Willamette Water Supply

Our Reliable Water

Seismic Design Alternative for Ductile Iron Boltless Segment Pipe Joints to Address Schedule Issues and Improve Installation Flexibility

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May 2, 2024

American Water Works Association Pacific Northwest Section

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.*

WASHINGTON COUNTY
Forest Grove
Cornelius
Hillsboro
Tualatin Valley Water District
Portland
Hagg Lake
Beaverton
Trask/ Tualatin River
Tigard
Lake Oswego
Tualatin
Sherwood
Wilsonville
Willamette River
PUD
Gresham
MULTNOMAH COUNTY
Bull Run River
Sunrise Water Authority
Sandy
Clackamas River
CLACKAMAS COUNTY

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

More than 130,000 LF (~25 miles) of 66-inch and 48-inch waterline installed to date

15 MG Storage Tanks

New Water Treatment Plant

Modified River Intake

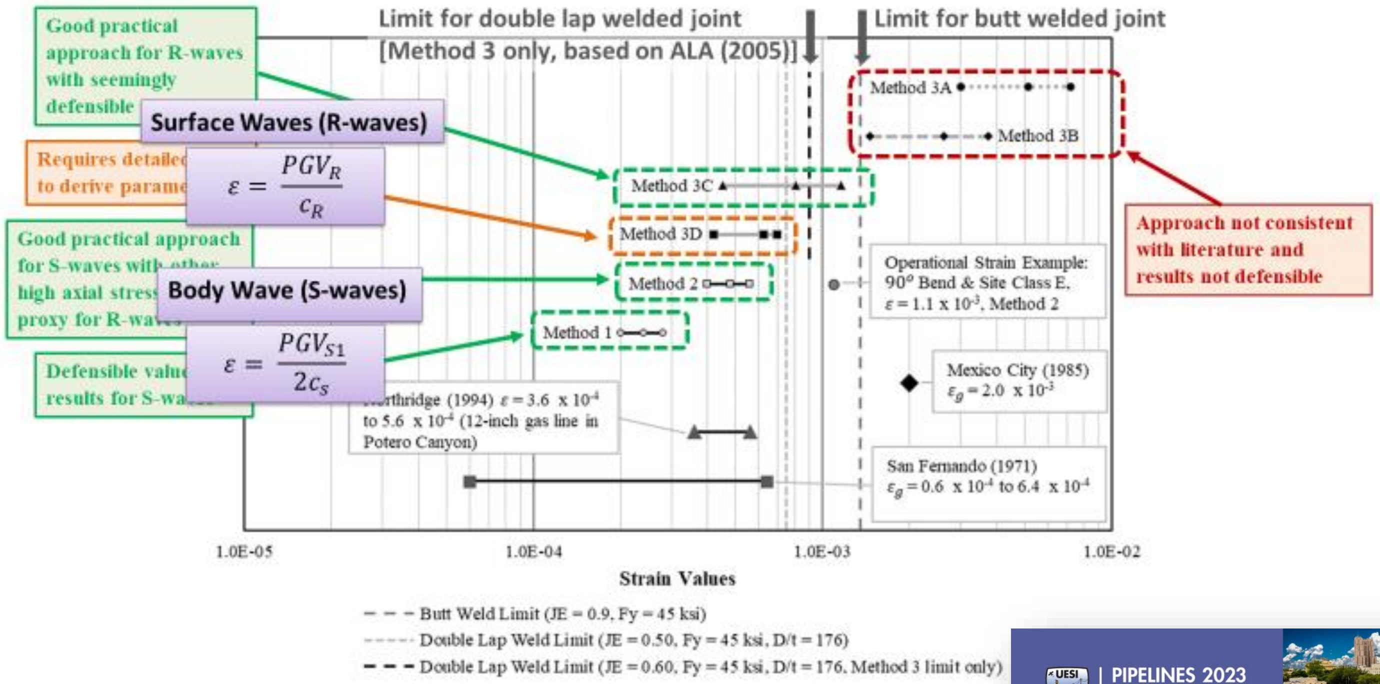
Seismic design procedures presented for ductile iron pipe based on what was learned from welded steel pipe seismic design

Image from the Regional Water Providers Consortium

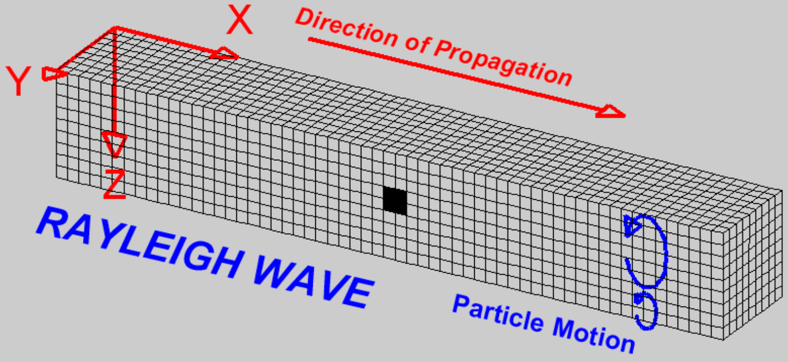
Willamette Water Supply
Our Reliable Water

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

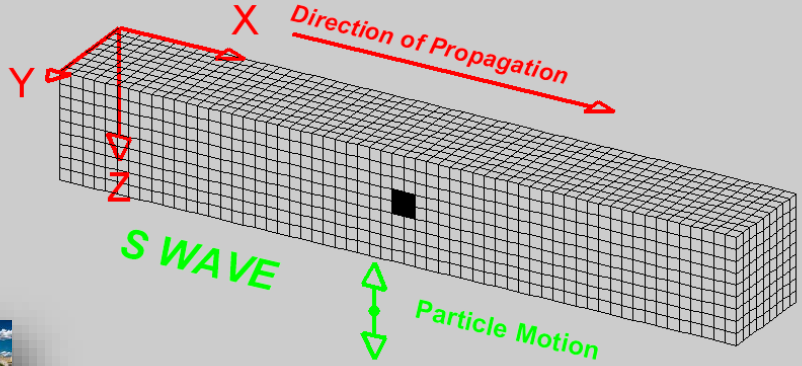
Calculations for Ground Strain



Source: Britch and Havekost (2023)



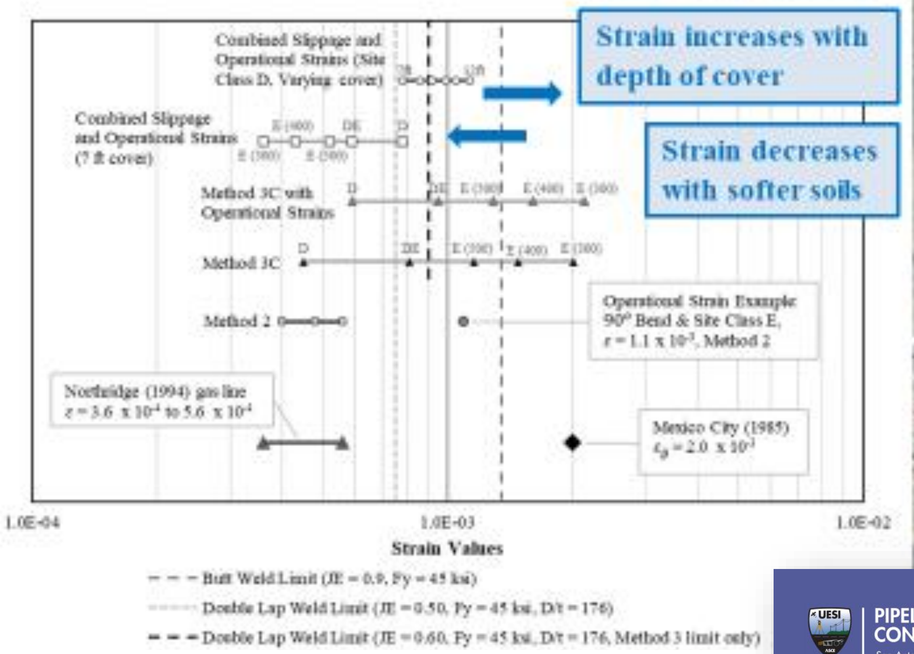
Source: All About Earthquakes | Alberta Geological Survey (aer.ca)

