TUALATIN VALLEY
WATER DISTRICT



"CRITICAL HOSPITAL DUCTILE IRON PIPE SUPPLY USING SLIPPAGE BASED SEISMIC DESIGN APPROACH"

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AWWA PNWS Conference

May 8, 2026

OUTLINE

Discussion Topics

- Concept Development History
- Case Study
- Seismic Design Parameters
- Performance Objectives
- Slippage Based Seismic Design (SBSD) Approach
- Final Considerations
- Future DIP Seismic Design Practice

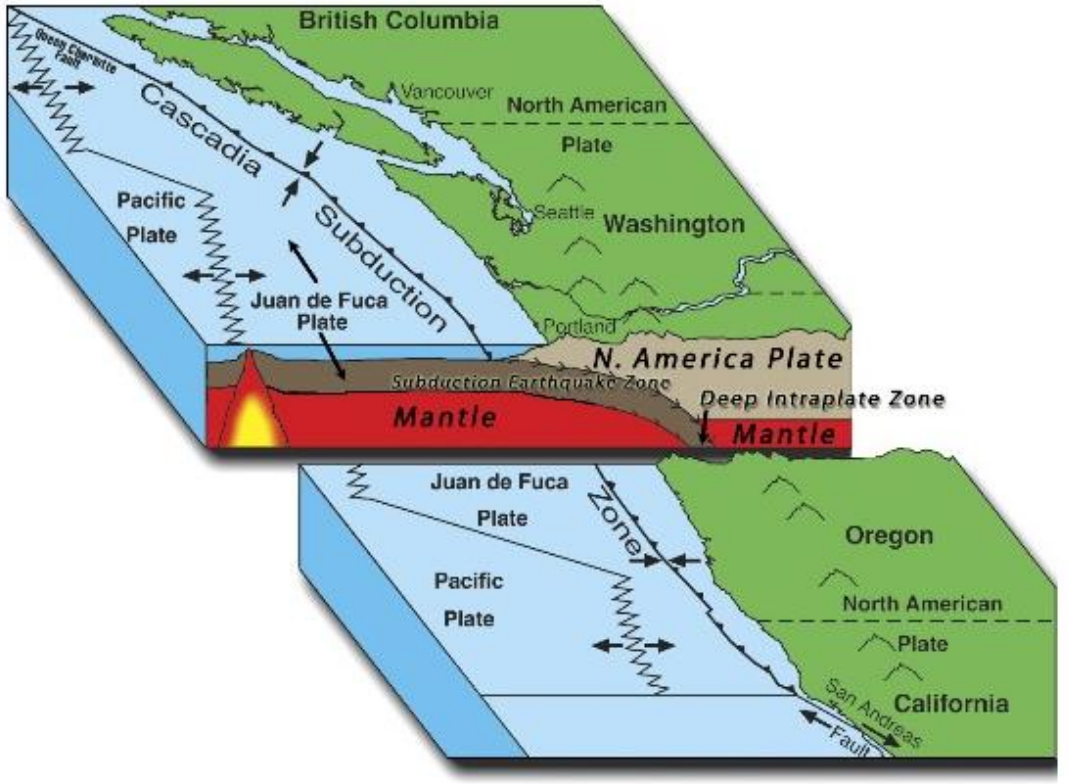
Willamette Water Supply Program (WWSP)

$1.6 Billion New Water Transmission System

Portland, Oregon Metro Area



M 9.0 Cascadia Subduction Zone



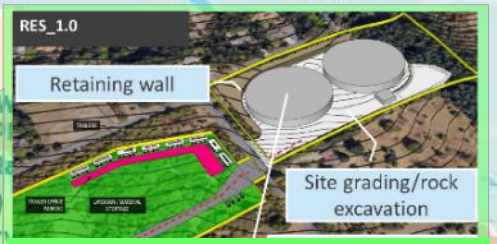
(Source: Oregon Office of Emergency Management)

Willamette Water Supply Program (WWSP)



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

~30 miles of 66-inch and 48-inch waterline installed to date



15 MG Storage Tanks



New Water Treatment Plant

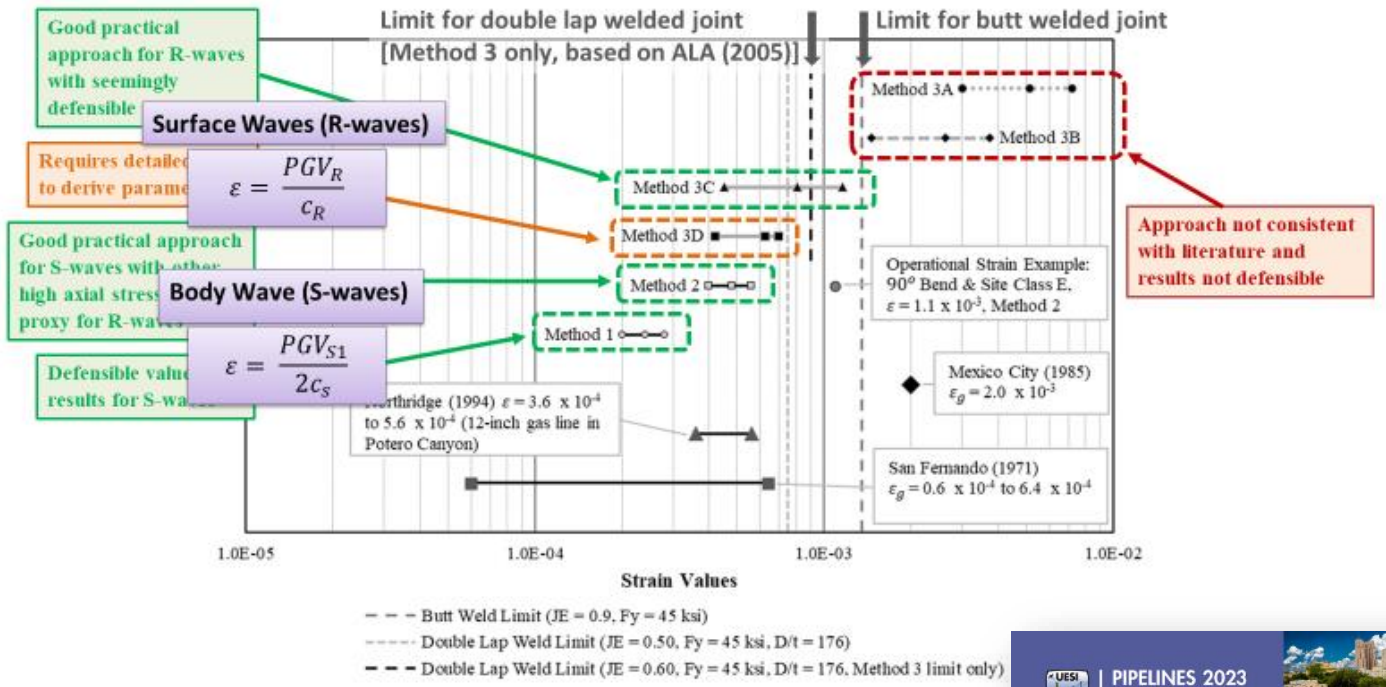


Modified River Intake

Image from the Regional Water Providers Consortium

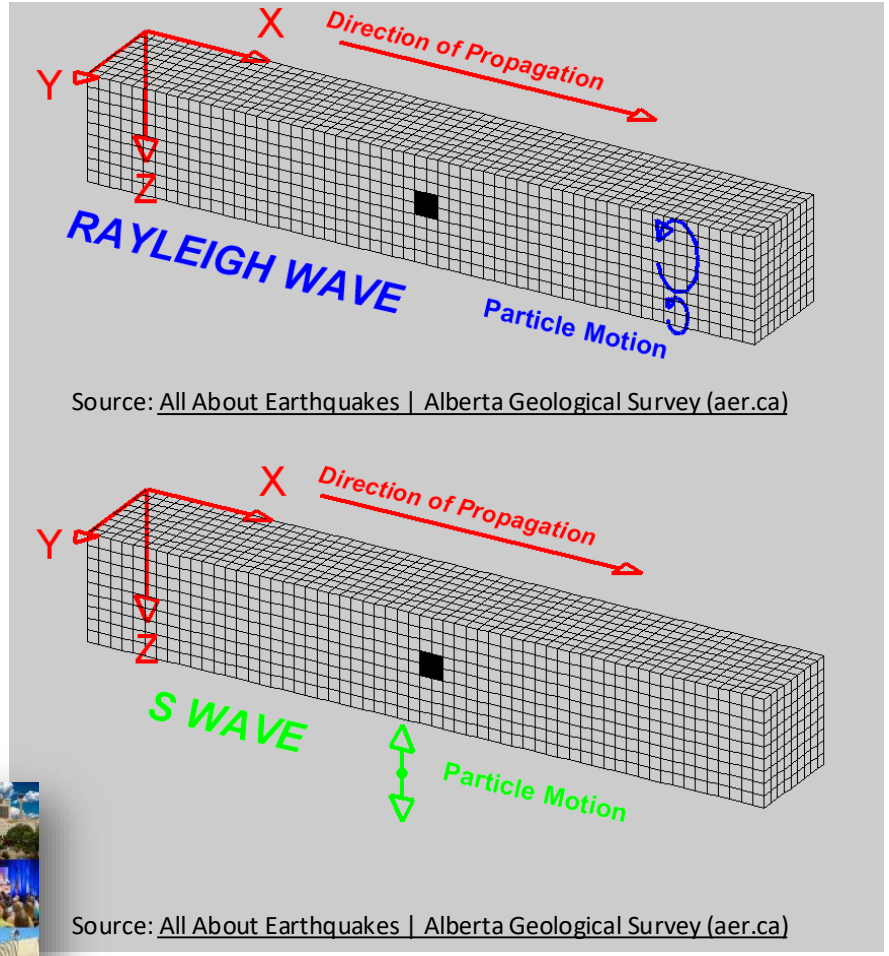
Ductile Iron Pipe Procedures based on What was Learned from Welded Steel Pipe Seismic Design

