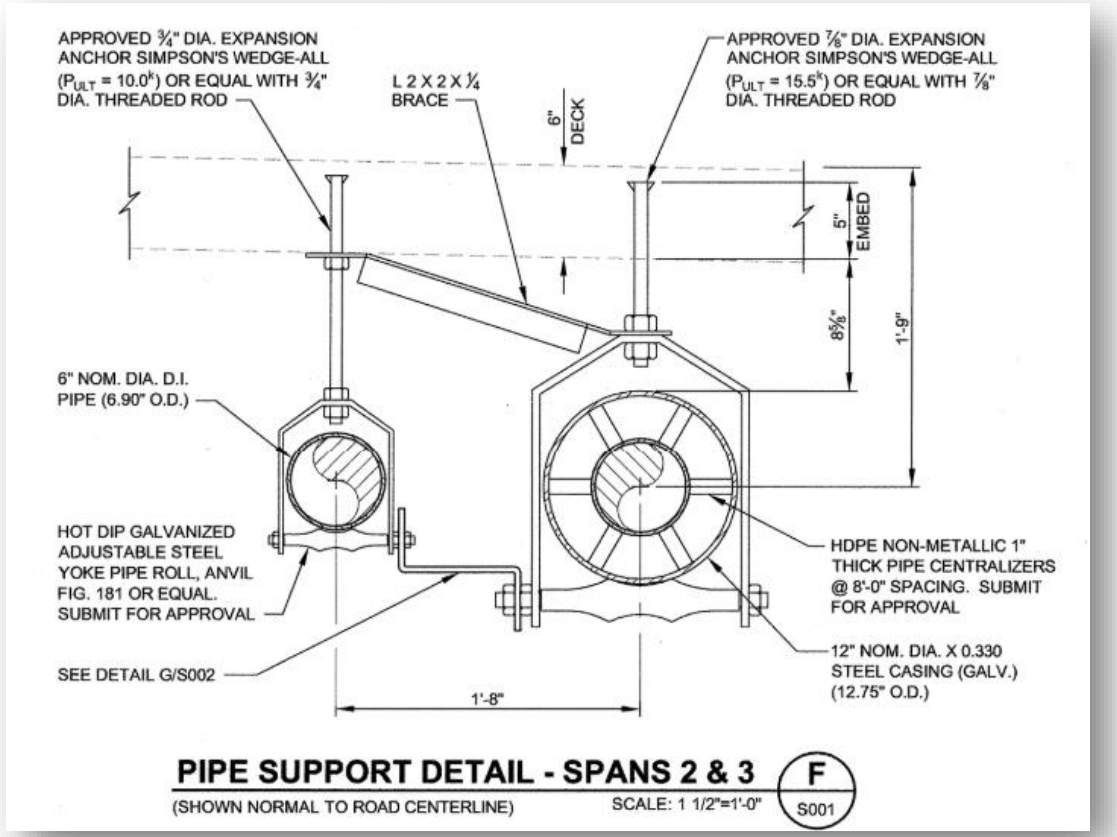
## Seismic Bracing

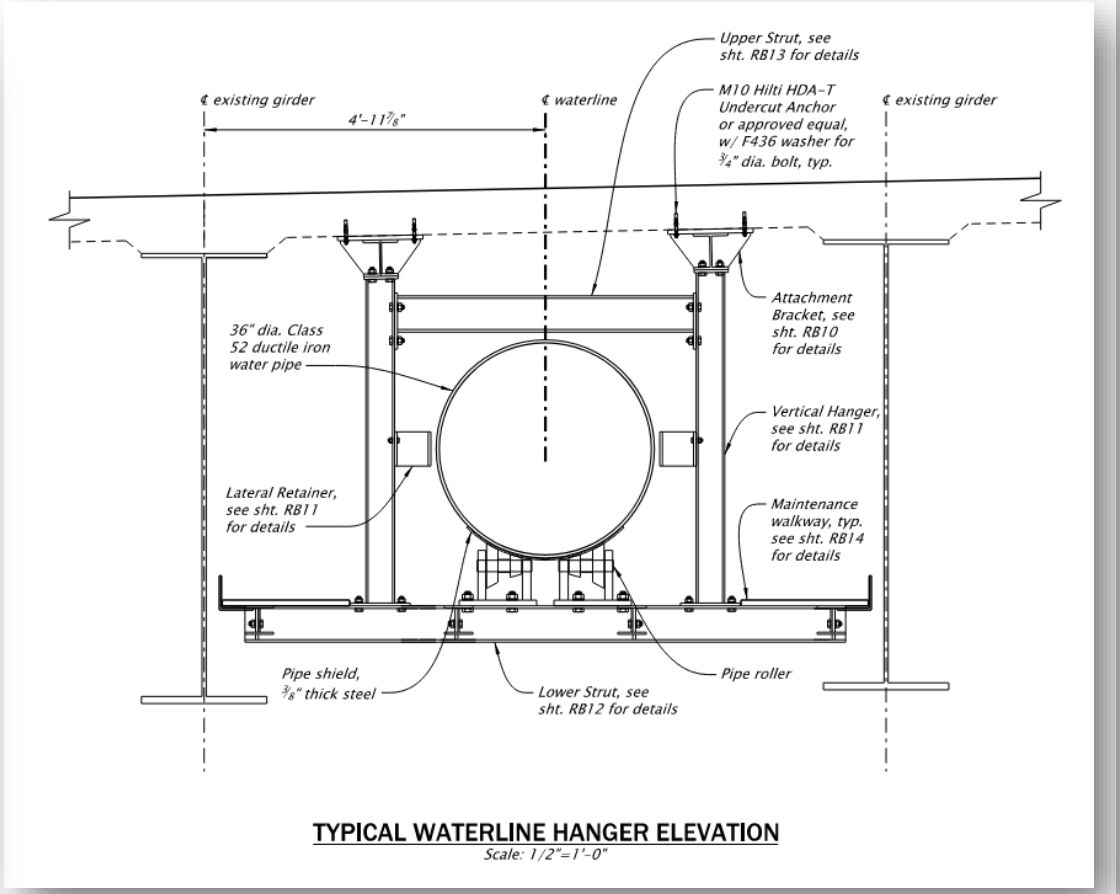