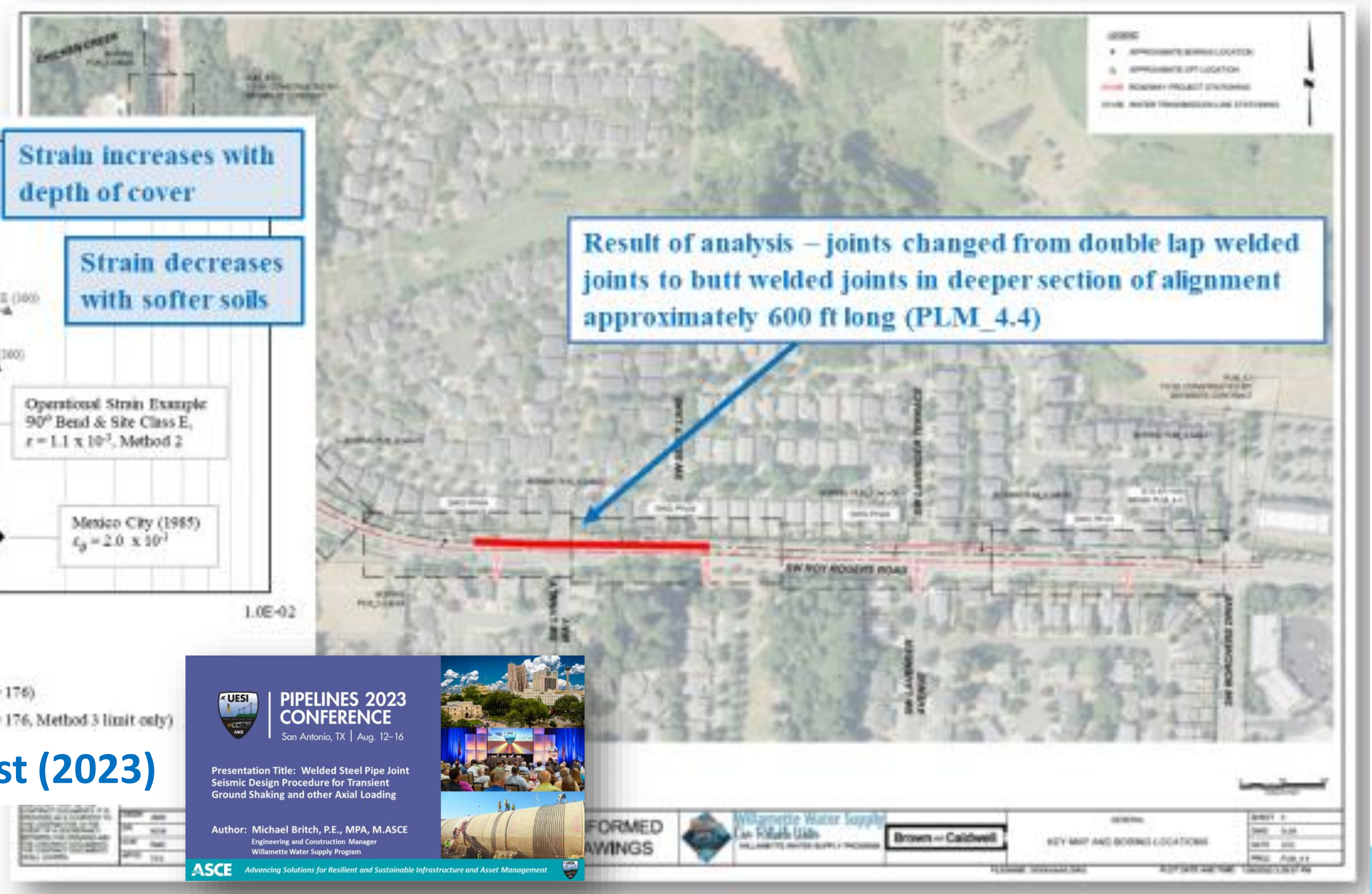


Source: All About Earthquakes | Alberta Geological Survey (aer.ca)

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

Calculations for Pipe Slippage



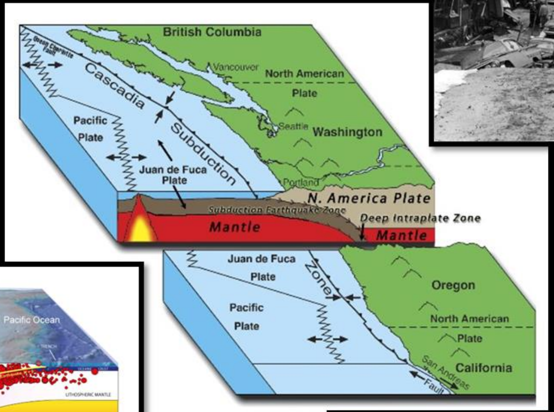


Source: Britch and Havekost (2023)

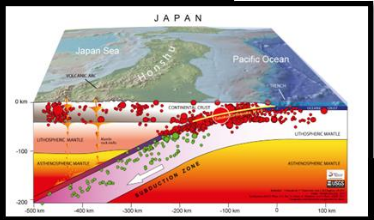
Outline

- How It All Fits Together
- Calculation Procedure Approach 1
  - Transmission Lines
- Calculation Procedure Approach 2
  - Sub-transmission Mains
    (Alternative for Ductile Iron Boltless Segment Pipe Joints)
- How Approach 2 was Implemented during Construction for the WWSP Water Treatment Plant Project

Cascadia Subduction Zone M 9.0



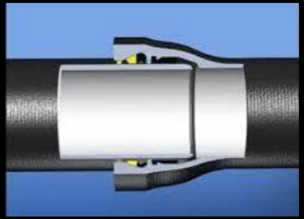
Alaska 1964 M 9.2

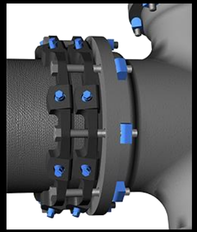


Tohoku 2011 M 9.0

Turkey 2023 M 7.8

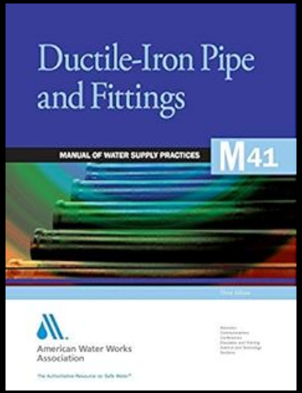
Increasing Earthquake Awareness





Higher Seismic Performance Products Available

"Manual of Practice on Seismic Design of Buried Water/ Wastewater Pipelines" ongoing

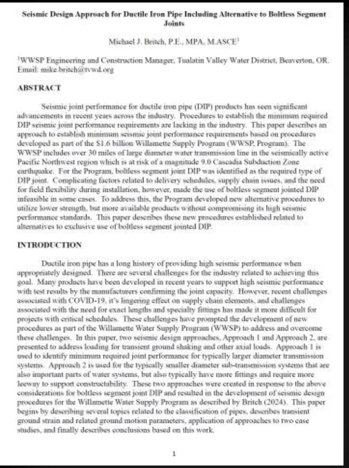


Upcoming new Chapter 13, "Seismic Guidelines for Ductile Iron Pipe"

New Documents Coming to the Industry

Paper on these procedures to be presented at the ASCE Pipelines Conference (Britch, 2024)

UESI | PIPELINES CONFERENCE
Calgary, Alberta | July 27–31, 2024



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

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ABSTRACT

Seismic joint performance for ductile iron pipe (DIP) products has seen significant advancements in recent years across the industry. Procedures to establish the minimum required DIP seismic joint performance requirements are lacking in the industry. This paper describes an approach to establish minimum seismic joint performance requirements based on procedures developed as part of the $1.6 billion Willamette Supply Program (WWSP, Program). The WWSP includes over 30 miles of large diameter water transmission line in the seismically active Pacific Northwest region which is at risk of a magnitude 9.0 Cascadia Subduction Zone earthquake. For the Program, boltless segment joint DIP was identified as the required type of DIP joint. Complicating factors related to delivery schedules, supply chain issues, and the need for field flexibility during installation, however, made the use of boltless segment jointed DIP infeasible in some cases. To address this, the Program developed new alternative procedures to utilize lower strength, but more available products without compromising its high seismic performance standards. This paper describes these new procedures established related to alternatives to exclusive use of boltless segment jointed DIP.