Calculations for Ground Strain



Source: Britch and Havekost (2023)





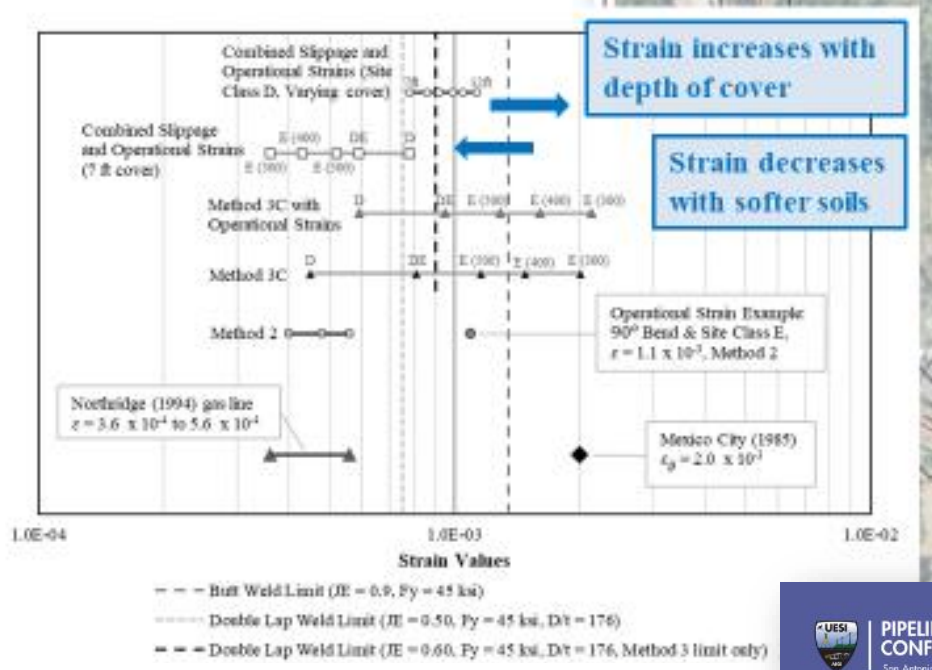
Source: All About Earthquakes | Alberta Geological Survey (aer.ca)

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Willamette Water Supply
Our Reliable Water

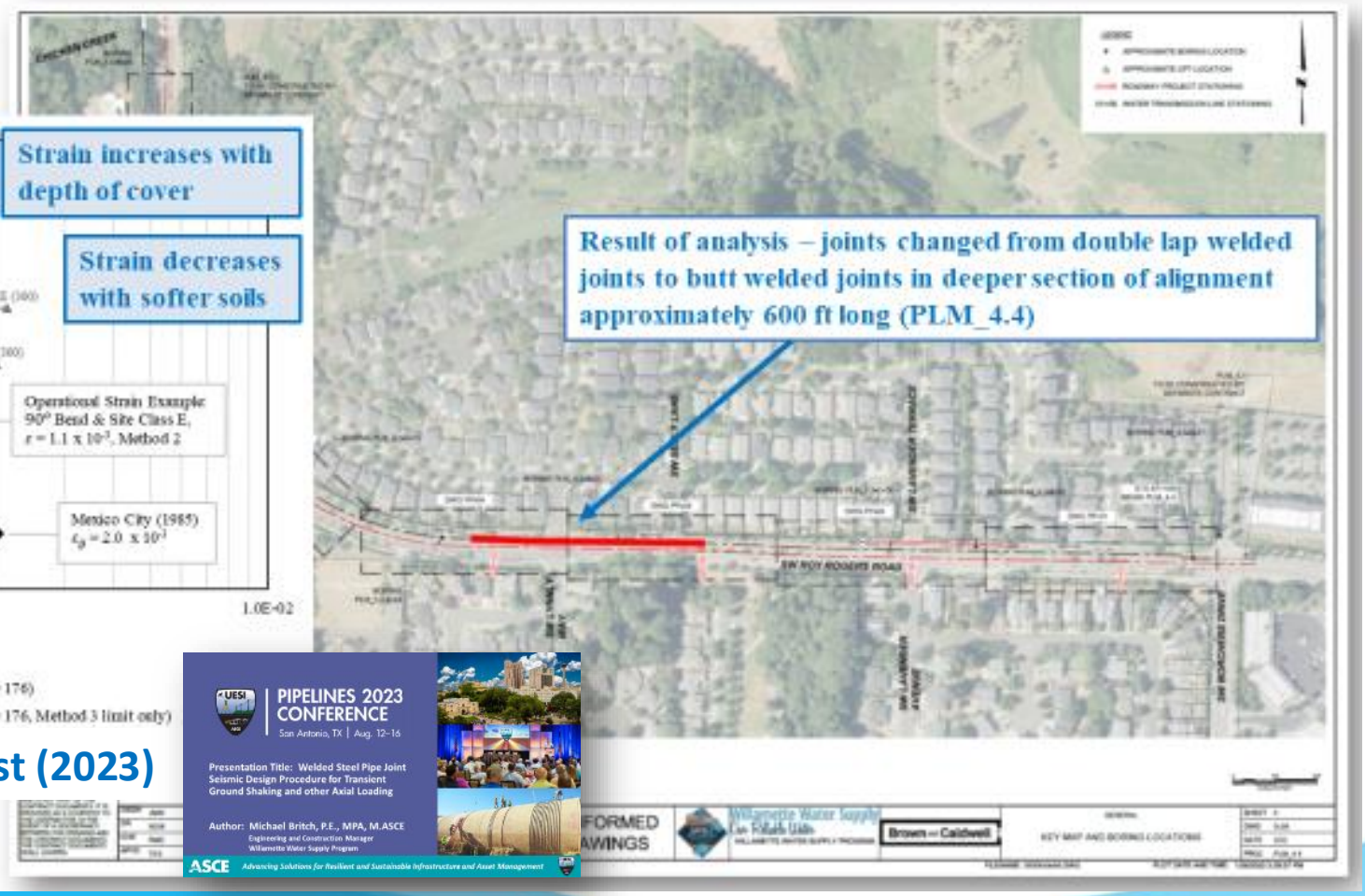
Ductile Iron Pipe Procedures based on What was Learned from Welded Steel Pipe Seismic Design

Calculations for Pipe Slippage



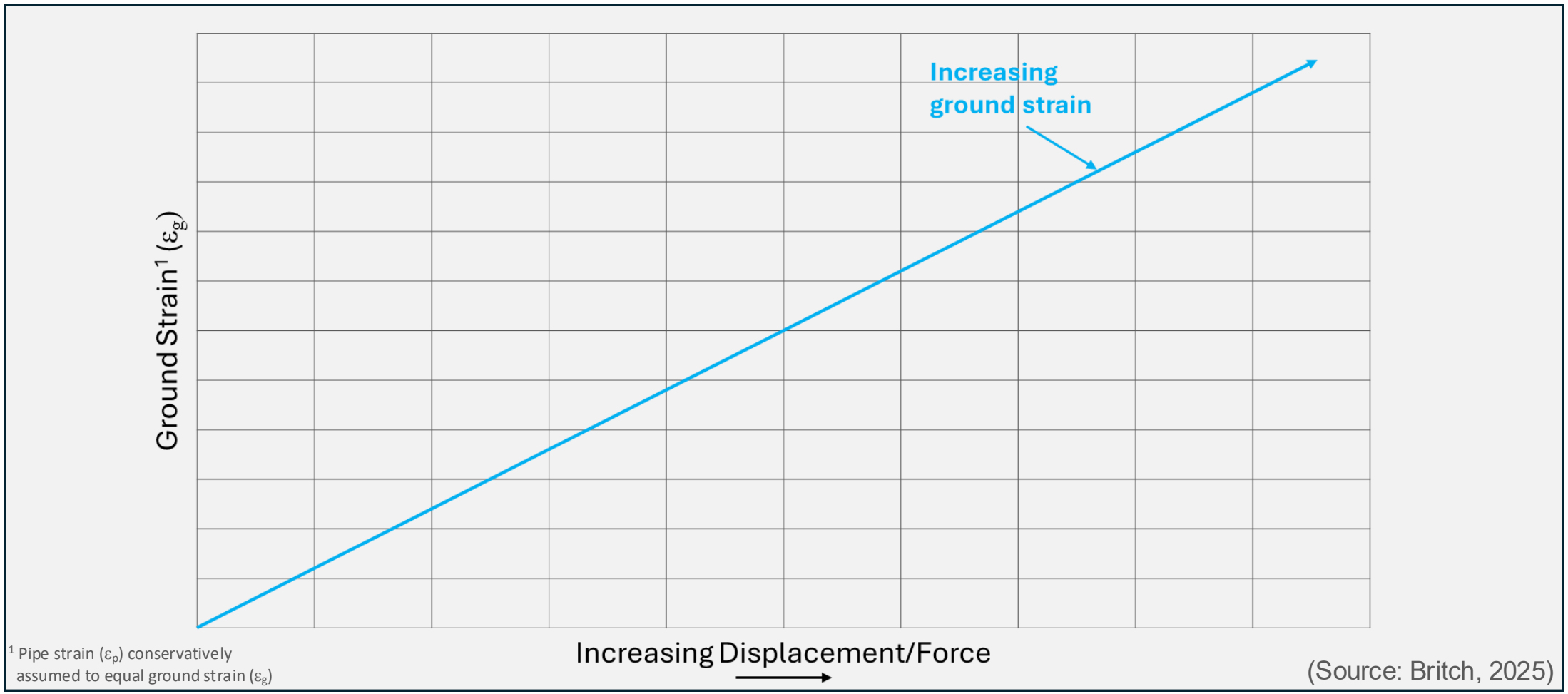
Strain increases with depth of cover

Strain decreases with softer soils



Source: Britch and Havekost (2023)