# Seismic Risk Mitigations

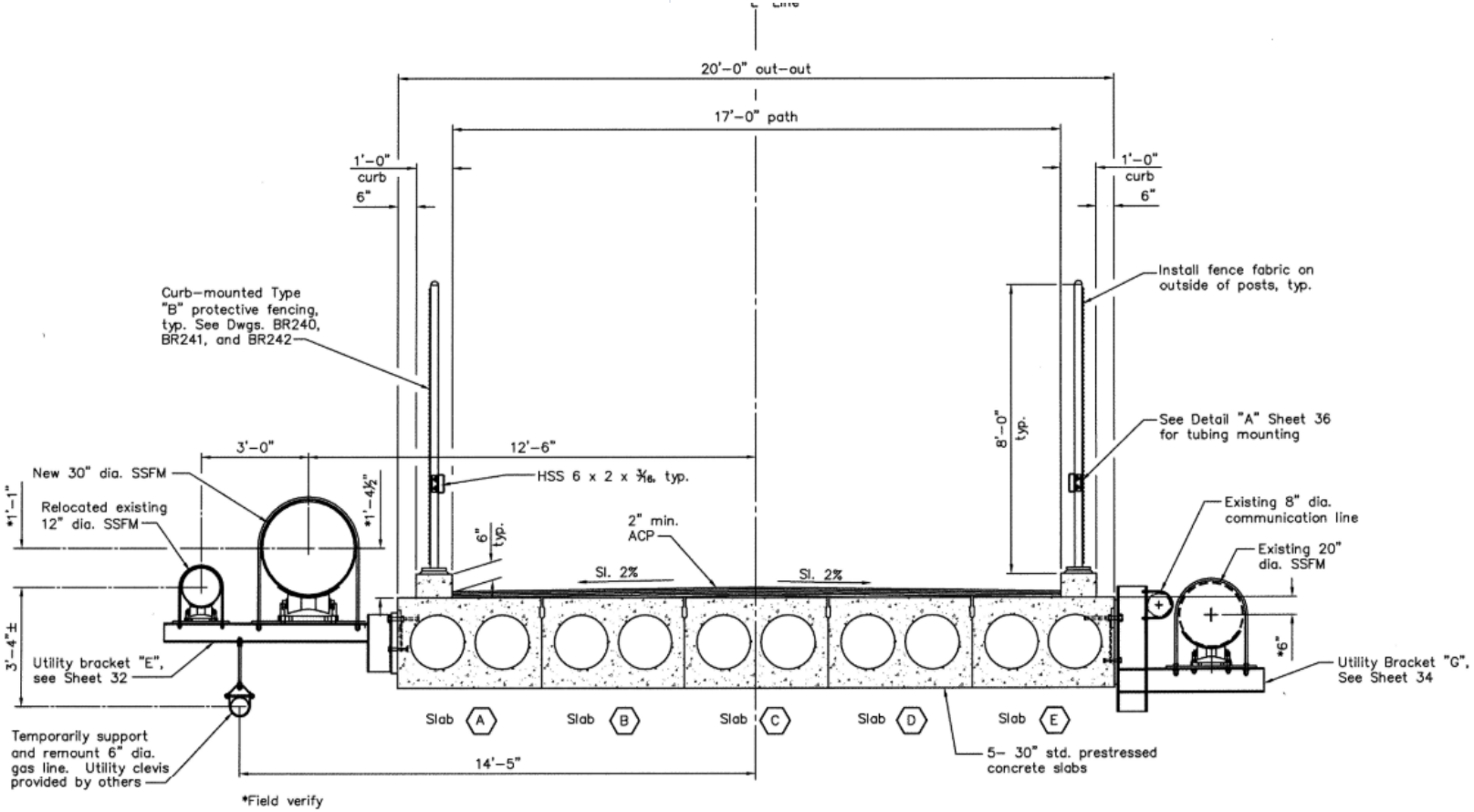
## Seismic Bracing



