Steel Pipe Design
Agenda

- History
- Hydraulics
- Pipe/Trench Design
- Joints
- Fittings
- Sustainability
**History**

- First uses date back to 1850s
- Riveted and lock bar pipe until the 1930s
- By the mid 1970s, there were over 200 documented 80-year installations
- Coatings and linings have significantly evolved over time
Steel Pipe Design Manuals

AWWA M11  
ASCE MOP 79  
ASCE MOP 119

Be Careful to not Mix Factors or Variables Between the Manuals
Best Practices

- Develop system hydraulics using Hazen-Williams with a range of C-factors; consider transient and field test pressures
- Do life-cycle cost analysis for sizing pipelines in pumped systems (construction, O&M, power costs)
- Use 8-12 fps max velocity in pipelines
- Consider larger diameter pipe/higher operating pressures to reduce the need for booster pump stations
Steel Pipe Design Considerations

- **Wall Thickness**
  - Internal Pressure
  - External Pressure/Loading
  - Handling and Installation

- **Trench Design**
Wall Thickness – Internal Pressure

Working Pressure Design:

\[ t = \frac{P_w D_o}{2S} \]

Where:

- \( t \) = Wall Thickness
- \( P_w \) = Pressure (working)
- \( D_o \) = Diameter (ID)
- \( S \) = Allowable Stress
  (limited to 50% of yield strength of steel)
Wall Thickness – Internal Pressure

Transient/Field Pressure Test Design:

\[ t = \frac{(P_w + P_t)D_o}{2S_t} \]

Where:

\((P_w + P_t)\) – Transient or field test condition

\(S_t\) – Limited to 75% of yield strength of steel
Wall Thickness – External Pressure/Loading

- AWWA M11 design for buckling
  - Full vacuum condition w/soil load
  - Live load
- Takes water table into account
- More conservative design

\[ q_a = \left( \frac{1}{FS} \right) \left( 32R_w B'E'E'I/D^3 \right)^{1/2} \]

Where \( q_a \) is the allowable buckling pressure

\[ \gamma_w h_w + R_w W_c \frac{1}{D} + P_v \leq q_a \]

\( R_w \) = Water Buoyancy Factor

\( h_w \) = height of water

\( W_c \) = soil load
Wall Thickness – Handling and Installation

Minimum Suggested D/t Ratios

- Shop applied cement mortar lining: $D/t = 240$
- Flexible lining: $D/t = 288$
- FNI Recommends: $D/t = 230$

<table>
<thead>
<tr>
<th>D (in)</th>
<th>$D/t = 240$</th>
<th>$D/t = 288$</th>
<th>$D/t = 230$</th>
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<tr>
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<td>0.083</td>
<td>0.104</td>
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<tr>
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<td>0.150</td>
<td>0.125</td>
<td>0.157</td>
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<tr>
<td>48</td>
<td>0.200</td>
<td>0.167</td>
<td>0.209</td>
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(Minimum per AWWA M11 is 14 ga = 0.075”)
Best Practices

- Use $D/t = 230$ with minimum 42 ksi steel
  - Minimum pressure class = 175 psi
  - For pressure over 175 psi, pressure controls thickness
  - Use minimum 3/16” (0.1875”) wall thickness for 42” and smaller pipe

- Use $D/t = 144$ minimum for aerial and tunnel carrier pipe and check beam strength

- Handling or internal pressure should control wall thickness, not external loading/buckling
Wall Thickness

Relationship between Pressure Class vs. D/t

![Graph showing the relationship between pressure class and D/t with a line indicating a certain pressure class (PC) and D/t value (230) controlled by handling.]

**Graph Details:**
- **Pressure Class (PSI):** Y-axis ranging from 0 to 500.
- **D/t:** X-axis ranging from 100 to 350.
- **PC = 175 psi** at D/t = 230, marked with a purple line.
- The graph indicates that D/t = 230 is controlled by handling, while other points are controlled by pressure class.
External Loading

Pipe/trench system:

Flexible pipe relies on pipe wall thickness (stiffness) and trench backfill to support the loads.
External Loading

Deflection Calculation:
Deflection is the ratio of load to the pipe and soil combined stiffness

\[
\text{Deflection} = \frac{\text{Load}}{\text{Pipe Stiffness} + \text{Soil Stiffness}}
\]

Types of loads: earth, live (HS-20/E-80), impact
External Loading – Deflection

Spangler’s Modified Iowa Formula

\[ \Delta x = D_l \frac{KWr^3}{EI + 0.061E'r^3} \]

- \( \Delta x \) = horizontal deflection of pipe (in.)
- \( D_l \) = deflection lag factor (1.0 - 1.5)
- \( K \) = bedding constant (0.1)
- \( W \) = load per unit of pipe length (lb/in of pipe)
- \( r \) = radius (in)
- \( EI \) = pipe wall stiffness (in - lb)
- \( E' \) = modulus of soil reaction (psi)
External Loading

AWWA Allowable Deflections:

Flexible coating with mortar lining

\[ \Delta x = 3\% \text{ (FNI Recommends 2\%)} \]

Mortar/concrete coating with mortar lining

\[ \Delta x = 2\% \text{ (FNI Recommends 1\%)} \]

Flexible coating with flexible lining

\[ \Delta x = 5\% \text{ (FNI Recommends 3\%) } \]