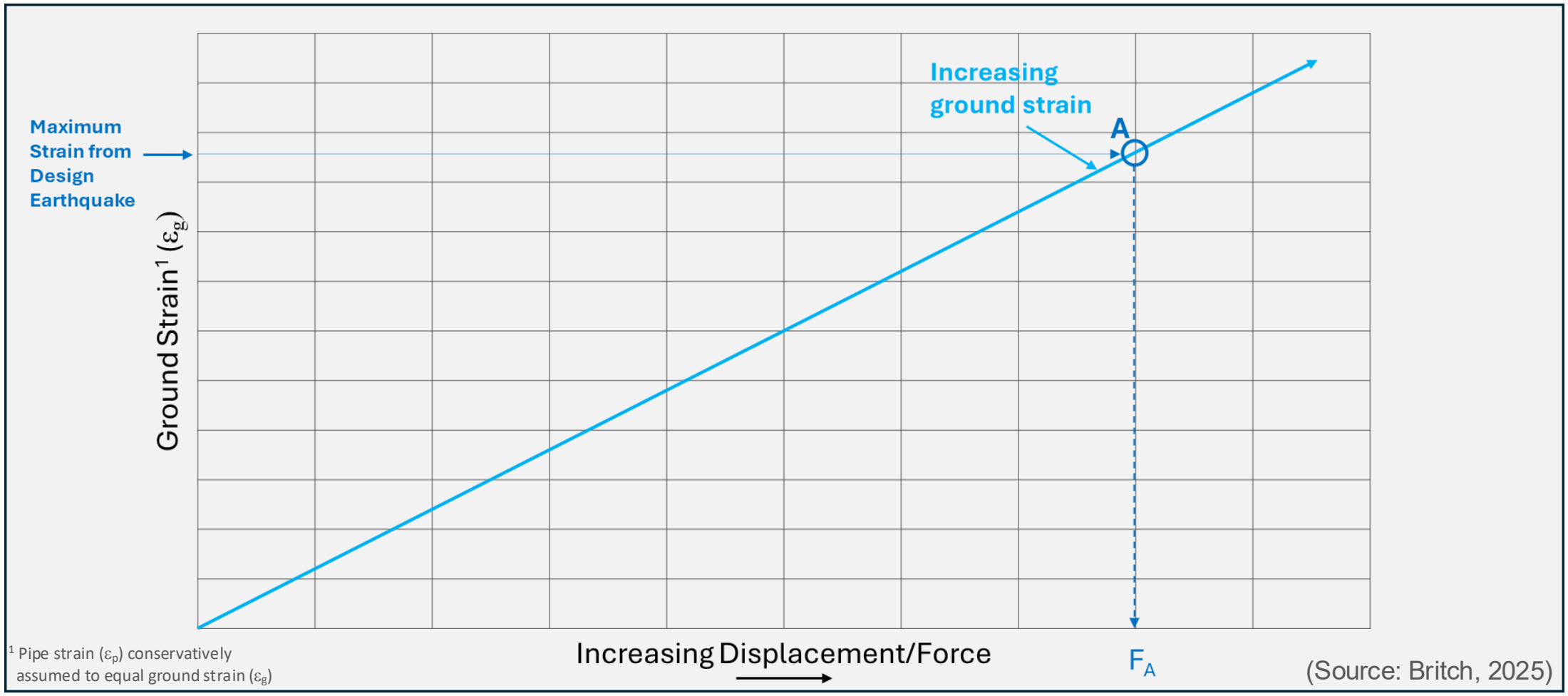
Pipe Slippage Concept



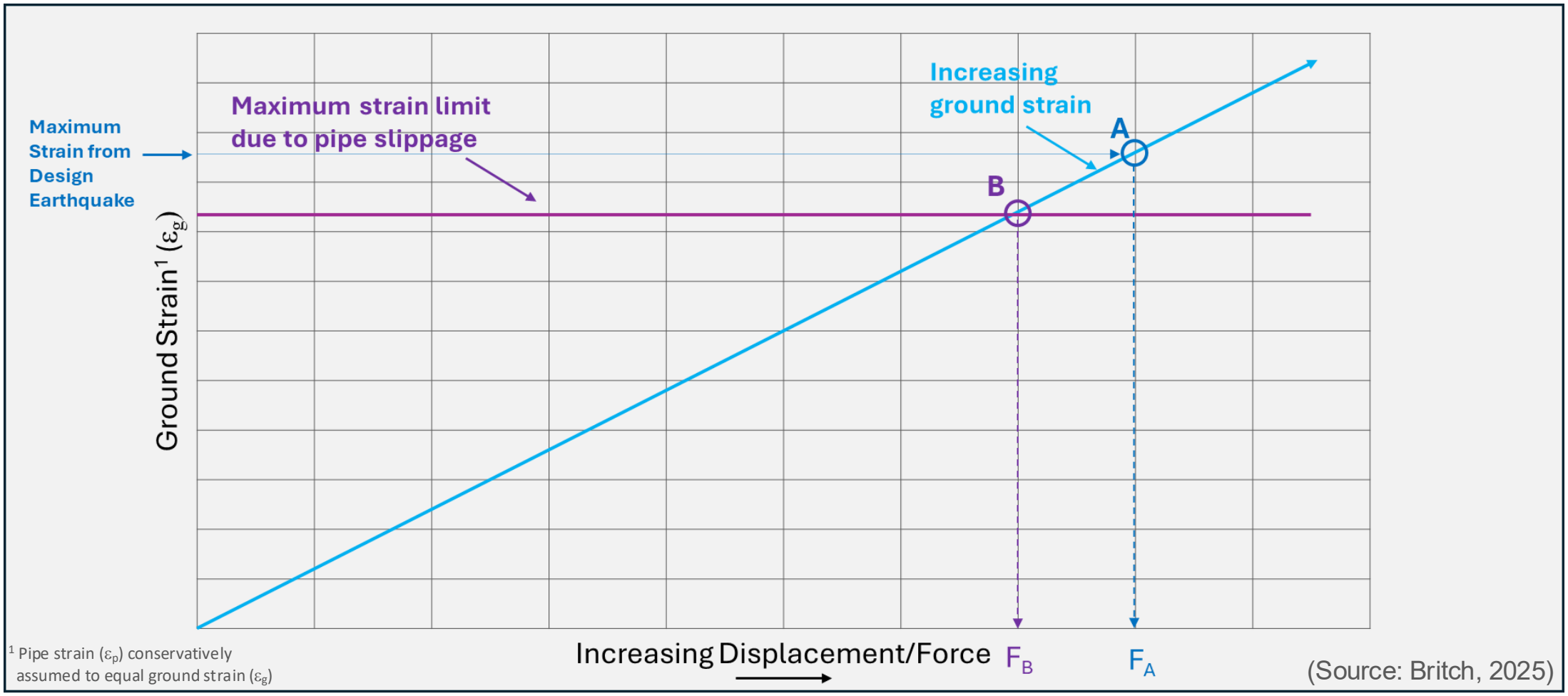
[1] Pipe strain (ε_p) conservatively assumed to equal ground strain (ε_g)

(Source: Britch, 2025)