INTRODUCTION

Ductile iron pipe has a long history of providing high seismic performance when appropriately designed. There are several challenges for the industry related to achieving this goal. Many products have been developed in recent years to support high seismic performance with test results by the manufacturers confirming the joint capacity. However, recent challenges associated with COVID-19, it's lingering effect on supply chain elements, and challenges associated with the need for exact lengths and specialty fittings has made it more difficult for projects with critical schedules. These challenges have prompted the development of new procedures as part of the Willamette Water Supply Program (WWSP) to address and overcome these challenges. In this paper, two seismic design approaches, Approach 1 and Approach 2, are presented to address loading for transient ground shaking and other axial loads. Approach 1 is used to identify minimum required joint performance for typically larger diameter transmission systems. Approach 2 is used for the typically smaller diameter sub-transmission systems that are also important parts of water systems, but also typically have more fittings and require more leeway to support constructability. These two approaches were created in response to the above considerations for boltless segment joint DIP and resulted in the development of seismic design procedures for the Willamette Water Supply Program as described by Britch (2024). This paper begins by describing several topics related to the classification of pipes, describes transient ground strain and related ground motion parameters, application of approaches to two case studies, and finally describes conclusions based on this work.

1

What's needed are Practical Ductile Iron Pipe Seismic Calculation Procedures

How It All Fits Together

Focus of this presentation

Level of Criticality of Pipe Systems

- Several systems of pipe classifications have been proposed (ASCE, 2018; OSSAP, 2013; JWWA, 1997). The proposed classification system presented most closely follows that by ASCE (2018) and uses the terms ***transmission line*** and ***sub-transmission main***

Category	Description	Design Approach
Transmission Line	These are typically the largest diameter pipe sections within an overall pipe network that provide flow from the source locations to key points of distribution.	Highest level approach with site specific ground motion parameters.
Sub-Transmission Main	This category generally includes connections from key points of transmission to critical functional points of distribution including critical resilient pipe grids within an overall pipe network.	Similar to above, but adaptation for flexibility of installation and the use of many fittings of varying nature.
Distribution	Lowest level of potable water system that comprises the largest and typically smallest diameter portions of the pipe network and serves the lowest level of customer criticality.	Use restrained joints consistent with area specific seismic hazard.
Non-Critical	Non-critical supply where service can be interrupted for long periods.	Owner driven approach based on perceived value.

How It All Fits Together

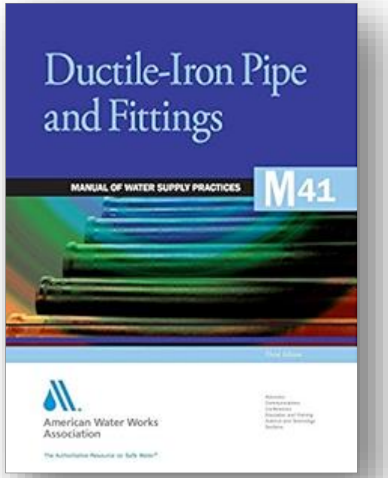
Seismic Behavior of Joints

- "Continuous Pipes" like welded steel pipe (WSP) with welded joints and HDPE
- "Segmented Pipes" like ductile iron pipe and other push-on pipe joint pipe materials

Ductile Iron Pipe Joint Classification

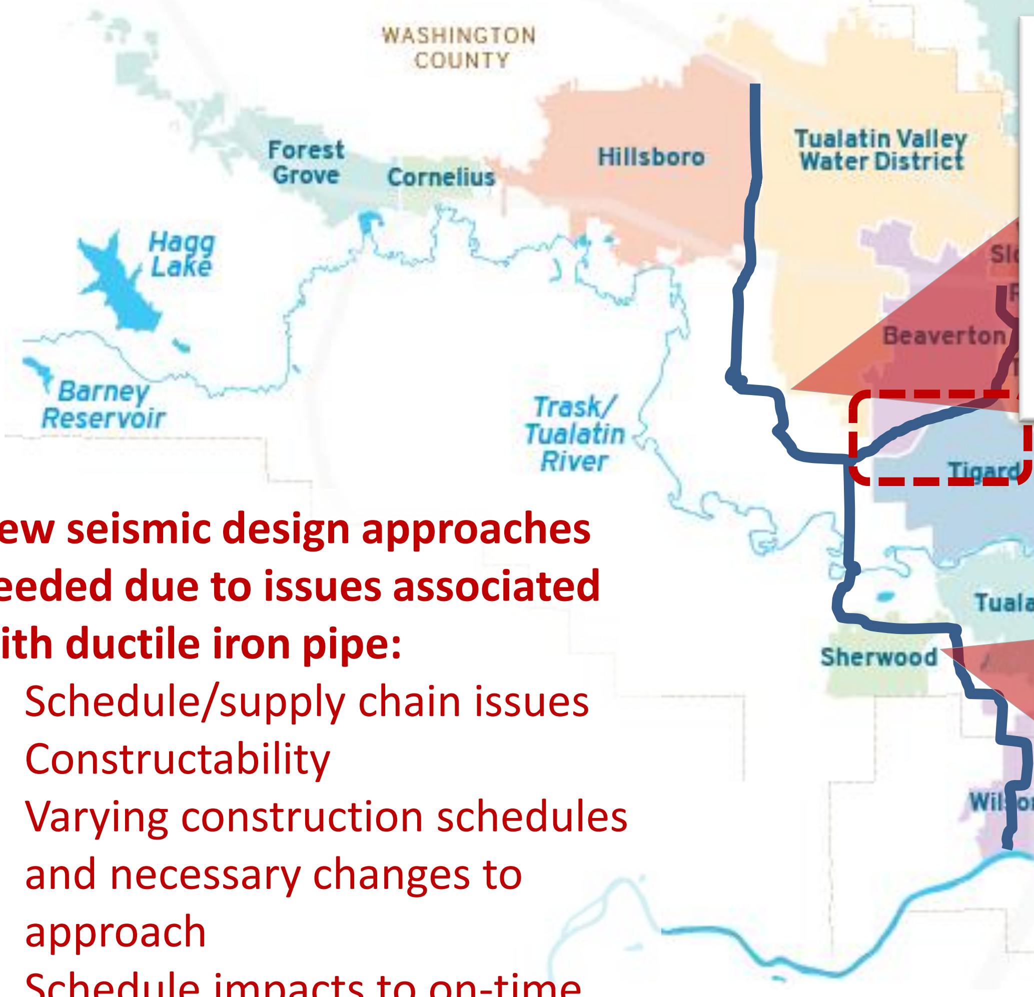
Classification	Description	Relative Joint Seismic Performance
Type IV	Special seismically designed joints	High to very high
Type III	Joints with boltless segments	Moderate to very high
Type II	Joints with gripping wedges	Moderate
Type I	Push-on unrestrained joints	Low (no pull-out resistance)

Focus of this presentation (Type III and Type II)



Upcoming new Chapter 13, "Seismic Guidelines for Ductile Iron Pipe"

Willamette Water Supply System DIP Case Studies



RES_1.0 Case Study Area:

- Several thousand feet of 4” to 12” Ductile Iron Pipe

48” DIP Case Study Area:

