Ductile Iron Pipe Research Association

Thrust Restraint

CA-NV Section AWWA
Annual Fall Conference

October 22, 2014
DIPRA Member Companies

- American Cast Iron Pipe Company
- Atlantic States
- Canada Pipe Company Ltd.
- CLOW
- Griffin Pipe Products Co.
- McWane
- PSCIPCO
- U.S. Pipe
AWWA Standards

- ANSI/AWWA C104/A21.4 Cement-Mortar Linings
- ANSI/AWWA C105/A21.5 Polyethylene Encasement
- ANSI/AWWA C110/A21.10 Ductile-Iron and Gray-Iron Fittings
- ANSI/AWWA C111/A21.11 Rubber-Gasket Joints
- ANSI/AWWA C115/A21.15 Flanged Ductile-Iron Pipe
- ANSI/AWWA C116/A21.16 Fusion-Bonded Epoxy Coatings for Fittings
- ANSI/AWWA C150/A21.50 Thickness Design
- ANSI/AWWA C151/A21.51 Ductile-Iron Pipe, Centrifugally Cast
- ANSI/AWWA C153/A21.53 Ductile-Iron Compact Fittings
- ANSI/AWWA C600 Installation of Ductile-Iron Water Mains
Regional Engineer Program

Paul H. Hanson, P.E.
Regional Director
NACE Certified Corrosion Specialist
Regional Engineer Program

Allen H. Cox, P.E.
Regional Director
NACE Certified Corrosion Specialist
Regional Engineer Activities

- Direct Calls
- Technical Presentations
- Engineering Investigations
- Technical Assistance
- Professional Groups
IRON PIPE IS SMART CERTIFIED

Ductile iron pipe is independently SMaRT® certified as a sustainable product.

LEARN MORE
Restraining Thrust Forces
Forces Causing Thrust

- Static forces
  (Internal pressure)
- Dynamic forces
  (Fluid velocity)
Thrust Force

Straight Run
Thrust Force

Bend

2PA \sin(\theta/2)
Resultant Thrust: 90° Bend

Pressure at 150 psi

<table>
<thead>
<tr>
<th>Nominal Pipe Size (in)</th>
<th>Thrust Force (lbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>7,932</td>
</tr>
<tr>
<td>12</td>
<td>29,030</td>
</tr>
<tr>
<td>24</td>
<td>110,901</td>
</tr>
<tr>
<td>36</td>
<td>244,396</td>
</tr>
<tr>
<td>48</td>
<td>429,956</td>
</tr>
<tr>
<td>64</td>
<td>718,506</td>
</tr>
</tbody>
</table>
Restraining Techniques

- Thrust blocks
- Restrained joint system
- Tie rods
- Combined systems
Types of Thrust Blocks

- Bearing
- Gravity
Bearing Thrust Block

Bearing Area (ft^2) = \frac{\text{Safety Factor} \times \text{Thrust Force (lbs)}}{\text{Bearing Capacity of Undisturbed Soil (lbs/ft}^2)}
<table>
<thead>
<tr>
<th>Soil</th>
<th>$S_B$ (lb/ft$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Muck</td>
<td>0</td>
</tr>
<tr>
<td>Soft clay</td>
<td>1,000</td>
</tr>
<tr>
<td>Silt</td>
<td>1,500</td>
</tr>
<tr>
<td>Sandy silt</td>
<td>3,000</td>
</tr>
<tr>
<td>Sand</td>
<td>4,000</td>
</tr>
<tr>
<td>Sandy clay</td>
<td>6,000</td>
</tr>
<tr>
<td>Hard clay</td>
<td>9,000</td>
</tr>
</tbody>
</table>
Bearing Thrust Block