* Lower deflection limits provide added construction tolerance, more robust coating/lining protection, and provides a buffer for future dead loading
Embedment and Backfill

Typical Trench Detail

- Trench width = Pipe O.D. + 24" min. to Pipe O.D. + 48" max.
- 12" top soil 24" in cultivated fields.
- Excavation may be widened above the pipe zone.
- Ordinary material compacted to 90% or 95% standard proctor density (see schedule).
- Select material compacted to 95% standard proctor density.
- Granular embedment compacted to 95% maximum density in accordance with ASTM D-4253 as tested in accordance with ASTM D1556 and ASTM D6938.
Granular Embedment & Compaction

Granular Embedment (Pea Gravel):
- Flows well under haunches
- Easy to compact
- High strength
- Does not break down
On-Site Mixed CLSM

Mobile Batching Plant

Self Propelled Pug Mill with Shredder
In-Situ Material
Embedment

Best Practice

 Design for conservative deflection values to allow for construction tolerance and future loading

 Use Gravel Bedding up to 15’ cover compacted to 95% of Maximum Density (ASTM D 4253)

 Use flowable fill for depths over 15’ cover

 Design backfill in roadways to limit settlement
Joint Types – Rubber Gasket and Welded

Flexible Coating

Heat Shrink Sleeve

Welded Steel Cylinder

Inside Joint Space
Cement Mortar Placed In Field

LAP-WELDED JOINT

Mastic Filler

Heat Shrink Sleeve

Dielectric Coating

Welded Steel Cylinder

Gasket

Cement Mortar Lining

Inside Joint Space
Mortar Placed in Field

RUBBER GASKET JOINT
Joint Types – Rubber Gasket and Welded

Mortar Coating

Rubber Gasket (O-Ring)  Welded Joint (Inside)
Flanges

Flange with Stiffener Ring
Joints

Best Practice

▪ Rubber gasket joints 48” and smaller/250 psi and lower

▪ Single inside lap weld for 54” and larger/250 psi and higher

▪ Use welded butt strap joints for closures

▪ Avoid buried flanges and couplings if possible
Fittings and Specials

- Fittings and specials
  - Short pipe for closures or station adjustments
  - Mitered end pipes
  - Outlets
  - Manways
  - Bends/elbows
  - Wyes
  - Tees

- Manufactured and designed per AWWA C200, C208, and M11

- Made from same plate steel as pipe and can require fittings be made from all hydrostatically tested pipe
Fittings

Bends or Elbows

- Mitered end pipe up to 5°
- Two-piece elbows up to 22.5°
- Three-piece elbows >22.5° to 45°
- Four-piece elbows >45° to 67.5°
- Five-piece elbows >67.5° to 90°

M11 Manual
Fittings

A. Tee

B. Cross

C. Reducing Tee

D. Case I Lateral—Equal Diameters

D. Case II Lateral—Unequal Diameters

*This dimension should be adjusted to suit conditions.

E. 90° Wye

F. Reducer

M11 Manual
Fittings

- M11 requires reinforcement when Pressure Diameter Value (PDV) > 6000

\[ PDV = \frac{Pd^2}{Dsin^2 \Delta} \]

Where
- \( P \) = Design Pressure
- \( d \) = Branch pipe OD
- \( D \) = Main pipe OD
- \( \Delta \) = Branch pipe angle of deflection

- Finite element analysis may be warranted for thrust, local stresses, lining protection
Fittings
**Fittings**

**Best Practice**

- Use long radius bends (bend radius equals 2.5 times the diameter) to limit stresses and allowing pigging
- Confirm wall thickness per M11 (PDV), which may require thicker wall or reinforcement
- Consider reinforcement requirements when laying out piping and connections
- Use epoxy linings for exposed pipe and fittings
Coatings

- **Flexible**
  - Polyurethane (AWWA C222)
  - Tape Coating (AWWA C214)
  - Fusion Bond Epoxy (AWWA C213)
  - Epoxy (AWWA C210)
  - Abrasion Resistant Overcoat (ARO used for HDD)
  - Extended Polyolefin (AWWA C215) - Pritec

- **Rigid Mortar Coating (AWWA C205)**

- **Concrete Encasement (Plant Piping)**
Polyurethane Coating (AWWA C222)
Tape Coatings (AWWA C214)
Heat Shrink Sleeves
Mortar Coating (AWWA C205)
Mortar over Polyurethane Coating for Tunnel Pipe
Linings

- Mortar Lining (AWWA C205) (typical)
- Flexible
  - Polyurethane (AWWA C222)
  - Epoxy Lined (AWWA C210)
Coatings and Linings

Best Practice for Coatings
- Polyurethane or mortar for 48” and smaller
- Polyurethane for 54” and larger
- Mortar over polyurethane thru tunnels
- UV resistant epoxy or polyurethane for exposed piping

Best Practice for Linings
- Mortar lining for buried pipe and some plant piping
- Epoxy linings for exposed pipe and some plant piping
Sustainability

- Use lowest life-cycle pipe diameter
- Design for head conservation
- Use fewer pump stations and higher operating pressures
- Consider re-use of excavated soils for embedment
- Consider crushed concrete/on-site CLSM
- Use local materials
- Steel pipe will have excellent service life with good design, manufacture, and installation
Steel Pipe Design

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