- Approximately 3 miles of DIP alternative to WSP (MPE_1.3)

WTP_1.0 Case Study Area:

- Approximately~$8M 4” to 24” Ductile Iron Pipe

New seismic design approaches needed due to issues associated with ductile iron pipe:

- Schedule/supply chain issues
- Constructability
- Varying construction schedules and necessary changes to approach
- Schedule impacts to on-time startup of the WWSS

“Necessity is the mother of invention” (quote attributed to Plato)

Source: Britch (2023)

Image from the Regional Water Providers Consortium

Transmission Lines

DUCTILE IRON PIPE SEISMIC CALCULATION PROCEDURE APPROACH 1

Approach 1 – DIP Transmission Lines

Design Approach 1 (Applies to joints with highest axial loads, e.g. near bends)		
Step 1 – Calculate Restrained Length	Follow DIPRA (2016) procedure to calculate the restrained length using the test pressure.	$L = \frac{S_f PA \tan\left(\frac{\theta}{2}\right)}{F_f + \frac{1}{2} R_s}$
Step 2 – Calculate Axial Load from Thrust	This is done by multiplying the test pressure with the internal cross-sectional area of the pipe.	P_{test} x A
Step 3 – Calculate Load from Ground Strain	When the pipe is installed near bends, joints near the bend should be fully pulled during installation to resist the thrust at the bend (assuming thrust block not used).	$\varepsilon = \frac{PGV_{S1}}{2c_s}$ Resulting stress x A_p gives load
Step 4 – Calculate Axial Load from Slippage	Use procedures described by Elhmadi and O'Rourke (1989) to calculate the ultimate axial force per unit length of pipe.	$f_x^u = \mu_s \gamma H \frac{(1 + K_o)}{2} \pi D$ Applied to actual restrained length
Step 5 – Calculate the Minimum Required Joint Strength	Use the lower of the two values calculated from Steps 3 and 4 will be used (per ASCE, 1984).	Load from Step 2 + lower value of load derived from Steps 3 or 4
Step 6 – Determine Strain Relief Needed at End of Restrained Length Section of Pipe	The amount of additional tensile relief needed is calculated using the ground strain multiplied by the actual installed length of restrained pipe.	Include appropriate factor of safety

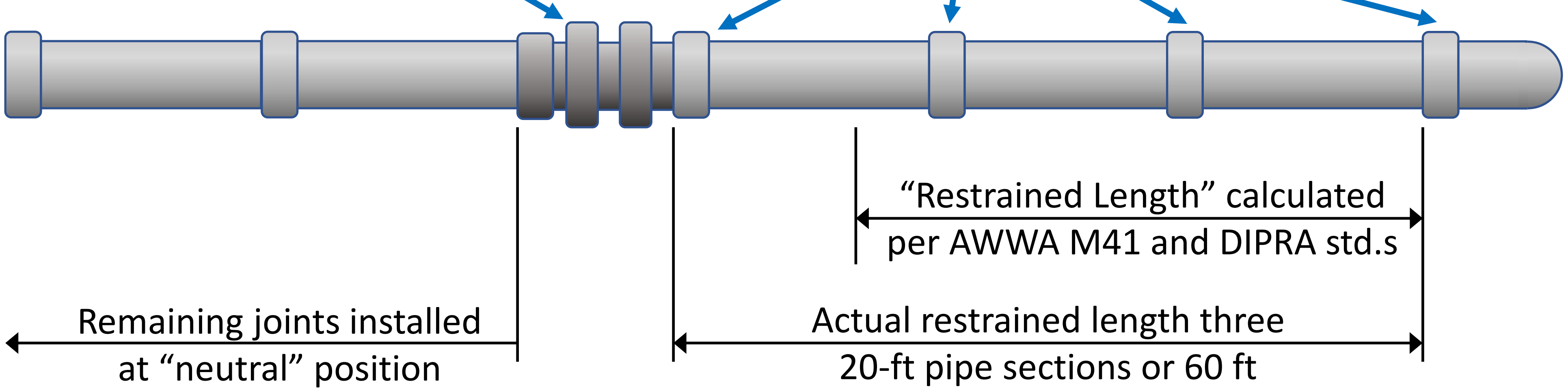
48” MPE Ductile Iron Pipe Example

MPE_1.3 Example:

- 48” Class 52 Ductile Iron Pipe
- Test Pressure 230 psi and 90-degree bend
- Site Class E Soils, ε_g = 0.000587 in/in (Method 2)

Joints pulled for thrust restraint near bend make pipe behave like “continuous” pipe with additional tensile load from ground strain

“Axial Strain Relief” **section prevents further accumulation of load on pipe joints**



Minimum Required Joint Strength:

Source: Britch (2023)

- Slippage force for 60 ft of 48” DIP = 945,000 lbs
- Maximum thrust force = 466,000 lbs
- Therefore, minimum required joint capacity approx. 1,400,000 lbs

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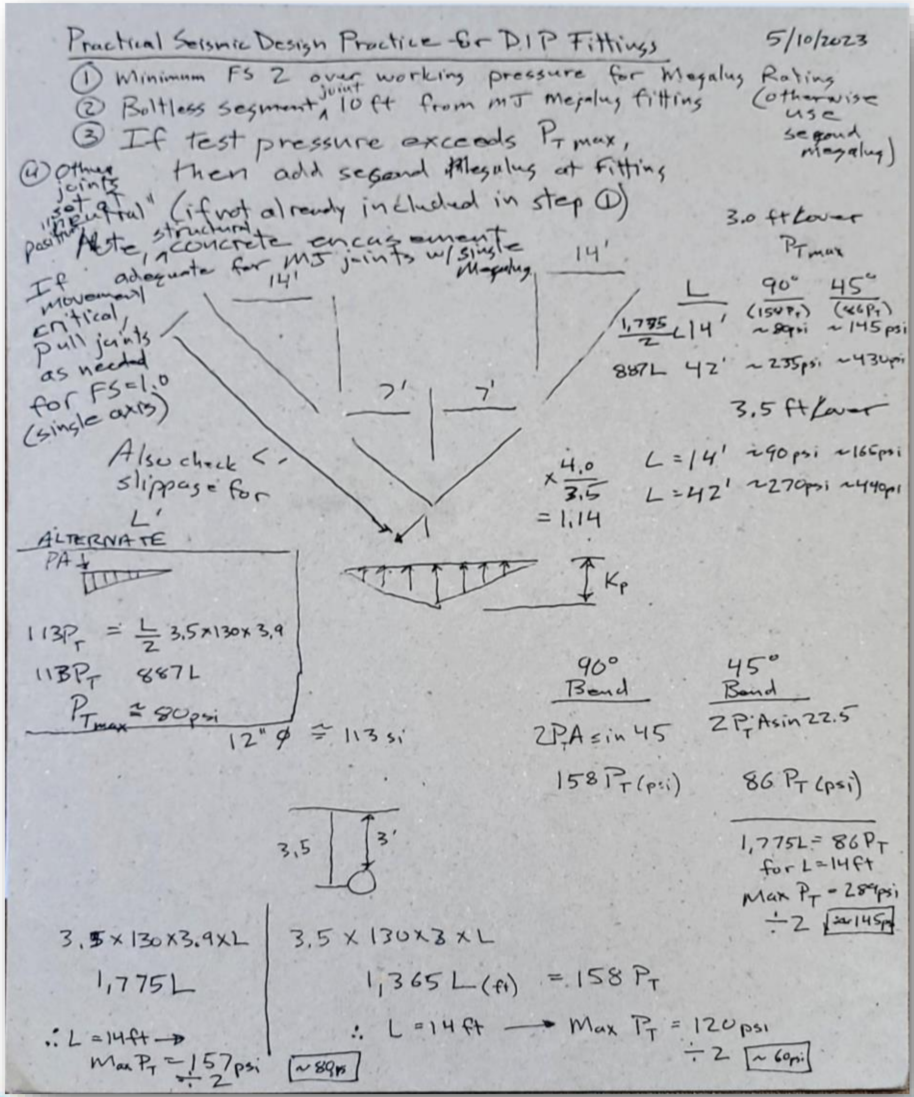
Sub-transmission Mains (Alternative for Ductile Iron Boltless Segment Pipe Joints)

