Florida Section AWWA Fall Conference
November 27, 2018

Steel Pipe Design



Agenda

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

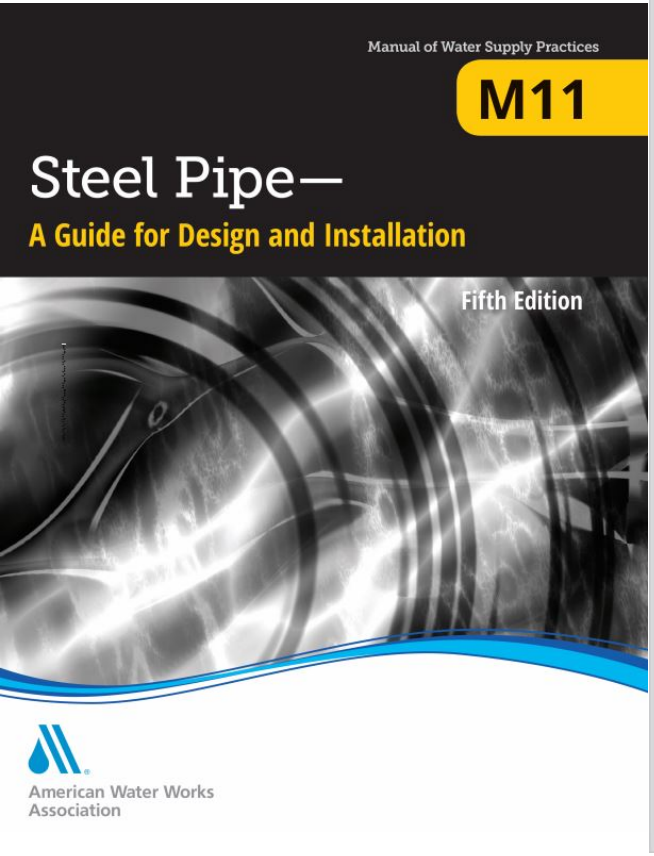


History

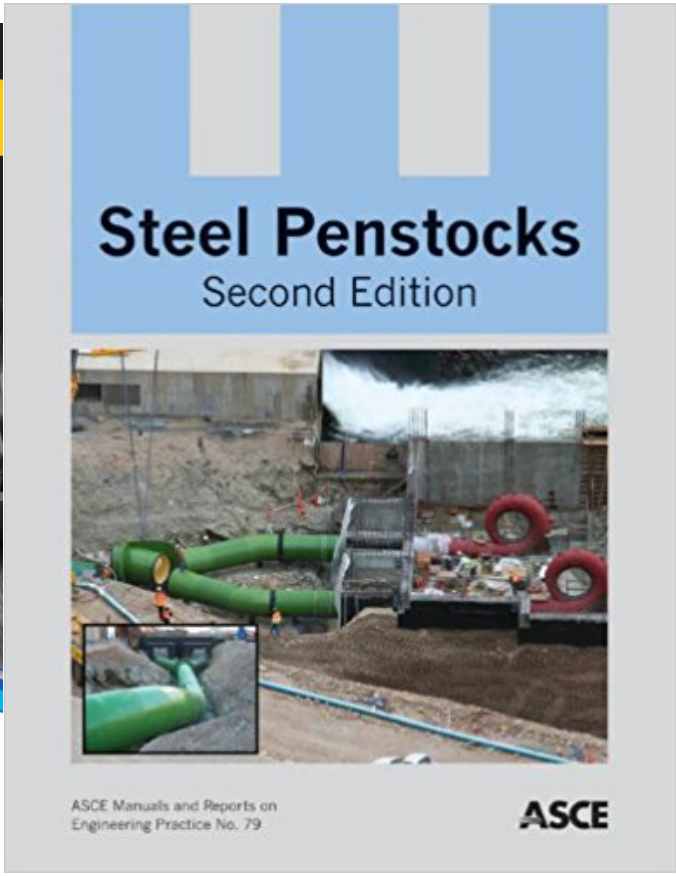
- First uses date back to 1850s
- Riveted and lock bar pipe until the 1930s
- By the mid 1970s, there were over 200 documented 80-year installations
- Coatings and linings have significantly evolved over time