# Seismic Risk Mitigations

## Seismic Bracing

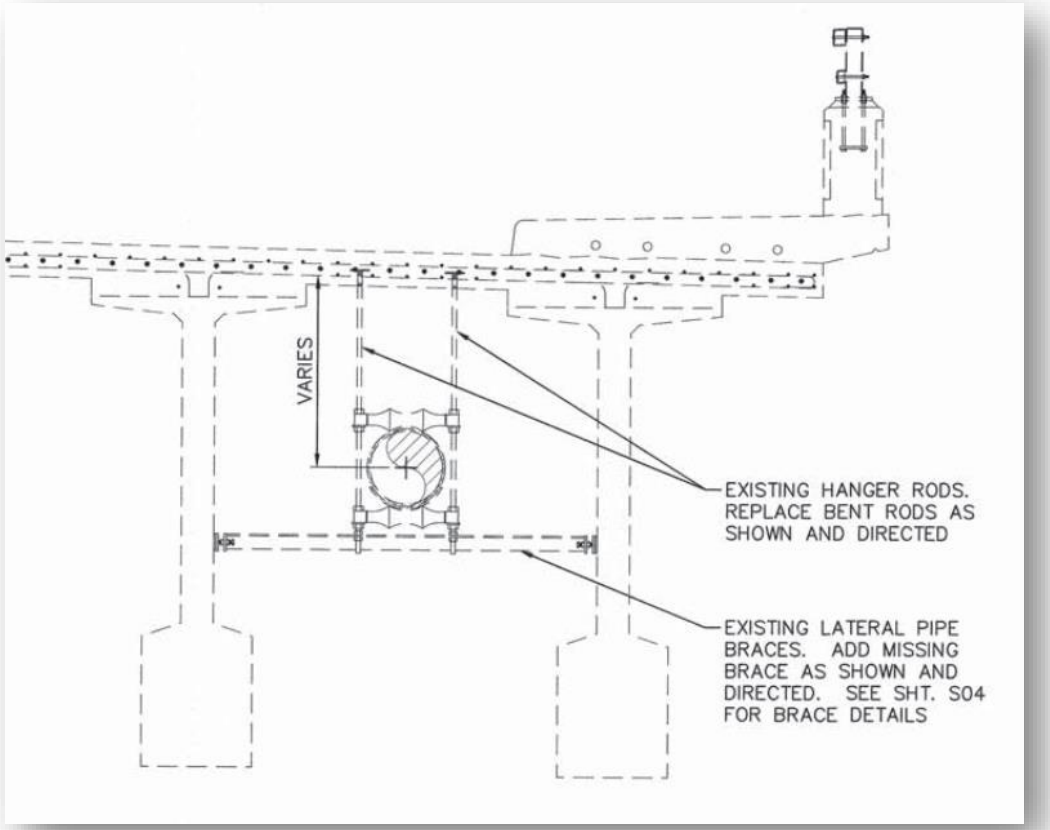