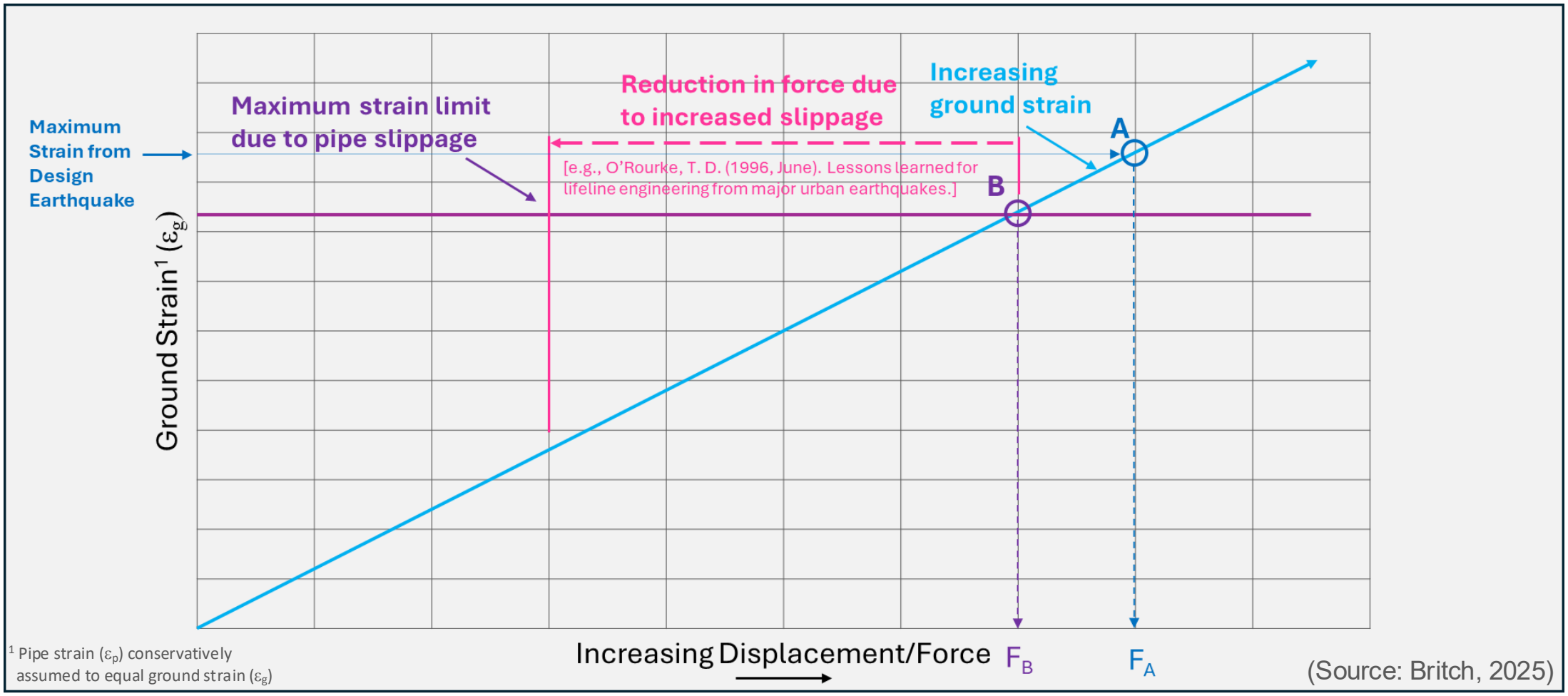
Pipe Slippage Concept



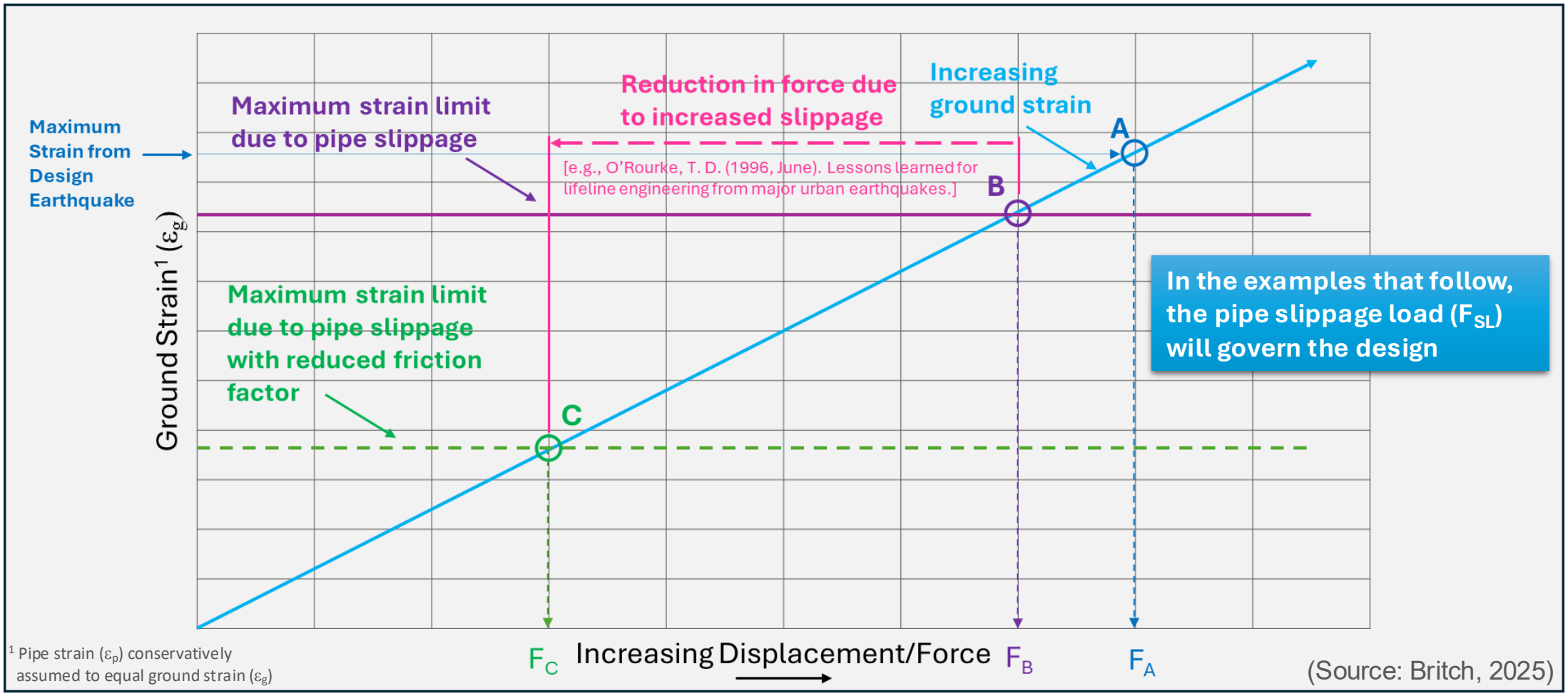
Pipe Slippage Concept



Pipe Slippage Concept

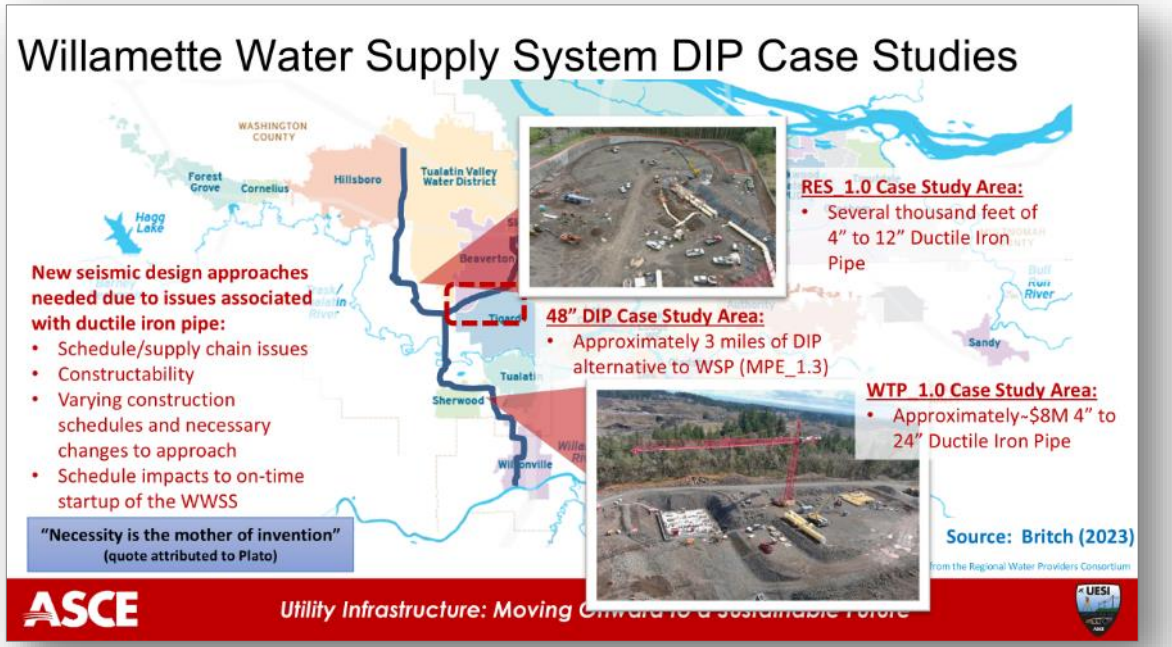


Pipe Slippage Concept



Seismic Design Approach for Ductile Iron Pipe Including Alternative to Boltless Segment Joints

Seismic Procedures Needed for DIP



Established Approach for Max Joint Load

Maximum Axial Strain/Force to Use

Source: American Society of Civil Engineers (ASCE). Committee on Gas, & Liquid Fuel Lifelines. (1984). *Guidelines for the Seismic Design of Oil and Gas Pipeline Systems*. Amer Society of Civil Engineers.

Lower value calculated due to transient ground shaking or from pipe slippage calculations:

Force derived from Transient Ground Shaking

$$\varepsilon = \frac{PGV_{S1}}{2c_s}$$

Using conservative values for peak ground velocity (PGV), wave propagation velocity for the shear wave (c_s), and coming up with the resulting pipe wall stress to determining the axial load.

Force derived from Pipe Slippage Calculations

$$f_x^u = \mu_s \gamma H \frac{(1+K_o)}{2} \pi D$$

Where:

μ_s = coefficient of friction near the pipe/soil interface

H = the depth to the center of the pipe (ft)

K_o = the coefficient of lateral earth pressure

D = the outside diameter of the pipe (ft)

[Source: Elhmadi and O'Rourke (1989)]

ASCE Utility Infrastructure: Moving Onward to a Sustainable Future UESI



Willamette Water Supply
Our Reliable Water

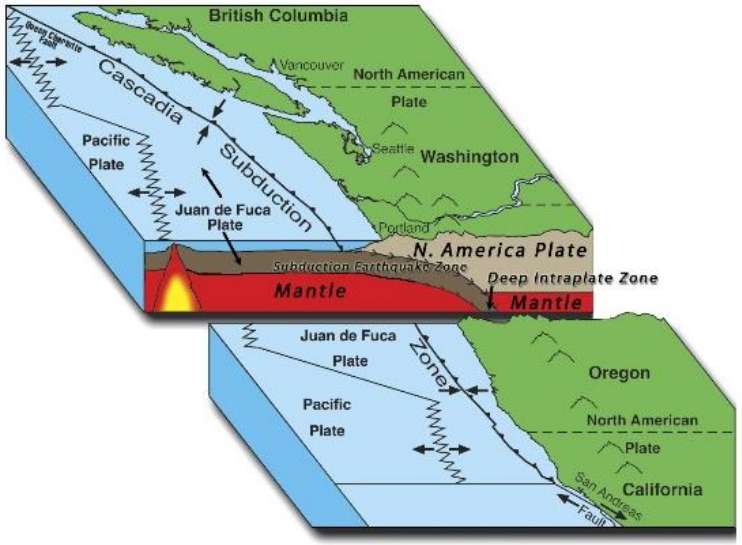
Case Study - St. Vincent Hospital Critical Ductile Iron Pipe Supply

Approximately 90% of pipe for used in water systems across the United States and Canada is 12-inch or smaller.