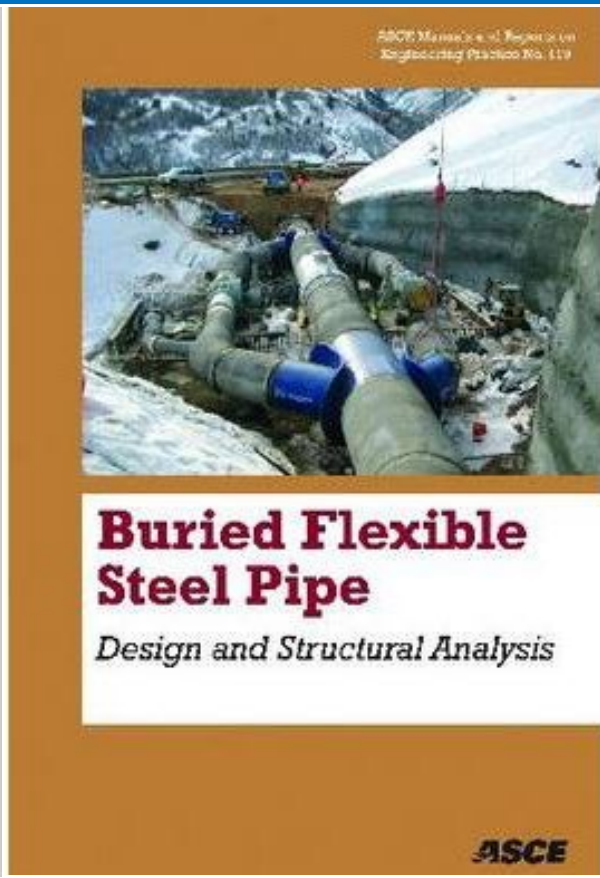
Steel Pipe Design Manuals



AWWA M11



ASCE MOP 79



ASCE MOP 119

Be Careful to not Mix Factors or Variables Between the Manuals



Hydraulics

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

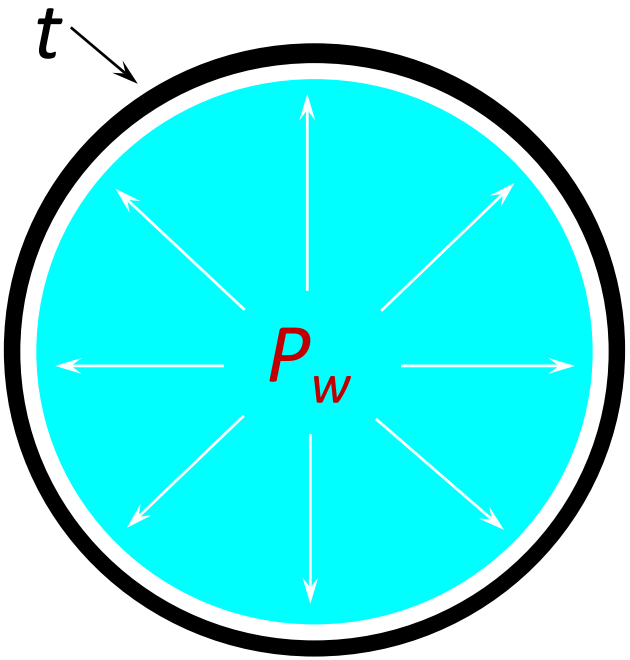
- Wall Thickness
  - Internal Pressure
  - External Pressure/Loading
  - Handling and Installation
- Trench Design