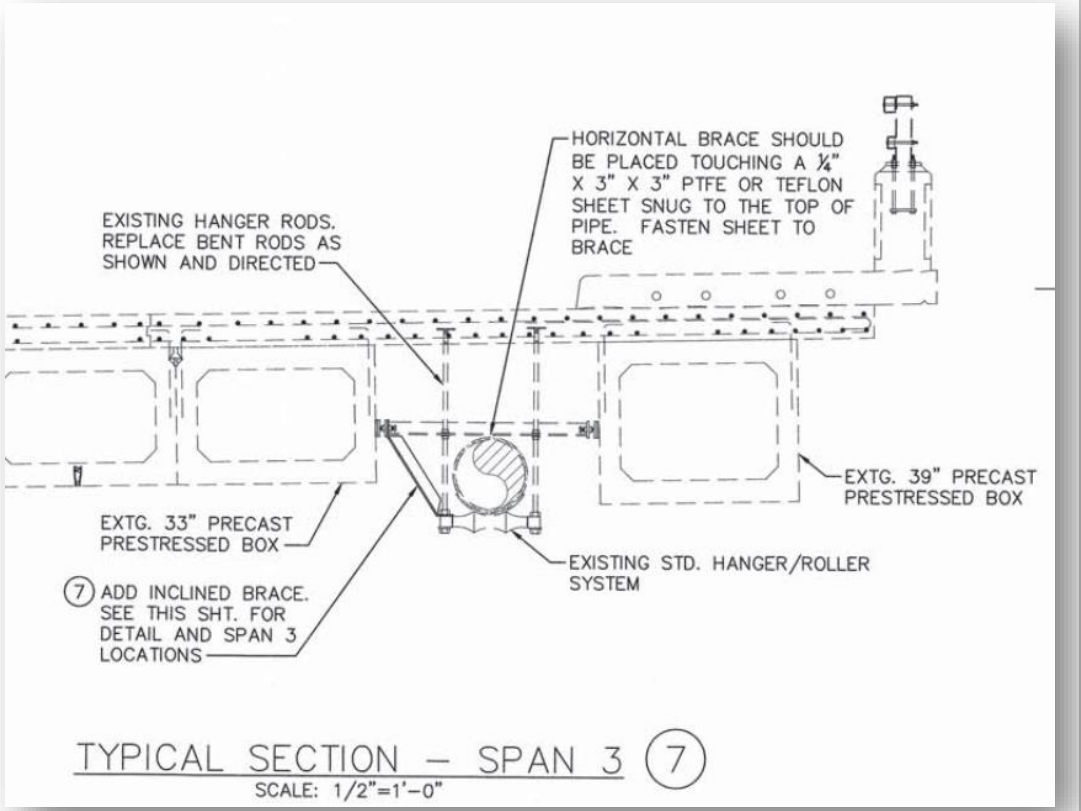

NORTH APPROACH TYPICAL SECTION (LOOKING NORTH)

Scale: ¼"=1'-0"