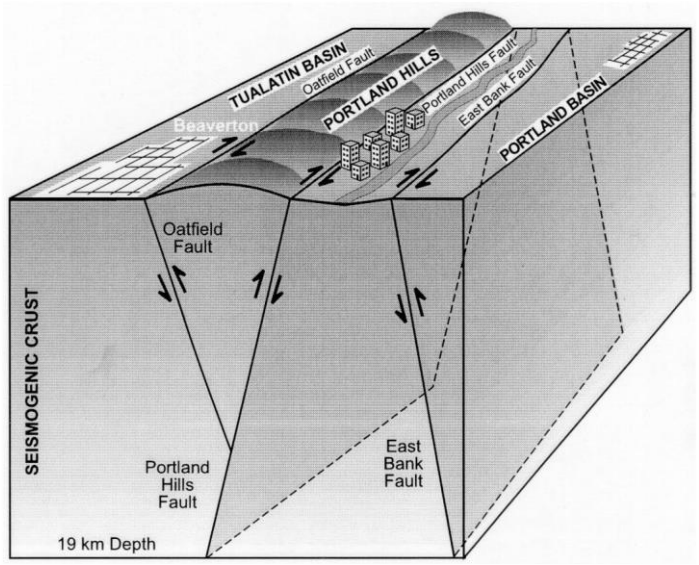
Regional Dominant Seismic Hazards

M 9.0 Cascadia Subduction Zone



(Source: Oregon Office of Emergency Management)

Portland Hills Crustal Fault



(Source: Wong et al., 2001)

Near Field Source with Surface Fault Rupture

"The potential ground shaking from such an event would exceed the ground motions from a M_w 9 Cascadia subduction zone megathrust event in the Portland area" (Wong et al., 2001)

Portland Hills Fault Rupture

Effects expected to be similar to the 1995 M 6.9 Kobe Earthquake

ers, 1992). If urban crustal faults such as the Seattle and the Portland Hills faults are seismogenic, they could generate large, disastrous earthquakes similar to the M_W 6.9 earthquake in Kobe, Japan, in 1995.

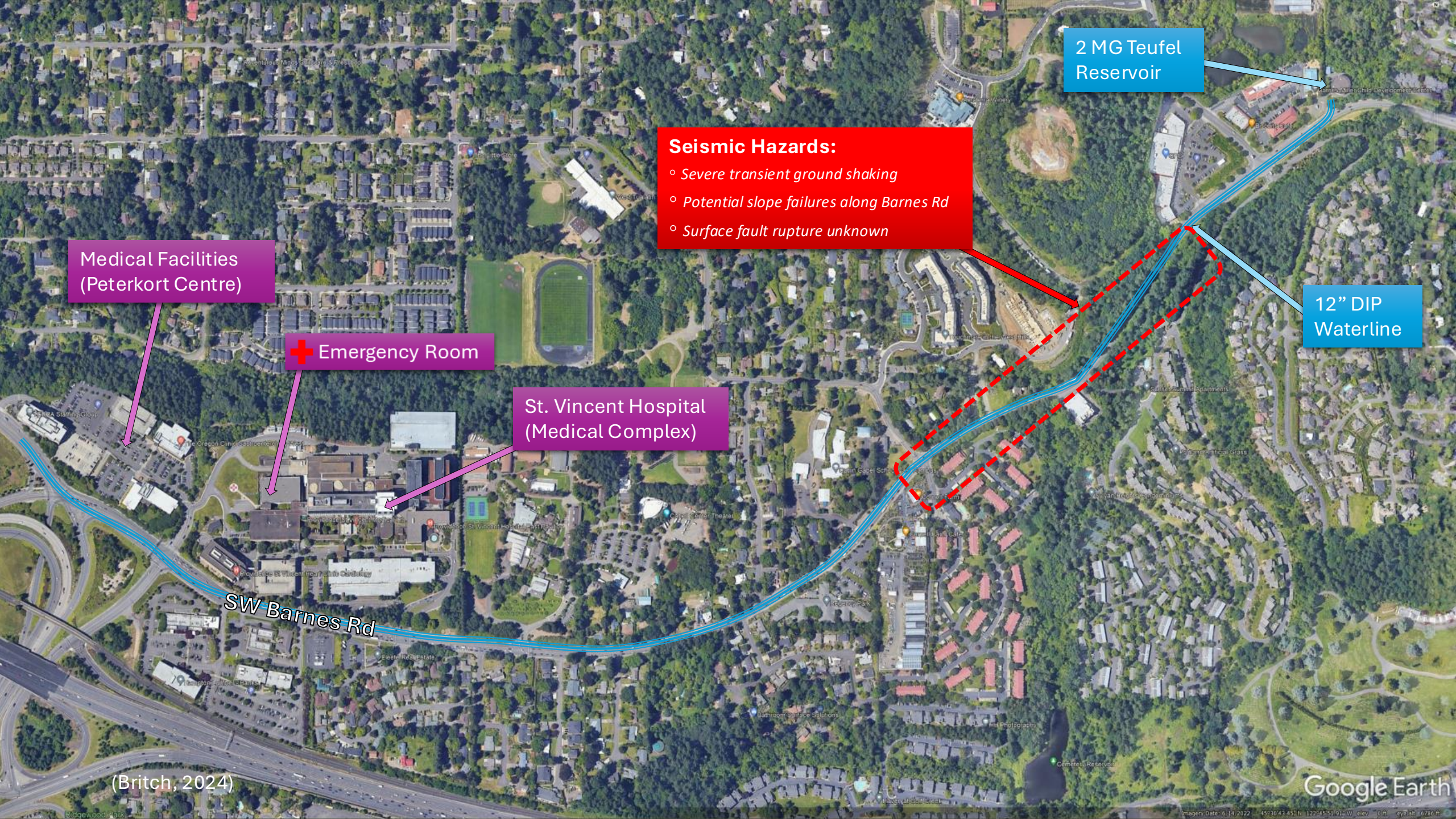
(Source: Wong et al., 2001)

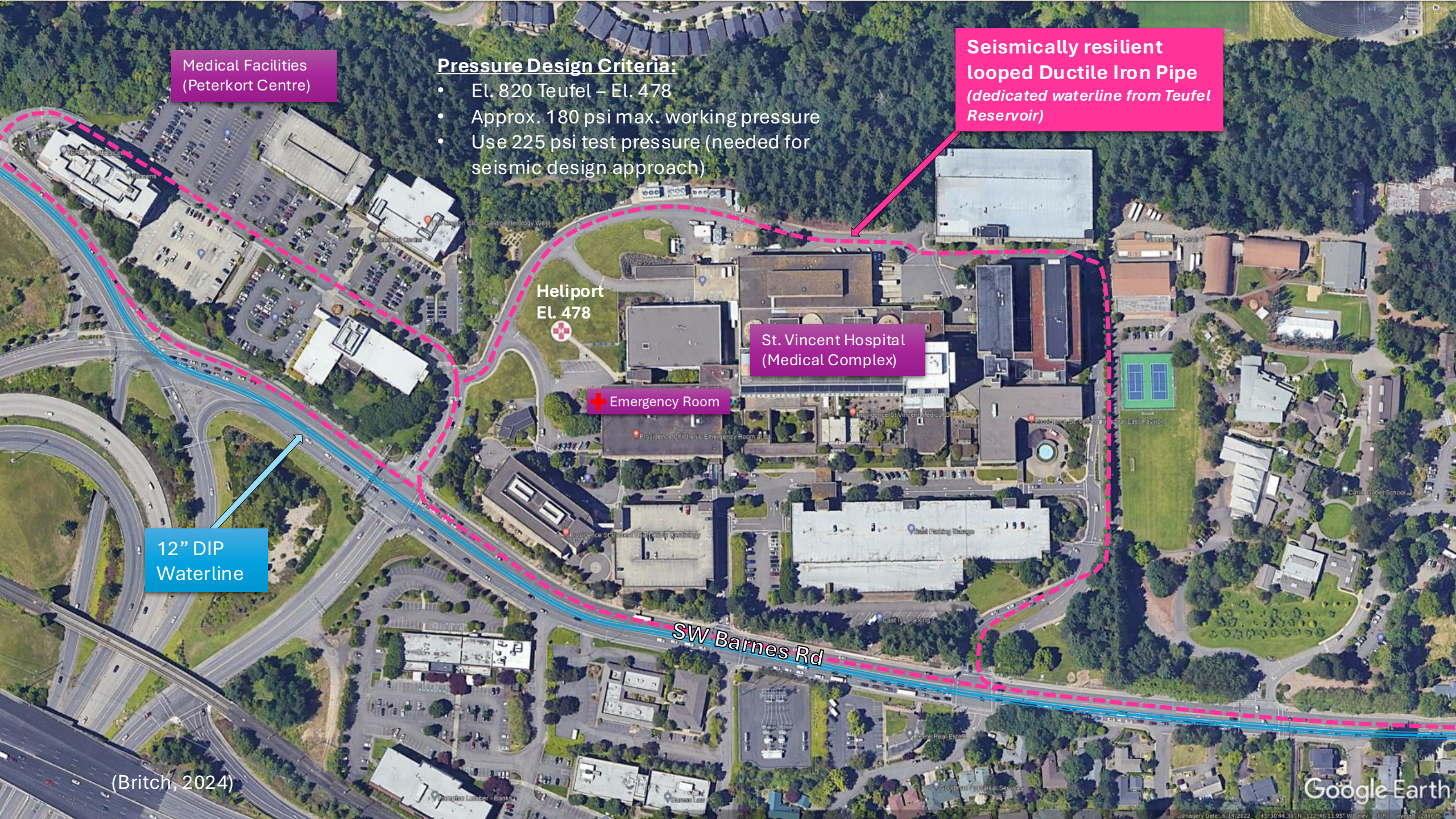
The proposed ductile iron pipe seismic design criteria for extreme conditions, using a worst-case scenario:

- **SA_1 = 1.8 g**
- **PGV = 180 cm/s** *[per Davis (2024)]*
- **$\varepsilon_p = 9.1 \times 10^{-4}$**



Wong also states that depending on how the fault ruptures, could ground accelerations could be like 1994 Northridge earthquake. Luco (2019) reports a maximum recorded acceleration of 1.8 g and a PGV of 148 cm/s.