A = hb = \frac{T}{S_B} (S_f)

h ≤ 1/2H_t
Bearing Block Construction

Right

Wrong

45° 45°

T T
Thrust Restraint
TYPICAL THRUST BLOCK DETAILS
Gravity Thrust Block

Gravity Block Size (ft³) = \frac{\text{Safety Factor \cdot Thrust Force (lb)}}{\text{Density of Block Material (lb/ft}^3\text{)}}
Restrained Joint Force System

\[ L = \frac{PA \tan(\theta/2)}{F_f + \frac{1}{2} R_s} \]

\[ [F_f + \frac{1}{2} R_s]LCos(\theta/2) \]
PUSH-ON JOINT
Restrained Joints
MECHANICAL JOINT
Mechanical Joint Retainer Glands

Set-Screw Mechanical Joint Retainer Gland

Wedge-action Mechanical Joint Retainer Gland
Restrained Joints
Designing Thrust Systems

Thrust Restraint Brochure

A brochure outlining design theory and a design aid of restrained joint systems for ductile iron pipe.
Restrained Joint Force System

\[ L = \frac{PA \tan(\theta/2)}{F_f + \frac{1}{2} R_s} \]

\[ [F_f + \frac{1}{2} R_s]LCos(\theta/2) \]
Restrained Length Dependant Upon

- Pipe size
- Type of fitting
- Internal pressure
- Depth of cover
- Soil characteristics
- Laying conditions
# Suggested Values for Soil Properties and Reduction Constant

<table>
<thead>
<tr>
<th>Soil Designation</th>
<th>Soil Description</th>
<th>$\phi$ (deg)</th>
<th>$f_\phi$</th>
<th>$C_s$ (psf)</th>
<th>$f_c$</th>
<th>$\gamma$ (deg)</th>
<th>$K_n$ A21.50 Laying Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clay 1</td>
<td>Clay of medium to low plasticity, LL&lt;50, &lt;25% coarse particles [CL &amp; CL-ML]</td>
<td>0</td>
<td>0</td>
<td>300</td>
<td>.50</td>
<td>.80</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2*</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>Coh-gran</td>
<td>Cohesive granular soils, &gt; 50% coarse particles [GC &amp; SC]</td>
<td>20</td>
<td>.40</td>
<td>200</td>
<td>.40</td>
<td>.65</td>
<td>.40</td>
</tr>
<tr>
<td>Sand Silt</td>
<td>Sand or gravel w/silt, &gt; 50% coarse particles [GM &amp; SM]</td>
<td>30</td>
<td>.50</td>
<td>0</td>
<td>0</td>
<td>.75</td>
<td>.40</td>
</tr>
<tr>
<td>Good Sand</td>
<td>Clean sand, &gt;95% coarse particles, [SW &amp; SP]</td>
<td>36</td>
<td>.75</td>
<td>0</td>
<td>0</td>
<td>.80</td>
<td>.40</td>
</tr>
</tbody>
</table>

Consult Table 3 of thrust brochure for pertinent notes.
Laying Conditions

Type 1

Type 2

Type 3

Type 4

Type 5
Thrust Restraint - Research

- Measurement Trench
- 12" MJ Pipe and fittings with DI retainer glands
- Movement sensing probes
- Railroad Cross Tie Bulkhead
- Measuring Frame
- Backfilled
- Approximately 3' of cover
- Bedding compaction varied during test
- Section “A-A”
- Approximately 3' of cover
Designing Thrust Systems

Thrust Restraint Computer Program

A computer program to aid in the design of restrained joint systems for ductile iron pipe.
### Table B-5

**Soil Type:** Coh-gran

**Soil Parameters**

\[
\begin{align*}
\phi &= 20 \text{ degrees} \\
C_s &= 200 \text{ psf} \\
\gamma &= 90 \text{ pcf}
\end{align*}
\]

<table>
<thead>
<tr>
<th>Size (in)</th>
<th>Depth (ft)</th>
<th>A21.50 – Laying Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Restrained Length (ft)</td>
</tr>
<tr>
<td>30</td>
<td>2.5</td>
<td>97 (112)</td>
</tr>
<tr>
<td>30</td>
<td>3.0</td>
<td>91 (105)</td>
</tr>
<tr>
<td>30</td>
<td>4.0</td>
<td>81 (93)</td>
</tr>
<tr>
<td>30</td>
<td>6.0</td>
<td>66 (76)</td>
</tr>
<tr>
<td>30</td>
<td>8.0</td>
<td>56 (64)</td>
</tr>
<tr>
<td>30</td>
<td>10.0</td>
<td>48 (56)</td>
</tr>
</tbody>
</table>