DUCTILE IRON PIPE SEISMIC CALCULATION PROCEDURE APPROACH 2

New RES_1.0 & WTP_1.0 DIP Seismic Design Approach

- New approach thinking started about a year ago as a “back of the notebook” series of thoughts and preliminary calcs (5/10/2023)

“Don’t let the perfect be the enemy of the good”
Voltaire (1694 – 1778)



Starts by Understanding Pipe Performance Limits

Stronger in Compression

Increasing Tensile Joint Performance

Ductile Iron "Segmented" Pipe

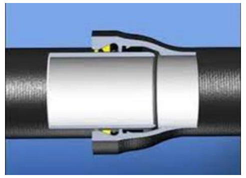
- *Unrestrained "push on" joints* (not used)

Joint Category Type I

MEGALUG®
Mechanical Joint
Restraint

- Joints with gripping wedges/gaskets

Joint Category Type II



AMERICAN
Flex-Ring Joint

U.S. Pipe TR
FLEX® Joint

- Boltless segment joints

Joint Category Type III

Force Balanced
FLEX-TEND®

- Specially designed seismic joints

Joint Category Type IV

What we're really trying to identify is the minimum tensile capacity that the joint must provide

DIP Join Categories Types I – IV in new AWWA M41 Manual chapter

Source: Britch (2023)

New RES_1.0 & WTP_1.0 DIP Seismic Design Approach

New Approach

- Provides installation flexibility (i.e. improves constructability)
- Works with available ductile iron products you can get
- Works with tensile strength performance limits associated with different types of available ductile iron pipe joints

Working around limitations associated with capacity of joints with gripping wedges

Source: "Behavior of Underground Piping Joints Due to Static and Dynamic Loading" (Meis et al., 2003)

Analysis based on "Table 2-1 Test Reults Summary for Static Axial Loading"

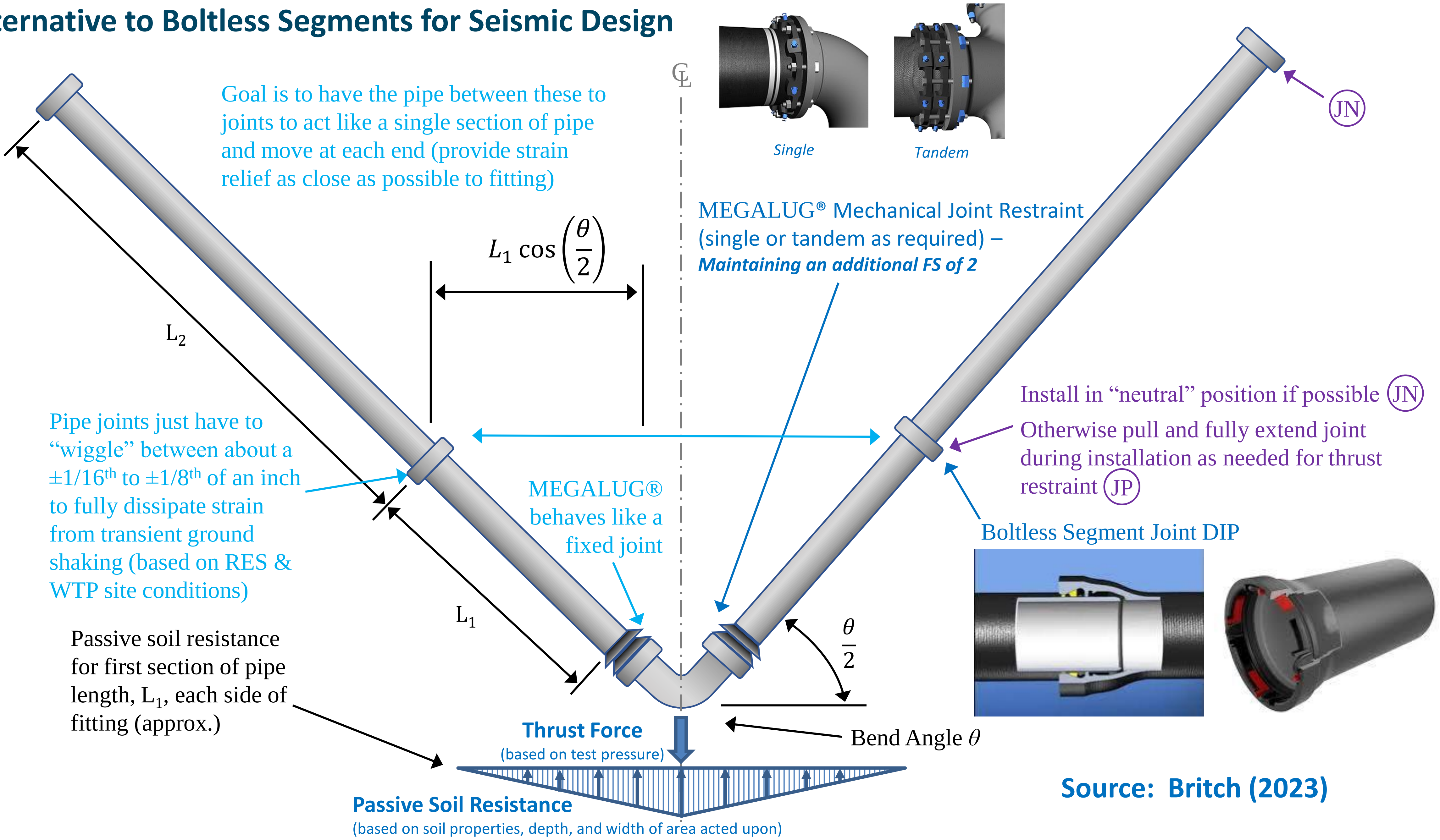
Table 14.x2 Comparison of DIP Gripper Gasket, Bolted Collar, and Retaining Ring Tensile Loading Results

Size	Pipe Material	Joint Type	Loading	F_{max} (kN)	Comparison of Loading Results	Comments on Joint Failure
6" (150 mm)	ductile iron	bell-spigot, gripper gasket	tension	253		ultimate failure of metal teeth in gasket
8" (200 mm)				539		
12" (300 mm)				488		
6" (150 mm)		bell-spigot, retaining ring joint		538	2.13 x gripper gasket	ultimate failure in bell end at retaining ring groove
8" (200 mm)				795	1.47 x gripper gasket	
12" (300 mm)				750	1.54 x gripper gasket	
6" (150 mm)		bell-spigot, bolted collar		195	0.771 x gripper gasket	
8" (200 mm)				280	0.519 x gripper gasket	fracture at collar wedge screw holes

Boltless segment style joint has approx. twice the tensile capacity of joints with gripping wedges