2 MG Teufel Reservoir
Seismic Hazards:
Severe transient ground shaking
Potential slope failures along Barnes Rd
Surface fault rupture unknown
12” DIP Waterline
Medical Facilities (Peterkort Centre)
Emergency Room
St. Vincent Hospital (Medical Complex)
SW Barnes Rd
(Britch, 2024)
Google Earth


Medical Facilities
(Peterkort Centre)
Pressure Design Criteria:
• El. 820 Teufel – El. 478
• Approx. 180 psi max. working pressure
• Use 225 psi test pressure (needed for seismic design approach)
Seismically resilient looped Ductile Iron Pipe
(dedicated waterline from Teufel Reservoir)
Heliport
El. 478
St. Vincent Hospital
(Medical Complex)
Emergency Room
12” DIP
Waterline
SW Barnes Rd
(Britch, 2024)
Google Earth

Performance Objectives

The primary goals can be accommodated by satisfying (i.e. don't exceed) one or both of the following performance limits for ductile iron pipe, and particularly related to its joints:

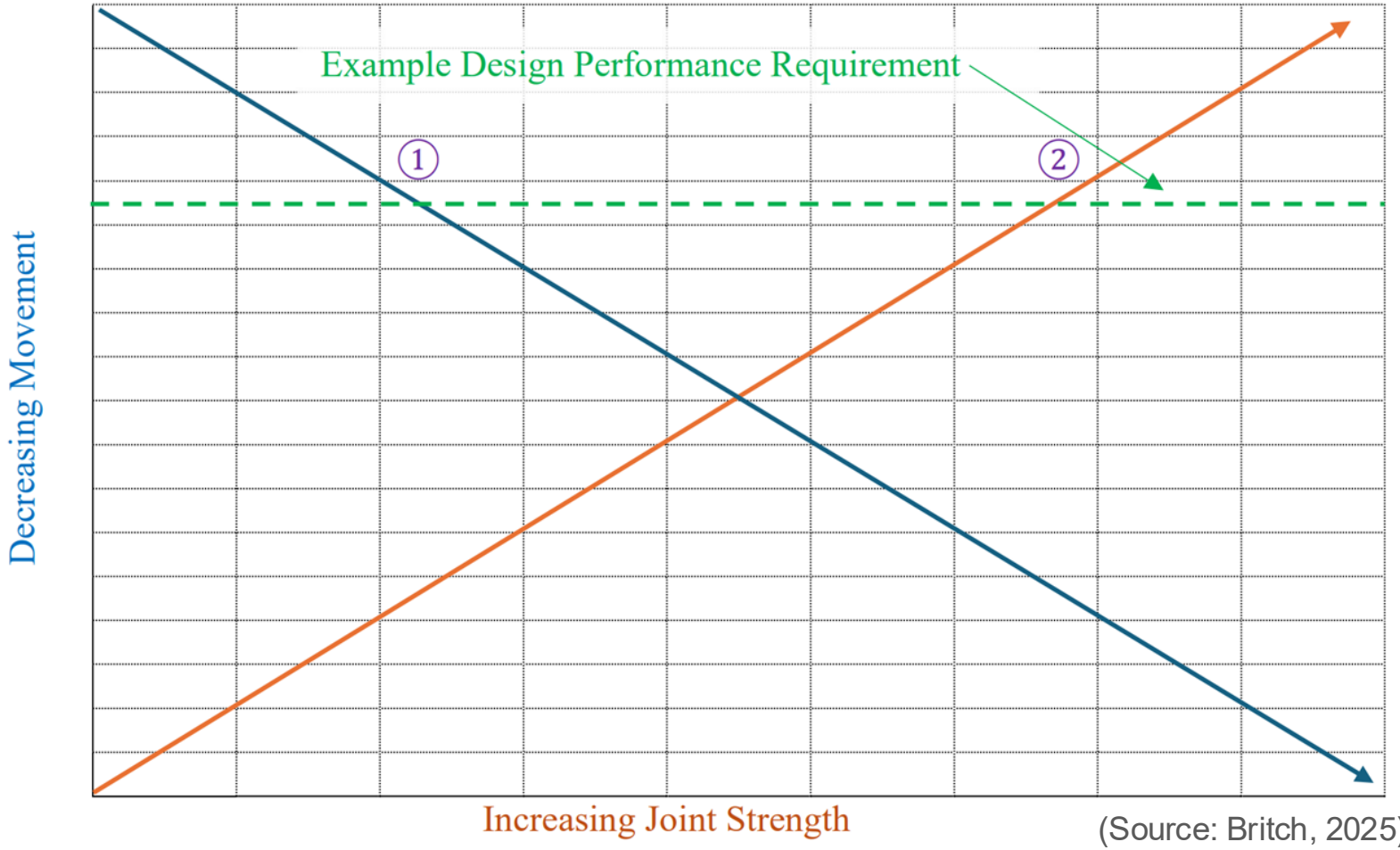
- Load performance limits
- Movement performance limits

The primary objectives can be met by having joints of sufficient strength to resist the loads. They can also be met by allowing adequate movement at the joints where possible to not create excessive additional loads on the joints.

Performance Objectives

Pipe Joint Movement vs. Joint Strength Concept:

- Providing sufficient movement allows joint strength to be low
- As available movement decreases (blue line), joint strength requirement (orange line) must increase
- The design performance requirement can be met by one or a combination of both approaches



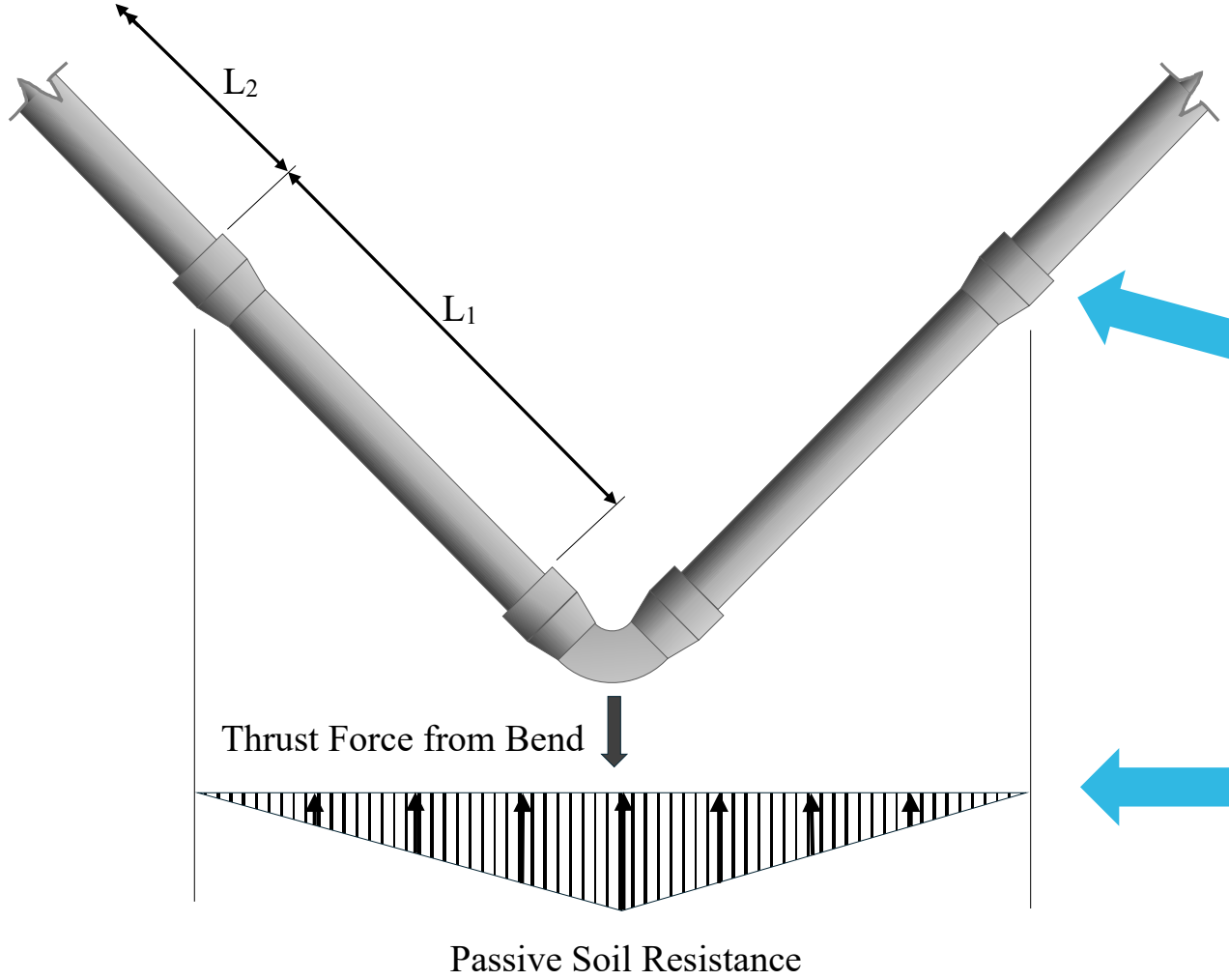
(Source: Britch, 2025)

Performance Objectives

Table 1. Secondary Seismic Design Approach Goals (Source: Britch, 2025)

Secondary Goals	Strategies/Comments
1. Limit load accumulation at joints	A. Use soil passive pressure to resist thrust at bends with the smallest pipe length possible on each side of fitting. B. Use smaller bend angles to limit axial loads from thrust. C. Locate bends away from other system components to help isolate loading at fittings.
2. Allow sufficient movement where possible	A. Set joints to approximated neutral position away from bends based on required strain relief for site conditions. B. For branching components to the main line (e.g. appurtenances) include additional allowable movement.
3. Where access is limited increase factor of safety	A. In areas where access is limited due to site constraints or conditions, critical traffic routes, or environmental considerations, design with higher factors of safety.