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

$$q_a = (1/FS)(32R_w B' E' EI/D^3)^{1/2}$$

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

D (in)	D/t = 240	D/t = 288	D/t = 230
24	0.100	0.083	0.104
36	0.150	0.125	0.157
48	0.200	0.167	0.209

(Minimum per AWWA M11 is 14 ga = 0.075”)



Wall Thickness

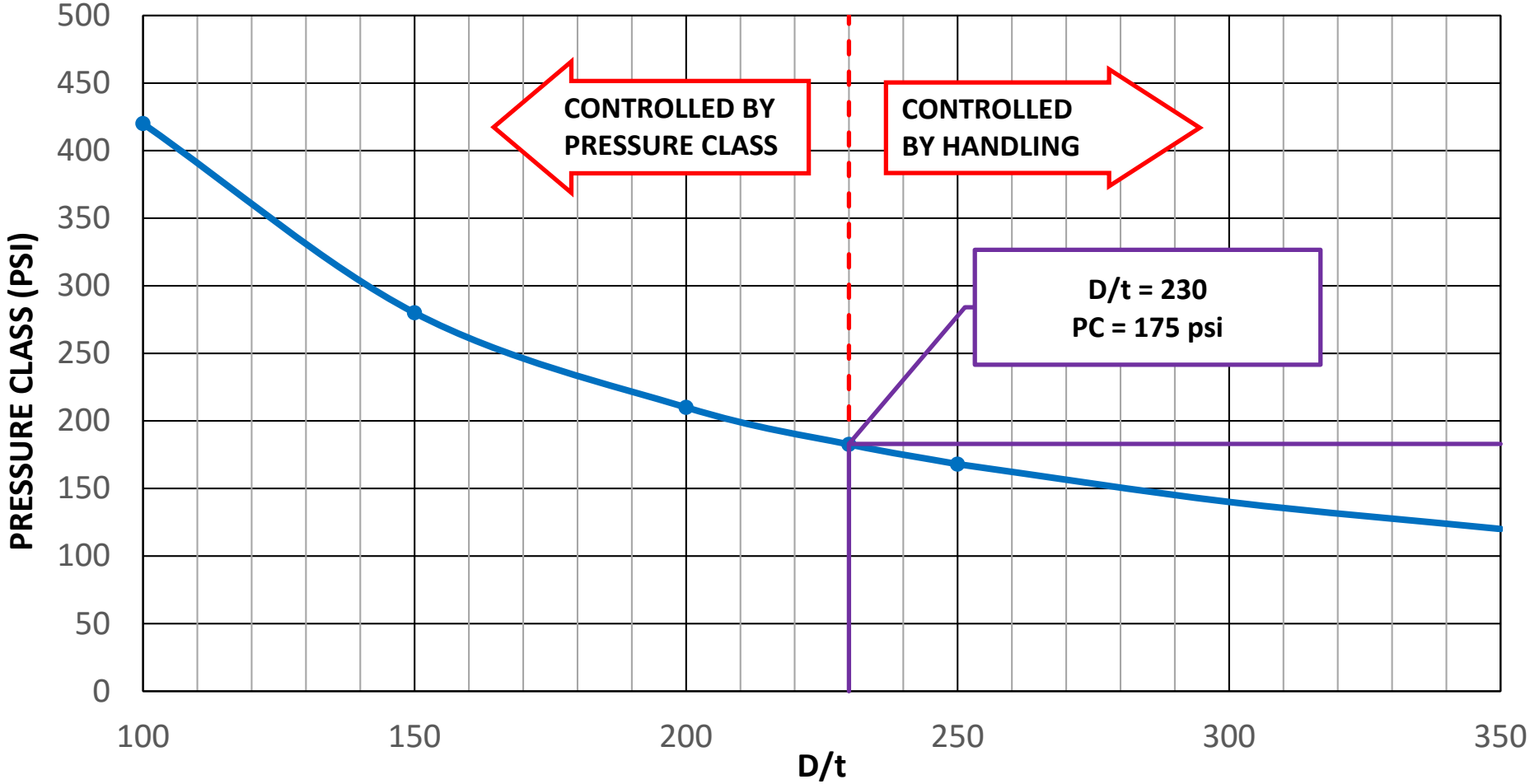