# Seismic Risk Mitigations

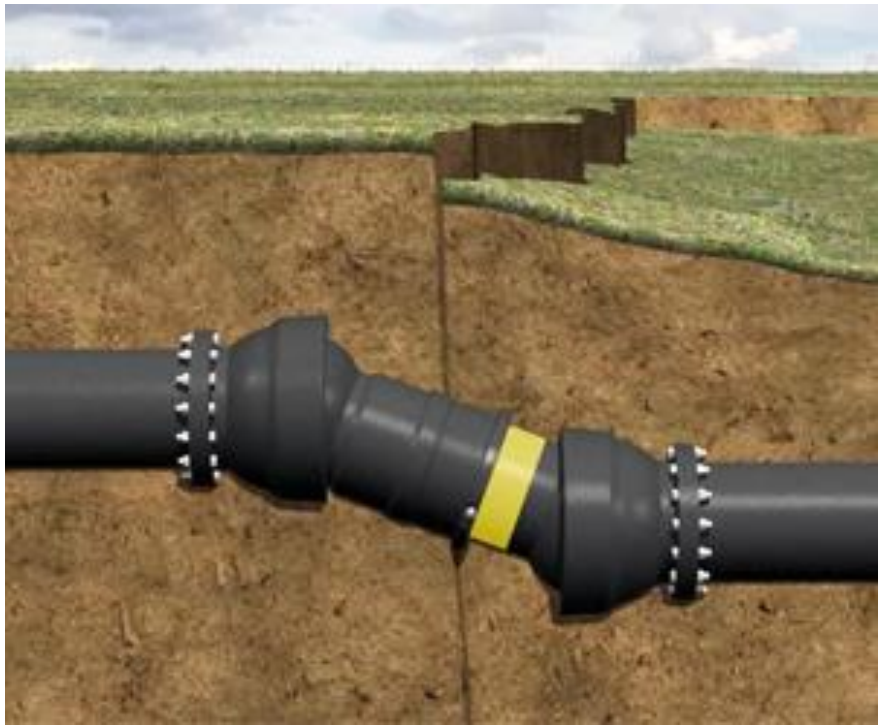
## Seismic Bracing



# Seismic Risk Mitigations

## Flexible Joints







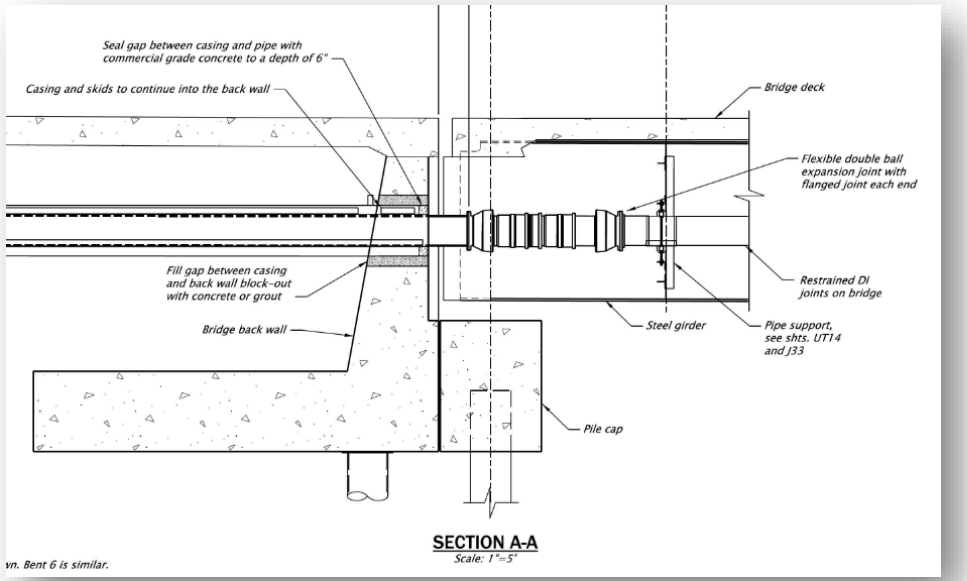
*Source: https://ebaa.com/files/pdf/brochures/Brochure.FLEX-TEND%20Force%20Balanced.pdf*