Slippage Based Seismic Design (SBSD) Approach

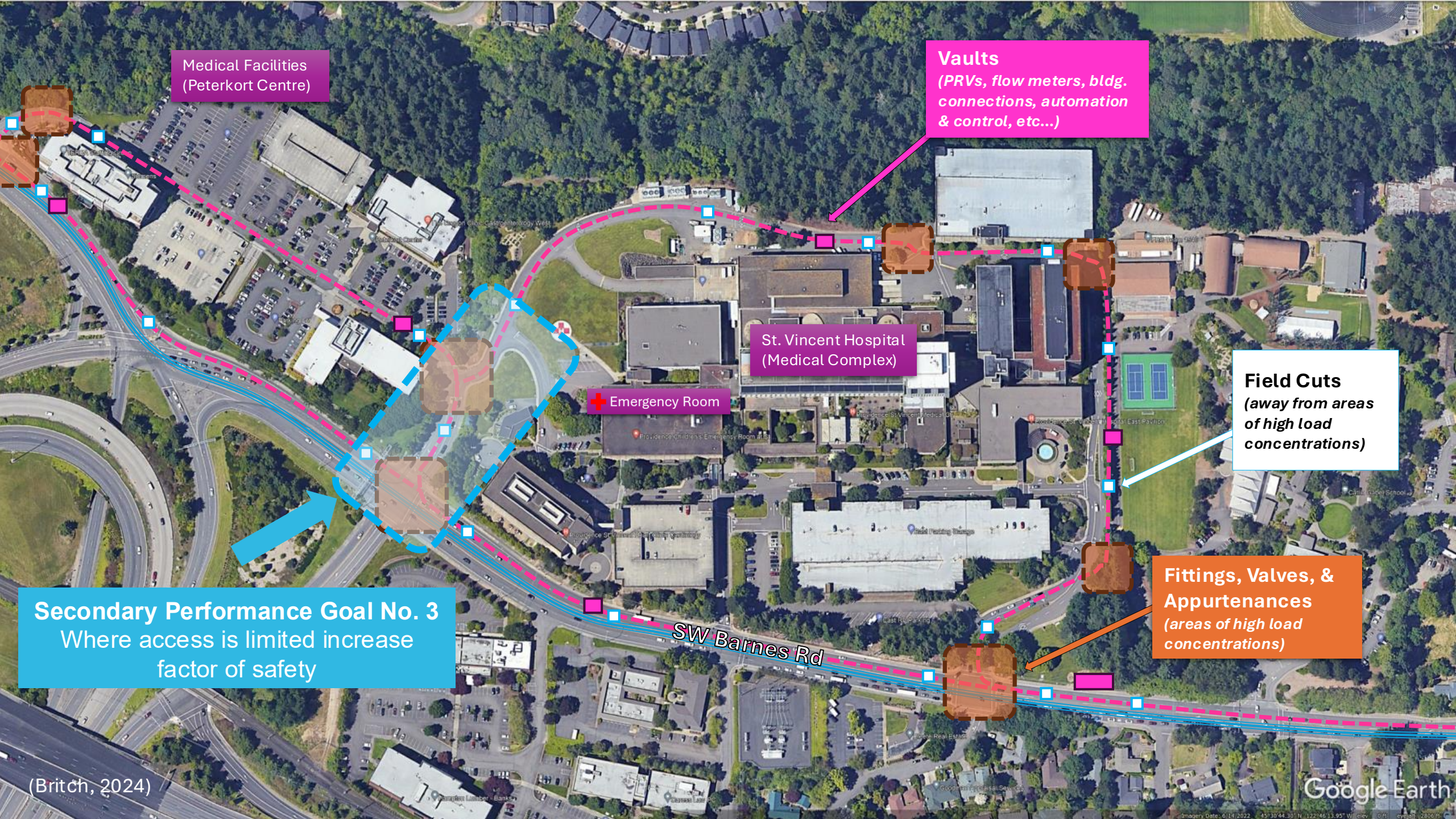


Limit pipe that contributes to F_{SL}

Secondary Performance Goal No. 2
Allow sufficient movement where possible
(Set joints to approximated neutral position away from bends based on required strain relief for site conditions)

Secondary Performance Goal No. 1
Limit load accumulation at joints
(Use soil passive pressure to resist thrust at bends with the smallest pipe length possible on each side of fitting)

Figure 2. Illustrative Example of Thrust at 90-degree Bend Being Resisted by Short Section of Pipe (Length = L_1) on each Side of Bend (Source: Britch, 2025)


Medical Facilities
(Peterkort Centre)
Vaults
(PRVs, flow meters, bldg. connections, automation & control, etc...)
St. Vincent Hospital
(Medical Complex)
Emergency Room
Field Cuts
(away from areas of high load concentrations)
Fittings, Valves, & Appurtenances
(areas of high load concentrations)
SW Barnes Rd
Secondary Performance Goal No. 3
Where access is limited increase factor of safety
(Britch, 2024)
Google Earth

Final Considerations

- **Pipe System Components.** Each requires specific consideration as to the required joint type, joint strength, and needed movement. Fittings can act like "*Anchors*".
- **Trench Backfill Material.** For slippage calculations, use maximum effective unit weight of the trench backfill material, material friction angle, and K_o = 1.0 (or higher).
- **Ground Motions.** There will be a point where loads transition from being dominated by slippage and dominated by ground strain. At lower magnitude earthquake events or where PGV is not excessive and should be used if less than F_{SL}.
- **Thrust Restraint Solutions at Fittings.** The approach described above for solving for the passive soil resistance for the thrust is a basic approach. More elaborate solutions are possible including buried thrust reaction panels, carefully designed thrust blocks, and other solutions to improve the thrust reaction at the bend or fitting.

Final Considerations

- **Slippage Loads at Joints with Movement.** Joints include elements that protrude out from the pipe, sometimes by substantial amounts relative to the pipe diameter, especially at smaller diameter pipe sizes. The protrusions include the pipe bell at joints, flanges, and other elements. As such when the movement is substantial like with permanent ground deformation (PGD), the seismic loads on the pipe can be substantially greater than those calculated ground strain or slippage. ***The slippage approach presented may not be appropriate for cases with PGD, especially when PGD is significant. Loads from PGD should always be investigated separately.***
- **Other Areas of Design Needing Analysis.** Additional areas requiring special consideration include corrosion control, hydraulic transients and appropriate mitigation as necessary, water quality implications of a looped system, and incorporation of automated controls and seismic valves as well as other elements depending on the project conditions.

Final Considerations

- Don't Forget Constructability. Specific elements incorporated in the design need to be constructable in a way that is practical and highly reliable.



"Seismic Design Workshop" (11/20/2024) [Source: Britch]

TUALATIN VALLEY WATER DISTRICT

Current DIP Seismic Design Practice

Movement based solutions

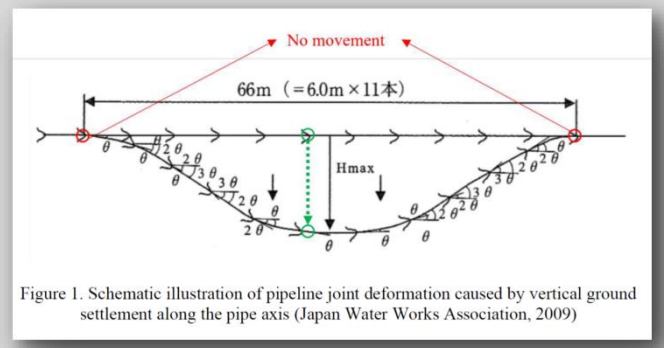
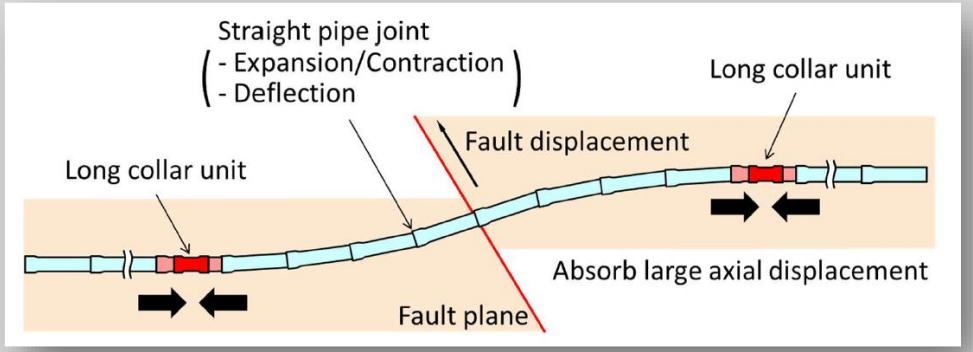


Figure 1. Schematic illustration of pipeline joint deformation caused by vertical ground settlement along the pipe axis (Japan Water Works Association, 2009)

Differential Settlement
[Source: Chu et al. (2025)]



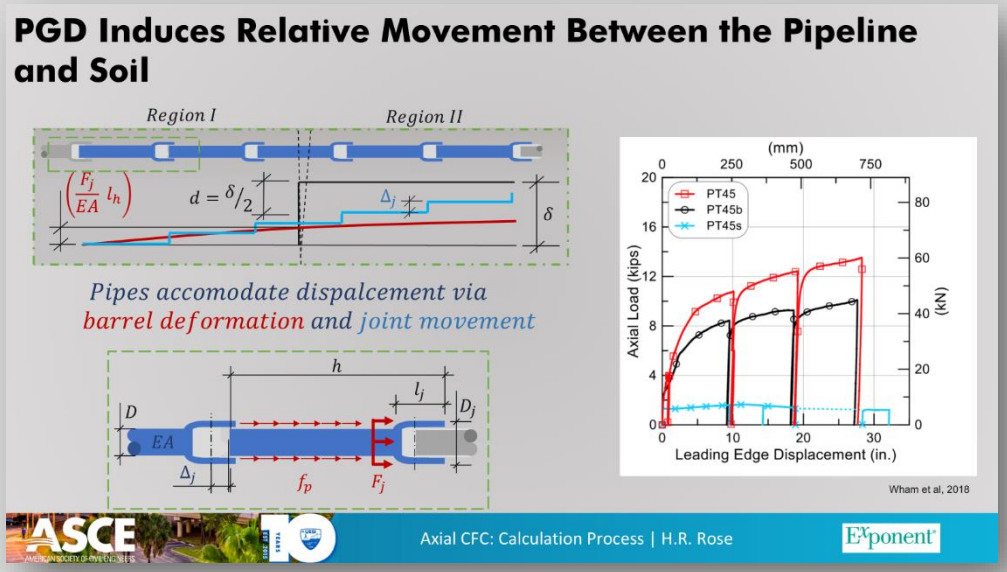
Longitudinal Slope Movement
[Source: Kagawa et al. (2025)]