Best Practices

- 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

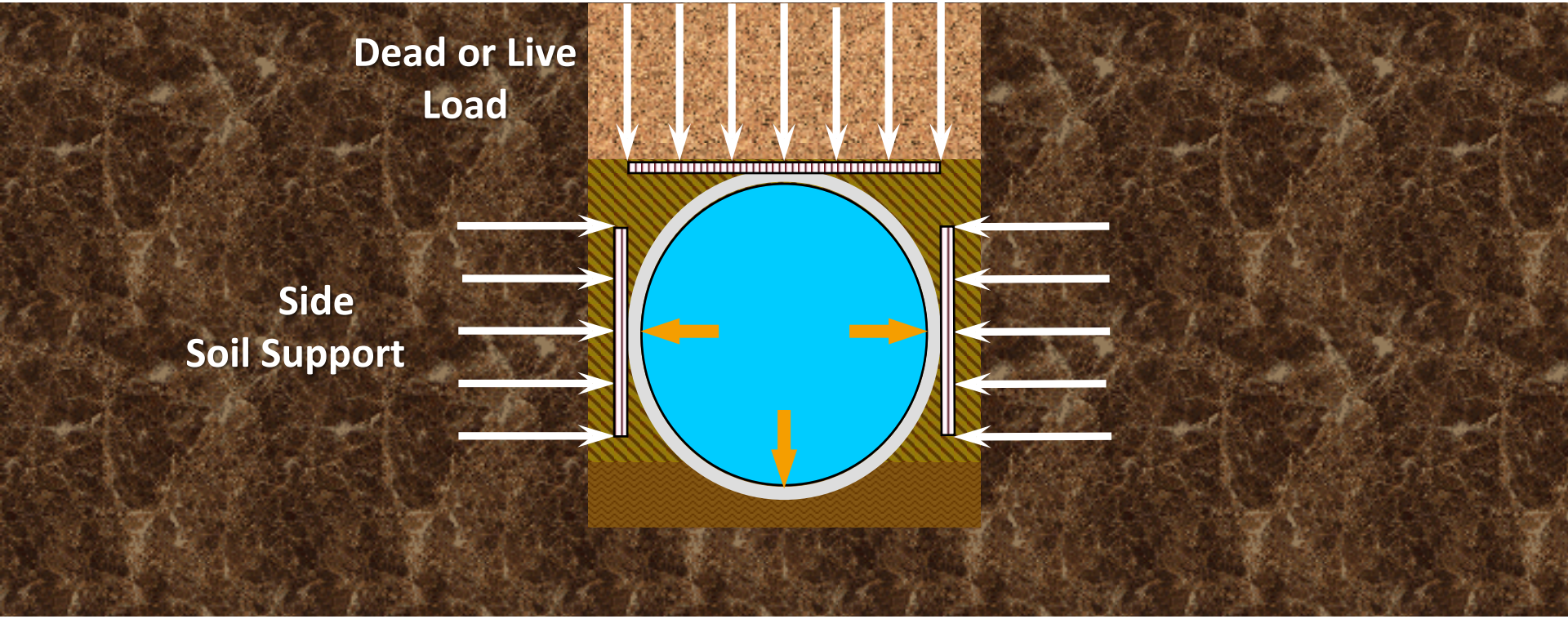




External Loading

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

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

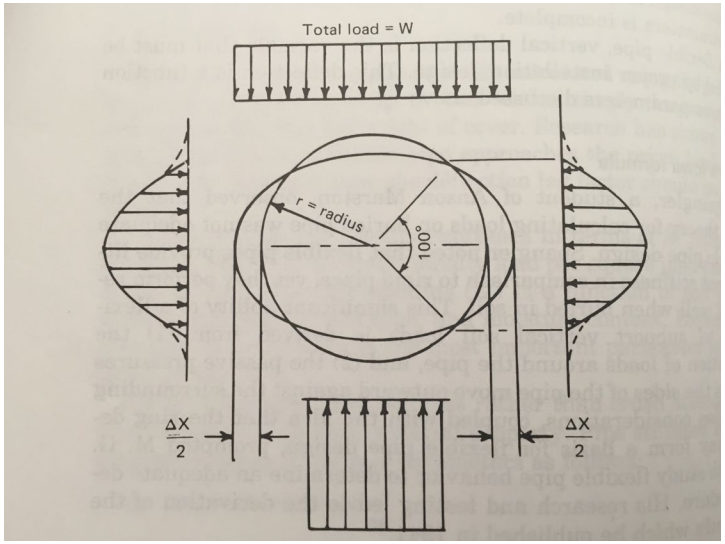
Types of loads: earth, live (HS-20/E-80), impact



External Loading – Deflection