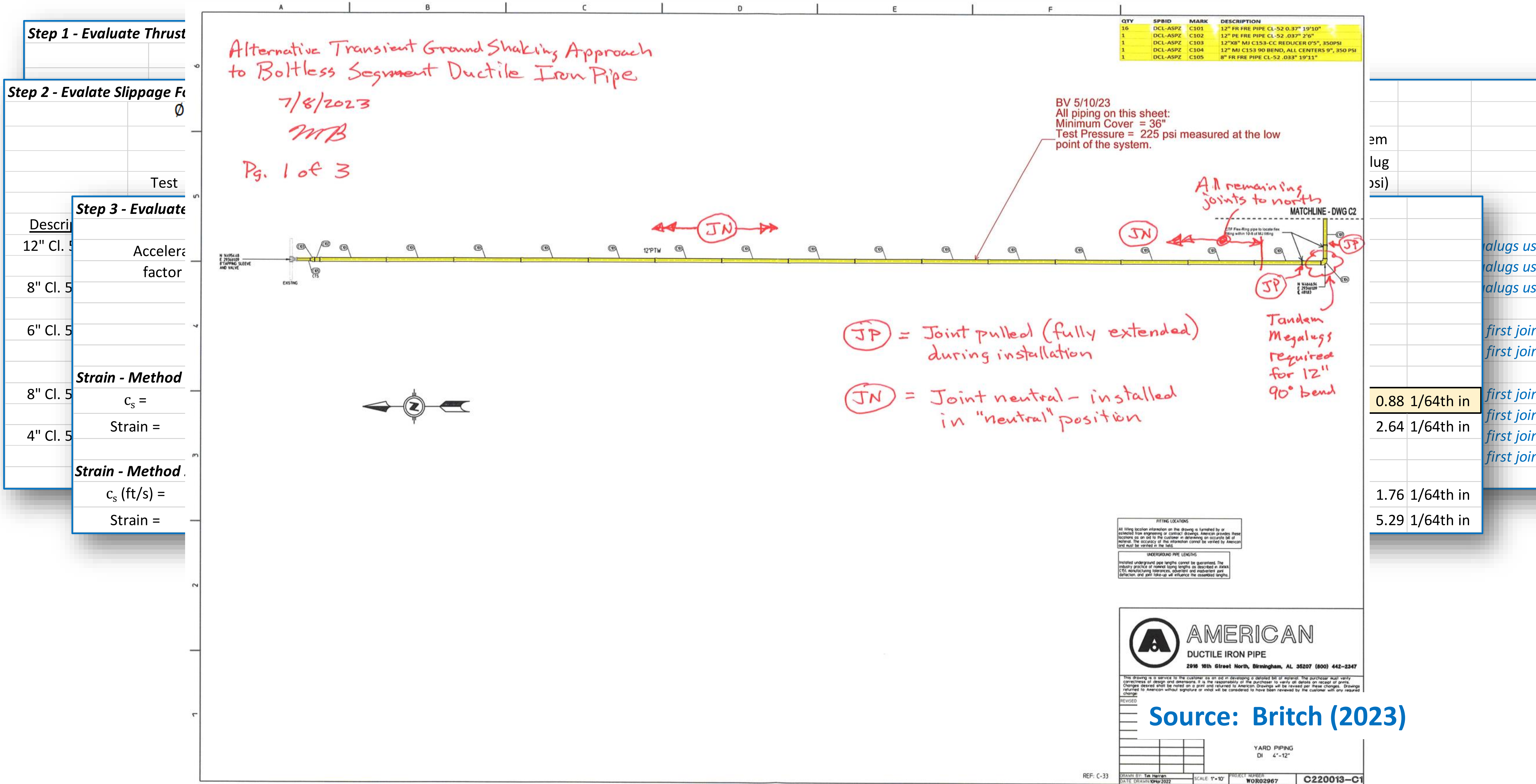
Source: Britch (2023)

DIP Alternative to Boltless Segments for Seismic Design



Source: Britch (2023)

DIP Alternative to Boltless Segments for Seismic Design



Source: Britch (2023)

Approach 2 – DIP Sub-transmission Mains Summary

Procedure Element	Description	Comments
First Part	Check for minimum factor of safety of 2 required for MEGALUG® based on pipe max working pressure	Assumes Category 3 DIP joints have approximately twice the tensile capacity of Category 2 DIP joints
Second Part	Check to see the maximum distance between boltless segment joints that contain MEGALUGs® between them doesn't exceed 20 ft	Where restrained length exceeds 10 ft on either side of fitting with mechanical joints, tandem MEGALUGs® required
Third Part	Check to see if restrained length of pipe, L_R, each side of joint is adequate from fitting joint to first boltless segment joint to resist loads	
Step 1	Evaluate thrust force and resistance loads for MEGALUG® requirements	Starting by using smallest L_1
Step 2	Evaluate slippage force total axial loads for MEGALUG® requirements	Include thrust vector force in direction of pipeline under consideration
Step 3	Evaluate transient ground shaking strain required to provide axial strain relief	Use Method 2 strain calculation procedure for Transmission and Sub-Transmission pipelines (Britch, 2022b)

Example: PLW_1.2 18” Turnout

Want the section of pipe with the fitting to behave like other 20 ft sections of pipe

Example: RES_1.0 12” 90° bend (P_{Test} 225 psi)

Results in the smallest passive soil resistance

Example: WTP deep pipes

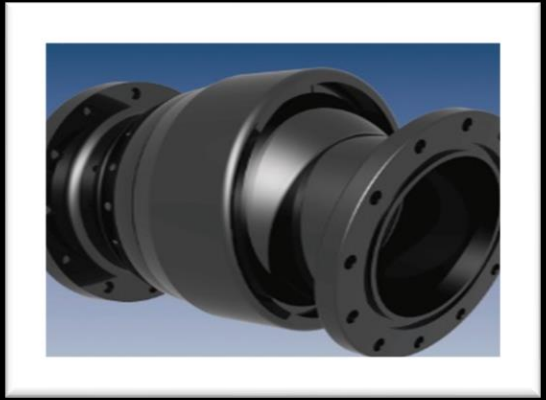
Typically nominal, except with long “restrained length” sections of pipe

HOW APPROACH 2 WAS IMPLEMENTED DURING CONSTRUCTION FOR THE WWSP WATER TREATMENT PLANT PROJECT

HOW DO WE BUILD IT?

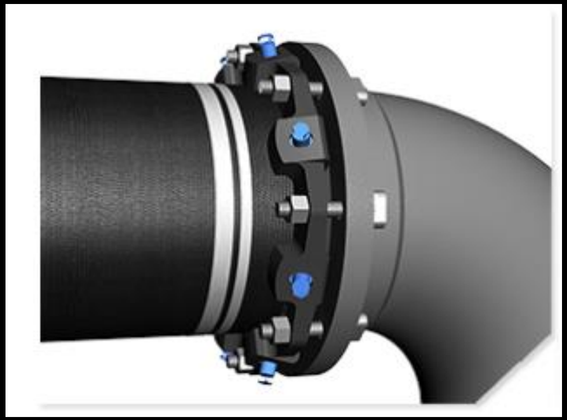
APPROACH

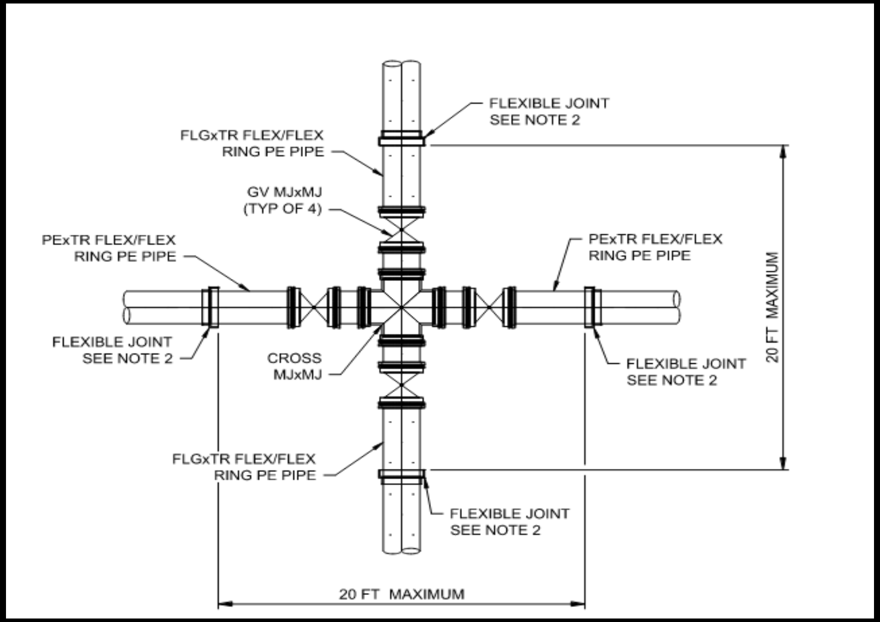
- CONTRACTOR & ENGINEER WORKSHOPS
- QUANTITY TAKEOFFS
- PROCUREMENT
- VDC (VIRTUAL DESIGN CONSTRUCTION)
- SCHEDULE & SEQUENCE REVIEW
- INSTALLATION
- WASTE MANAGEMENT