**A21.50 – Laying Conditions**

<table>
<thead>
<tr>
<th></th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>(f_\phi)</td>
<td>0.40</td>
<td>0.65</td>
<td>0.65</td>
<td>0.65</td>
</tr>
<tr>
<td>(f_c)</td>
<td>0.40</td>
<td>0.40</td>
<td>0.40</td>
<td>0.40</td>
</tr>
<tr>
<td>(K_n)</td>
<td>0.40</td>
<td>0.60</td>
<td>0.80</td>
<td>1.00</td>
</tr>
</tbody>
</table>
## Horizontal Bend Multiplier

<table>
<thead>
<tr>
<th>$\theta$</th>
<th>$\tan(\theta/2)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>90°</td>
<td>1.000</td>
</tr>
<tr>
<td>45°</td>
<td>0.414</td>
</tr>
<tr>
<td>22½°</td>
<td>0.199</td>
</tr>
<tr>
<td>11¼°</td>
<td>0.098</td>
</tr>
</tbody>
</table>
Vertical Down Bend

\[ L = S_f \left( \frac{\text{PA Tan}(\theta/2)}{F_f} \right) \]

\[ 2PA \sin(\theta/2) \]
L_b = S_f \left( \frac{P_{A_b} - 1/2 R_s L_r}{(F_f)_b} \right)

Tee
Extend Restrained Joints at:

- Casings
- Bridge crossings
- Aboveground applications
- Poor soil conditions
- Closely located fittings
Combined Horizontal Bends

\[ L_1 = S_f \left( \frac{2PA \tan(\theta/2)}{F_f + 1/2R_s} \right) - L \]

2PA Sin(\( \theta/2 \))

\( \frac{\pi}{2} \)

\( F_f \)

\( R_s \)

\( L \)

\( L_1 \)

Known

\( \frac{\pi}{2} \)

\( F_f \)

\( R_s \)

\( L \)

\( L_1 \)

Known
Vertical Offset

\[ L_1 = S_f \left( \frac{2PA \tan(\theta/2)}{F_f} \right) - L \]

\[ L_2 = S_f \left( \frac{2PA \tan(\theta/2)}{F_f + 1/2R_s} \right) - L \]

\[ 2PA \sin(\theta/2) \]
Combined Vertical Equal Angle Offsets

\[ L_1 = S_f \left( \frac{2 \text{PA} \tan(\theta/2)}{F_f} \right) - L \]
Thrust Restraint – Deflected Joints

First unrestrained joint do not deflect

Second unrestrained joint begin deflect
## Maximum Thrust of Deflected Joints

### Push-On Pipe Joint at 100 psi

<table>
<thead>
<tr>
<th>Nominal Pipe Size (in)</th>
<th>Maximum Joint Deflection (deg)</th>
<th>Maximum Lateral Thrust (lbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>5.00</td>
<td>158</td>
</tr>
<tr>
<td>8</td>
<td>5.00</td>
<td>561</td>
</tr>
<tr>
<td>12</td>
<td>5.00</td>
<td>1,194</td>
</tr>
<tr>
<td>20*</td>
<td>3.00</td>
<td>1,918</td>
</tr>
<tr>
<td>24*</td>
<td>3.00</td>
<td>2,737</td>
</tr>
<tr>
<td>36*</td>
<td>3.00</td>
<td>6,032</td>
</tr>
<tr>
<td>48*</td>
<td>3.00</td>
<td>10,611</td>
</tr>
<tr>
<td>54*</td>
<td>3.00</td>
<td>13,623</td>
</tr>
<tr>
<td>60*</td>
<td>3.00</td>
<td>15,608</td>
</tr>
<tr>
<td>64*</td>
<td>3.00</td>
<td>17,733</td>
</tr>
</tbody>
</table>