Spangler's Modified Iowa Formula

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



Δx = 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

Δx = 3% (FNI Recommends 2%)

Mortar/concrete coating with mortar lining

Δx = 2% (FNI Recommends 1%)

Flexible coating with flexible lining

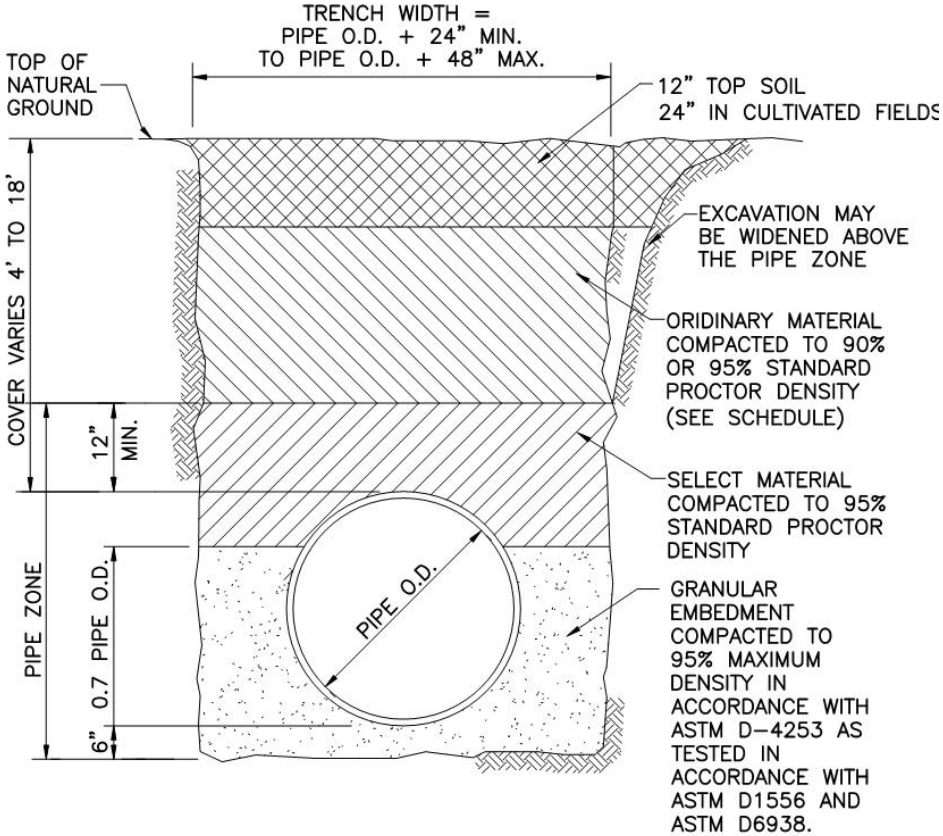
Δx = 5% (FNI Recommends 3%)