ENGINEER & CONTRACTOR WORKSHOPS

- IDENTIFY COMPONENTS
- IDENTIFY CONSTRAINTS
- REVIEW AVAILABLE PRODUCTS
- REVIEW PRODUCT LEAD TIME

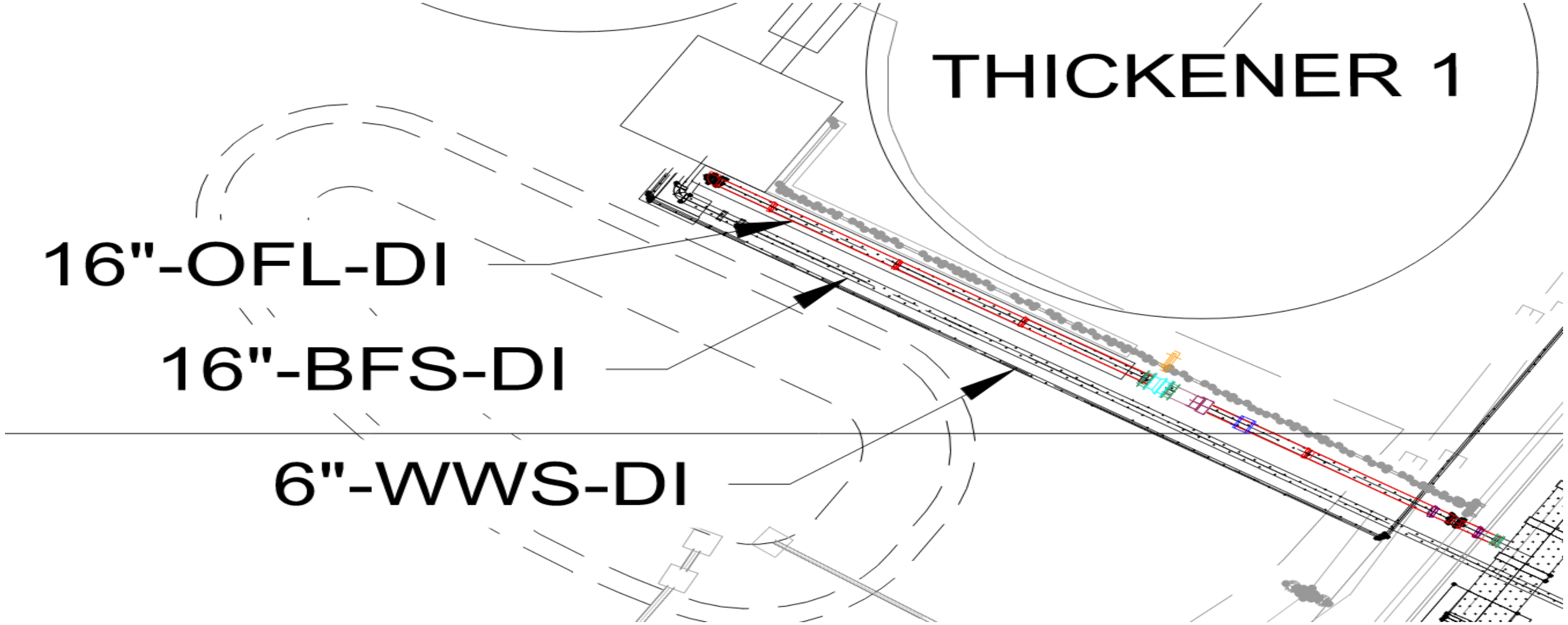


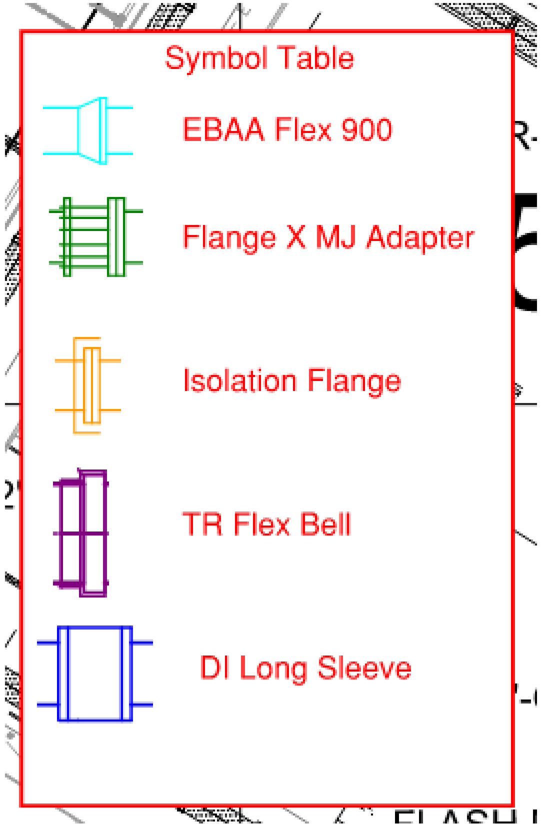


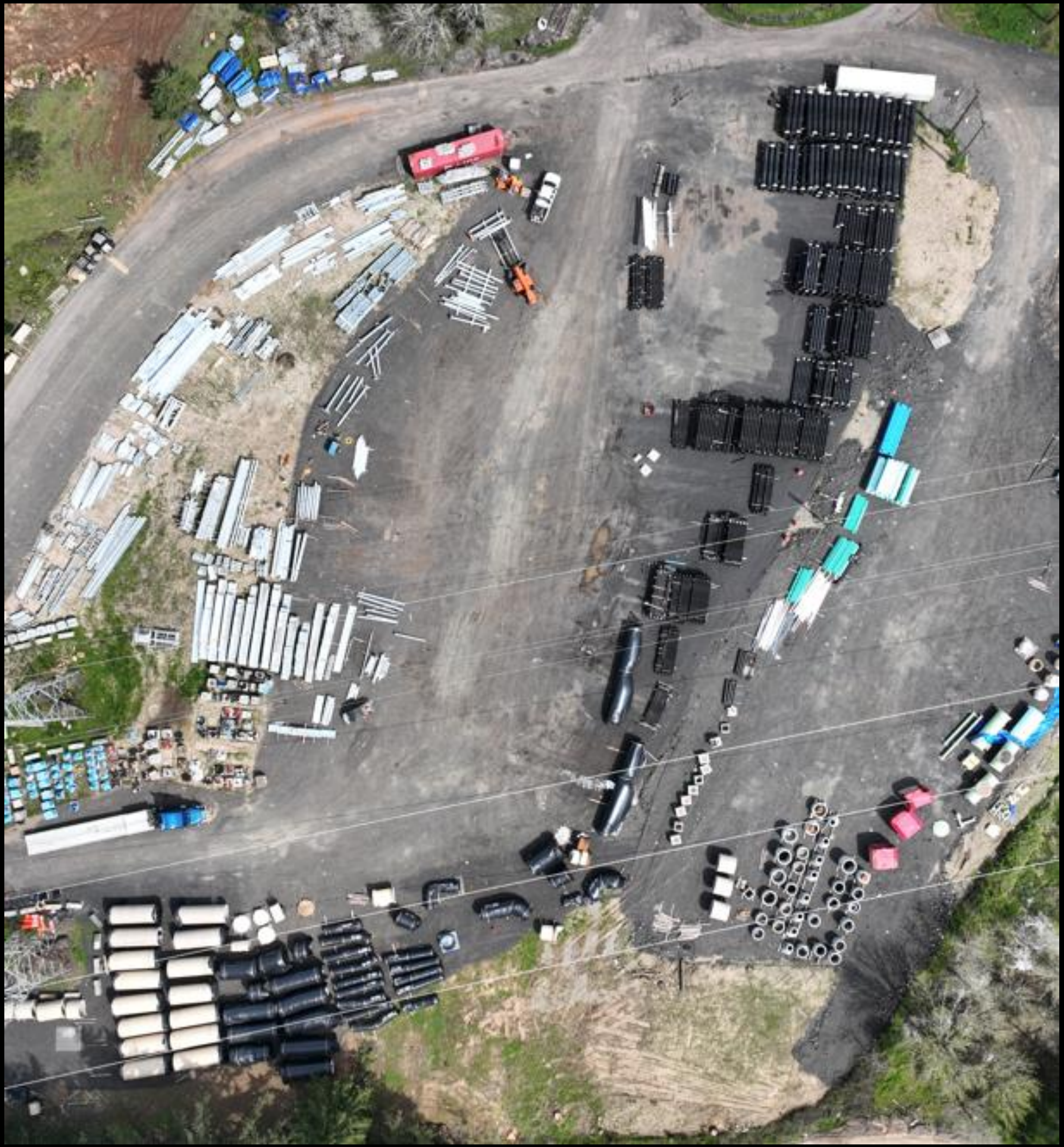
QUANTITY TAKEOFFS

Utilized Bluebeam

- Complete Process Pipe Takeoff
- Complete Potable & Non-Potable Takeoff
- Selected Probable Makeup Locations
- Quantified Extra Pipe Required to Meet TR Flex Joint Detail



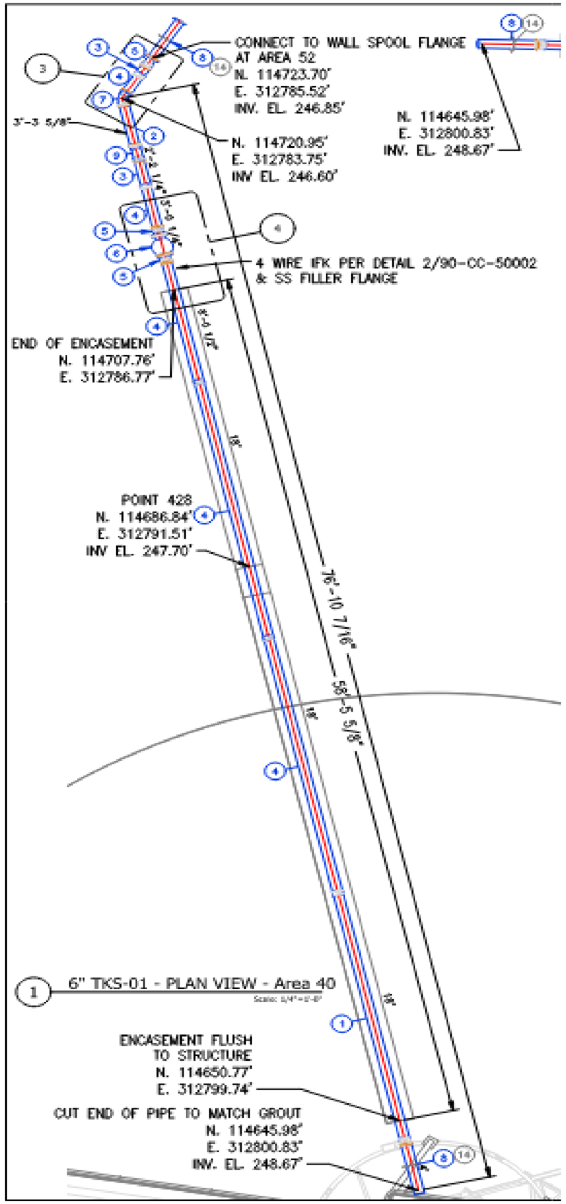


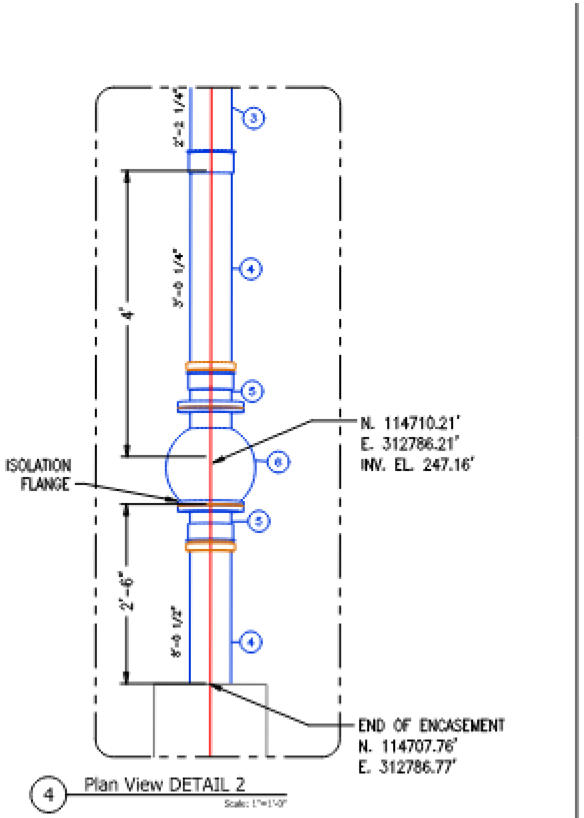


PROCUREMENT

- SOLICITED THREE VENDORS
- ENTIRE PROJECT PROCURED IN ONE ORDER
- OVER 19,000 FEET OF DI PIPE 4” – 24”
- DIRECT SHIPMENT FROM MANUFACTURE TO JOBSITE
- IDENTIFY EXTRA QUANTITIES NEEDED TO FACILITATE FIELD CHANGES

VDC (VIRTUAL DESIGN CONSTRUCTION)





BILL OF MATERIALS			
ID	QTY	ND	DESCRIPTION
1	18'-0"	6"	PIPE, MJxPE, AWWA C151
2	3'-3 5/8"	6"	PIPE, PExPE, AWWA C151
3	3'-2 7/16"	6"	PIPE, PExPE, W/ TR-FLEX LOCK BEAD ON ONE SIDE, AWWA C151
4	49'-0 3/4"	6"	PIPE, TRFxPE W/ TR-FLEX LOCK BEAD
5	3	6"	Flange Adapter MJxFE - DI C153
6	1	6"	Flexible Ball Joint FLEX-900
7	1	6"	BEND 45, 350 PSI, MJxMJ, AWWA C153
8	2	6"	CP IMPERIAL Sleeve