*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



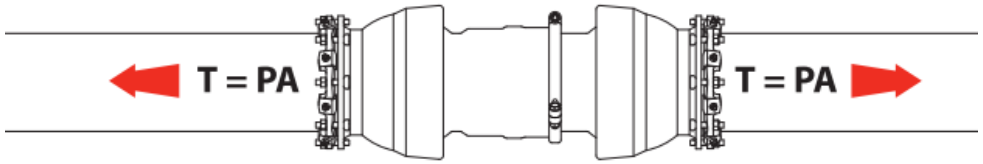
Force Balanced



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

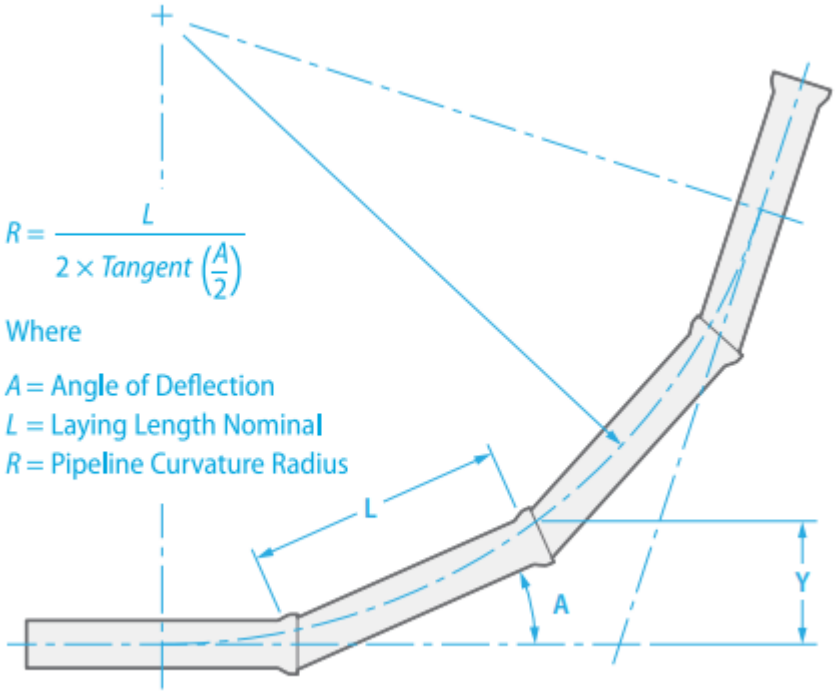


## Buried spools

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

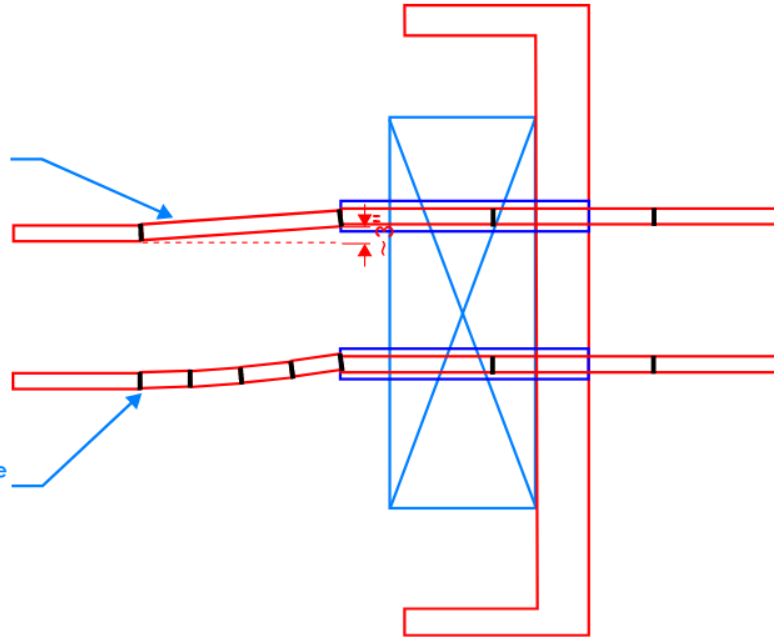
Where

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




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

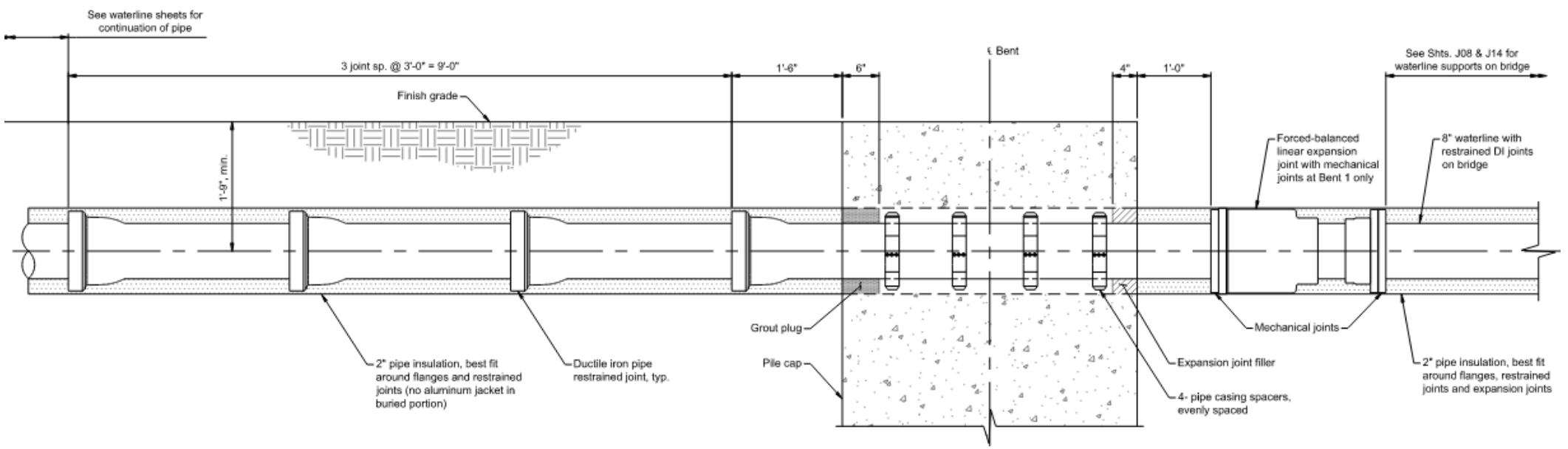
Each joint can handle 3 deg of deflections