* Maximum deflection may be larger than shown. Consult the manufacturer.
Pipe on Supports
Pipe on Supports
Pipe on Supports
Is Steel Strap Required?
Combined Horizontal Bends

\[
\begin{align*}
L_1 &= S_f \left( \frac{2PA \tan(\theta/2)}{F_f + 1/2R_s} \right) - L \\
2PA \sin(\theta/2) &= \frac{1}{2}R_s \\
2PA \sin(\theta/2) &= R_s
\end{align*}
\]
Thrust Restraint Project

Test Pressure = 250 psi

720 Kips

405 Kips

405 Kips

ΔX

ΔX

ΔX

ΔX

720 Kips

405 Kips

20'

4'

Test Pressure = 250 psi
Thrust Restraint Project

Test Pressure = 250 psi
Thrust Restraint Project

Test Pressure = 250 psi
Horizontal Bend / Vertical Up Bend

Pull the ‘slack’ out of the joints!

Fully extend the joints

PA

F

f

R

s

θ

PA Sin(θ/2)

L

F_f

R_s

[F_f + ½ R_s]LCos(θ/2)

Pull the ‘slack’ out of the joints!
Development of Analytical Model for Thrust Restraint Design -
Part 2: Segmented Pipelines

ASCE Task Committee on Thrust Restraint Design of Buried Pipelines
(Corresponding Author: Sri Rajah, Ph.D., P.E., M.ASCE, HDR Engineering, Inc.)

500 108th Avenue, Suite 1200, Bellevue, WA 98004;
E-mail: sri.rajah@hdrinc.com, Tel: (425) 450-6269

ABSTRACT

Thrust restraint design of buried pipelines is dependent on internal pressure, piping configuration, and the pipe-soil interaction at the pipe-soil interface. Pipe-soil interface behavior is dependent on the, pipe material, native and backfill soil properties, and installation conditions. It is generally recognized that a buried pipe has to move through the soil to develop friction and adhesion resistance. It also has to move against the soil in order to develop lateral (passive) resistance forces, which in combination with the frictional and adhesive resistance forces resist the unbalanced thrust. Axial and transverse pipe movements cause additional pipe stresses (axial, shear and bending) on the pipe at or near the unbalanced forces. Magnitude of the additional pipe stresses are also dependant on the axial and rotational flexibility of the pipe joints. The current American Water Works Association (AWWA) pipe design manuals do not consider the soil-pipe interaction near the bends and the resulting additional pipe stresses (axial, bending and shear) adequately, except to a certain extent in the M9 (AWWA 2008) procedure.
Components Requiring Thrust Restraint

- Bends
- Tees
- Dead ends
- Hydrants
- Offsets
- Reducers
Components Requiring Thrust Restraint

- Bends
- Tees
- Dead ends
- Hydrants
- Offsets
- Reducers

\[ T = (P_1 - P_2) A \]
Horizontal Bend / Vertical Up Bend

\[ L = S_f \left( \frac{PA \tan(\theta/2)}{F_f + \frac{1}{2} R_s} \right) \]

\[ \theta \]

PA

L

PA Sin(\theta/2)

PA

L

PA Sin(\theta/2)

\[ [F_f + \frac{1}{2} R_s]LCos(\theta/2) \]
Tie Rods
Calculating Number of Tie Rods

\[ F = SA \]

\[ N = \frac{S_f T_{(X \text{ or } Y)}}{F} \]

Where:

- \( F \) = Force Developed per Rod (lbs.)
- \( S \) = Tensile Strength of Rod Material (psi)
- \( A \) = Cross Sectional Area of Rod (in.\(^2\))
- \( N \) = Number of Rods Required
- \( T_{(X \text{ or } Y)} \) = Thrust Force Component (lbs.)
- \( S_f \) = Safety Factor (usually 1.5)
Combined Systems
Installation