9	1	6"	SLEEVE, SOLID, LONG, 350 LB, MJ, AWWA C153, CM LINED, AC and DBL PEE COATED
10	24	3/4"x3"	BOLT SET, FF
11	3	6"	GASKET, NEOPRENE, 150 LB, AWWA C110
12	5	6"	GASKET, WITH TR-FLEX LOCKING LUGS
13	8	6"	GLAND, MJ, MEGALUG, AWWA C111
14	2	6"	WEEP RING

VDC Process

- Produce shop drawings for all alignments.
- WWSP & EOR Review to identify need for additional seismic resiliency requirements, i.e. tandem mega lugs as well as compliance with contract documents.
- Final shop drawing produced and issued for construction.

Schedule & Sequence Review

- Verify start and stop locations shown in shop drawings are consistent with CPM schedule.
- Verify that makeup locations shown in shop drawings are adequate.

CONSTRUCTION

Installation

- TR Flex Joints installed in neutral position.
- Flex 900 & IFK assemblies prebuilt & hydro tested above ground.
- Correlating seismic and cathodic requirements

Waste Management

- Several sticks of pipe could be wasted with this method if not properly managed, i.e. cutting pipe to use just the proprietary bell and or spigot.
- Cut pipe can be reused, this process can be maximized with a solid VDC effort and organized staging.

Questions

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