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

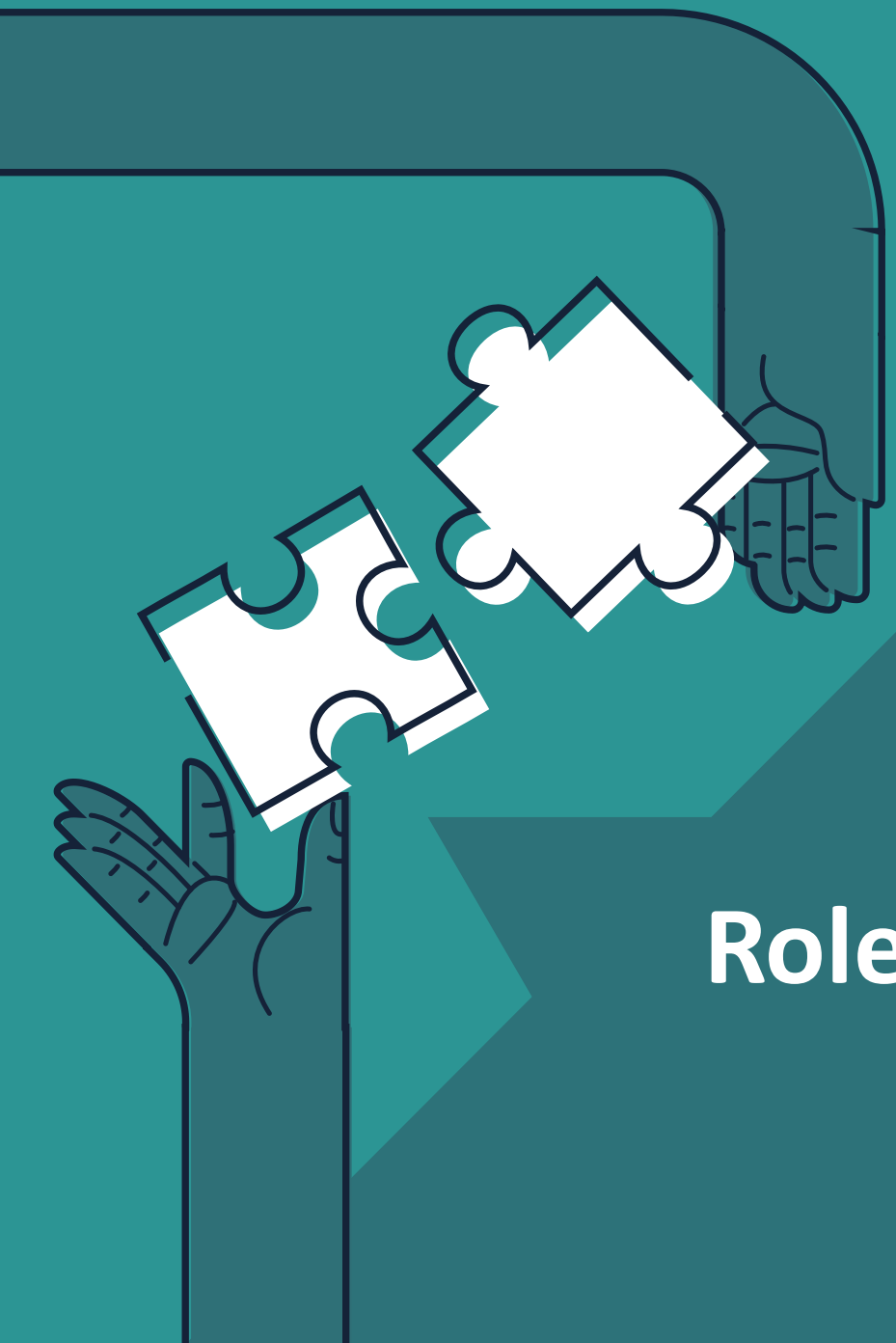
# Seismic Risk Mitigations

## 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

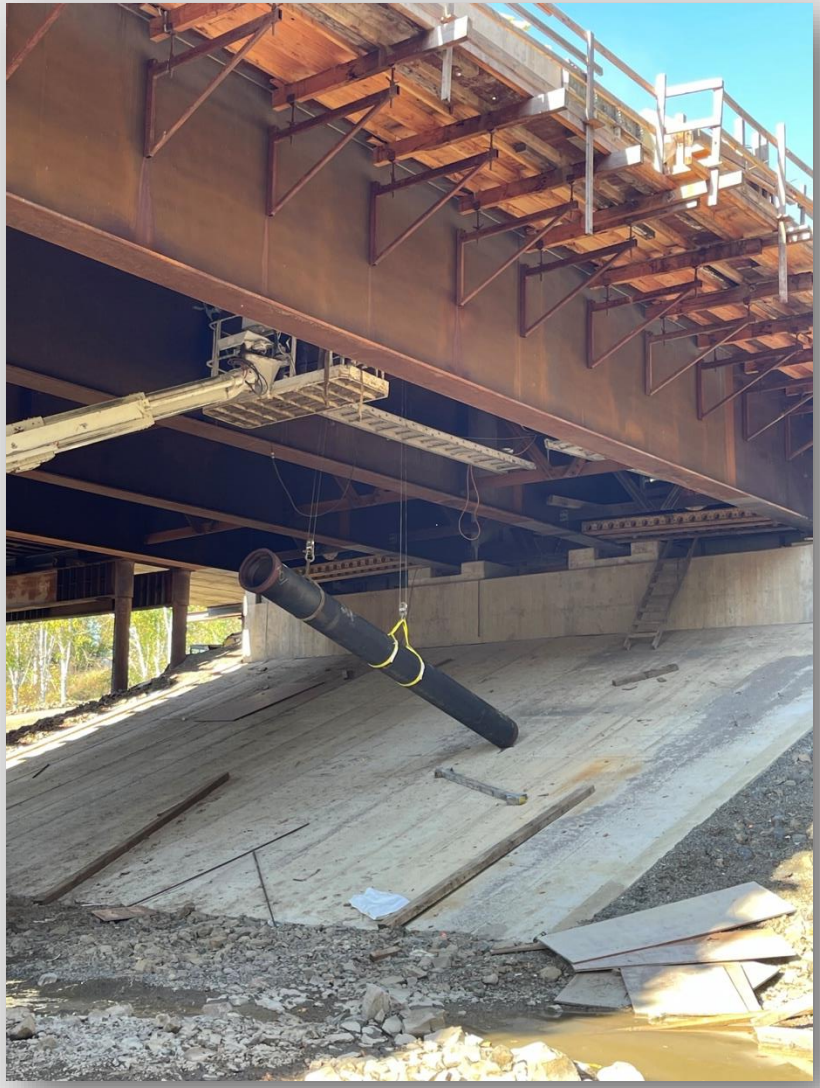


Bridge Engineer





Waterline Engineer





# Take-aways

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# 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?




DOWL