Abrupt Offset – Fault Crossing
[Source: Kagawa et al. (2026)]

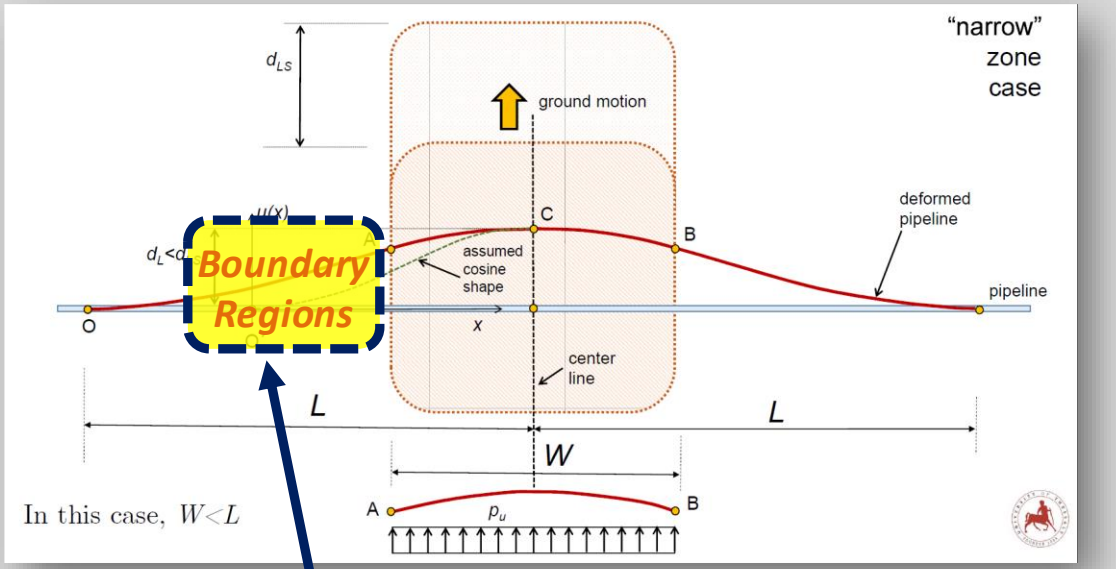
Current DIP Seismic Design Practice

Current and future needed research areas



Longitudinal Slope Movement Load Based Solution

[Source: Rose and Wham (2025)]

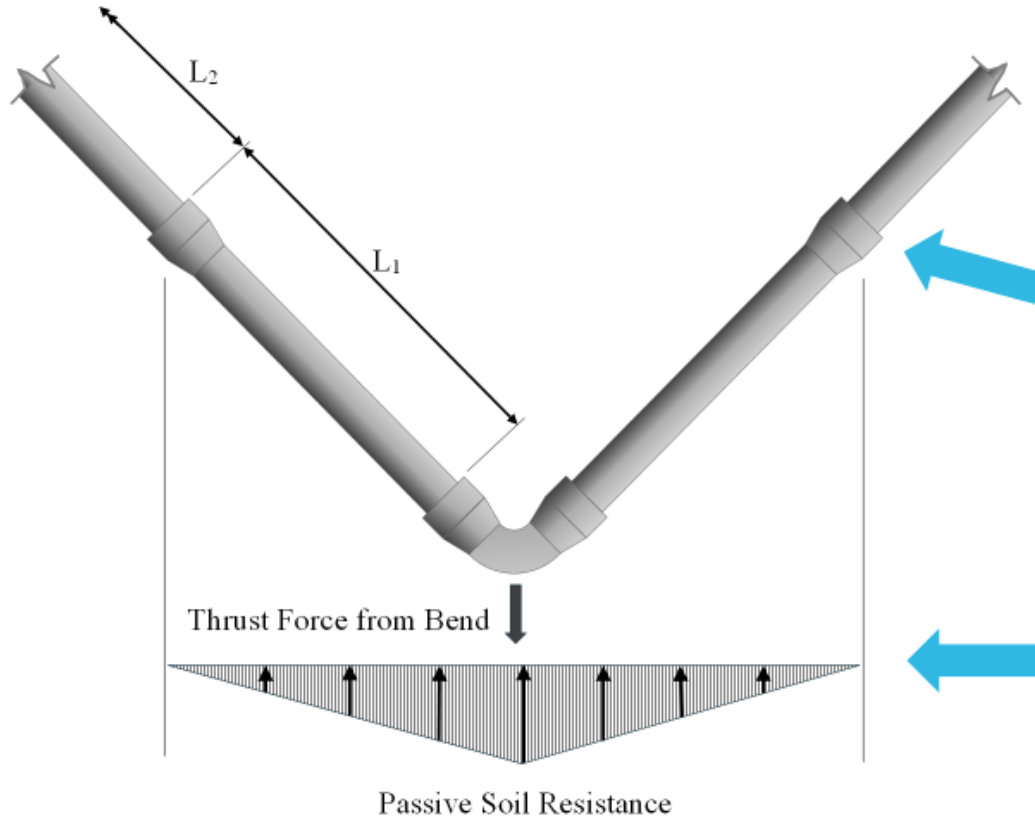


[Figure Source: Karamanos (2025)]

Transverse Slope Movement & Moment/Load Based Solutions

Future DIP Seismic Design Practice

Slippage Based Seismic Design (SBSD) Approach



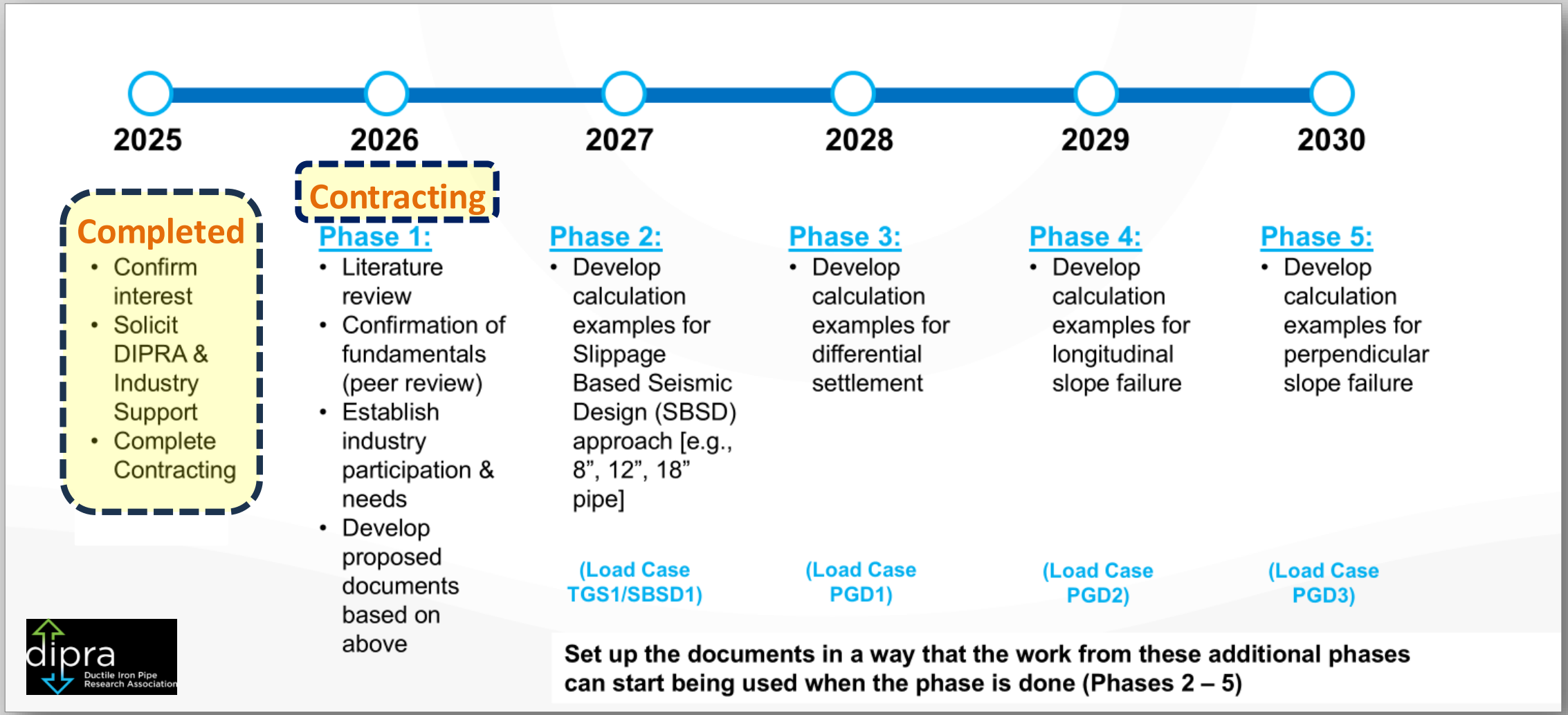
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Future DIP Seismic Design Practice



QUESTIONS/COMMENTS

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