Note: Many Prefer to Use Restrained Joints in Place of Thrust Blocks for Thrust Restraint
Chicopee, MA – 20 inch Cast Iron Pipe
Installed: 1898 – Inspected: 2014
Member: Cast Iron Pipe Century Club
Chicopee, MA– 20 inch Cast Iron Pipe
Installed: 1898 – Inspected: 2014
Member: Cast Iron Pipe Century Club
**Figure 5: Average Estimated Service Lives by Pipe Materials (average years of service)**

<table>
<thead>
<tr>
<th>Derived Current Service Lives (Years)</th>
<th>CI</th>
<th>CICL (LSL)</th>
<th>CICL (SSL)</th>
<th>DI (LSL)</th>
<th>DI (SSL)</th>
<th>AC (LSL)</th>
<th>AC (SSL)</th>
<th>PVC</th>
<th>Steel</th>
<th>Conc &amp; PCCP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northeast Large</td>
<td>130</td>
<td>120</td>
<td>100</td>
<td>110</td>
<td>50</td>
<td>80</td>
<td>80</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Midwest Large</td>
<td>125</td>
<td>120</td>
<td>85</td>
<td>110</td>
<td>50</td>
<td>100</td>
<td>85</td>
<td>55</td>
<td>80</td>
<td>105</td>
</tr>
<tr>
<td>South Large</td>
<td>110</td>
<td>100</td>
<td>100</td>
<td>105</td>
<td>55</td>
<td>100</td>
<td>80</td>
<td>55</td>
<td>70</td>
<td>105</td>
</tr>
<tr>
<td>West Large</td>
<td>115</td>
<td>100</td>
<td>75</td>
<td>110</td>
<td>60</td>
<td>105</td>
<td>75</td>
<td>70</td>
<td>95</td>
<td>75</td>
</tr>
<tr>
<td>Northeast Medium &amp; Small</td>
<td>115</td>
<td>120</td>
<td>100</td>
<td>110</td>
<td>55</td>
<td>100</td>
<td>85</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Midwest Medium &amp; Small</td>
<td>125</td>
<td>120</td>
<td>85</td>
<td>110</td>
<td>50</td>
<td>70</td>
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<td>55</td>
<td>80</td>
<td>105</td>
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<tr>
<td>South Medium &amp; Small</td>
<td>105</td>
<td>100</td>
<td>100</td>
<td>105</td>
<td>55</td>
<td>100</td>
<td>80</td>
<td>55</td>
<td>70</td>
<td>105</td>
</tr>
<tr>
<td>West Medium &amp; Small</td>
<td>105</td>
<td>100</td>
<td>75</td>
<td>110</td>
<td>60</td>
<td>105</td>
<td>75</td>
<td>70</td>
<td>95</td>
<td>75</td>
</tr>
<tr>
<td>Northeast Very Small</td>
<td>115</td>
<td>120</td>
<td>100</td>
<td>120</td>
<td>60</td>
<td>100</td>
<td>85</td>
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<td>100</td>
<td>100</td>
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<tr>
<td>Midwest Very Small</td>
<td>135</td>
<td>120</td>
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<td>110</td>
<td>60</td>
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<td>75</td>
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<td>South Very Small</td>
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<td>100</td>
<td>80</td>
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<td>105</td>
</tr>
<tr>
<td>West Very Small</td>
<td>130</td>
<td>100</td>
<td>75</td>
<td>110</td>
<td>60</td>
<td>105</td>
<td>65</td>
<td>70</td>
<td>95</td>
<td>75</td>
</tr>
</tbody>
</table>

LSL indicates a relatively long service life for the material resulting from some combination of benign ground conditions and evolved laying practices etc.

SSL indicates a relatively short service life for the material resulting from some combination of harsh ground conditions and early laying practices, etc.
Integrity isn’t Expensive
it’s
PRICELESS

Ductile Iron Pipe
The Right Decision