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



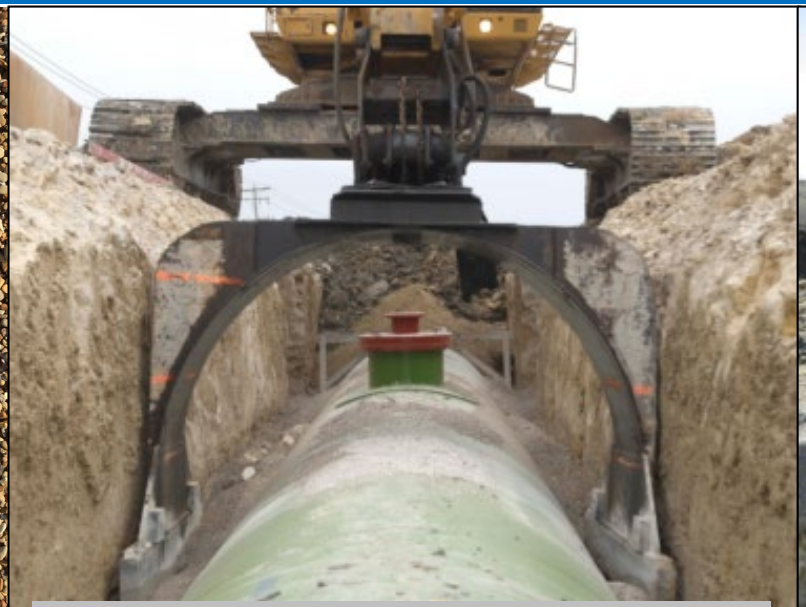
Embedment and Backfill

Typical Trench Detail





Granular Embedment & Compaction

Vibrating Compactor

Roller Compaction

Granular Embedment (Pea Gravel):

- Flows well under haunches
- Easy to compact
- High strength
- Does not break down



Flowable Fill



On-Site Mixed CLSM

Mobile Batching Plant

On-Site Mixed CLSM

Self Propelled Pug Mill with Shredder



In-Situ Material




Embedment

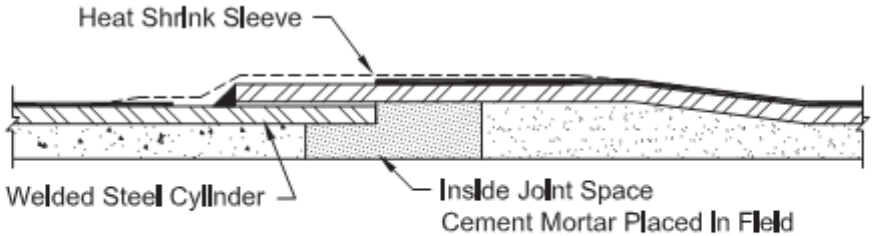
Best Practice

- 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

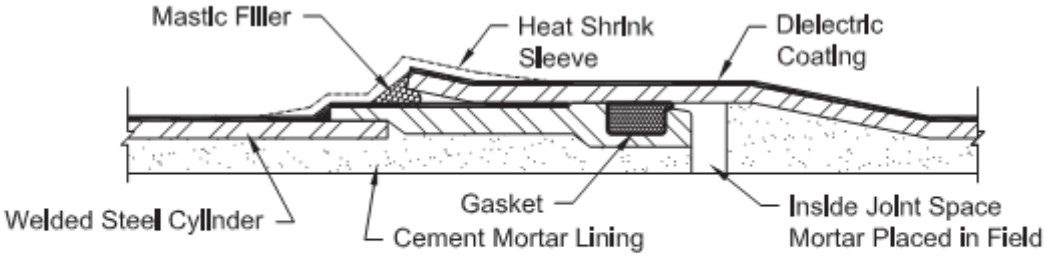


Joint Types – Rubber Gasket and Welded

Flexible Coating



LAP-WELDED JOINT

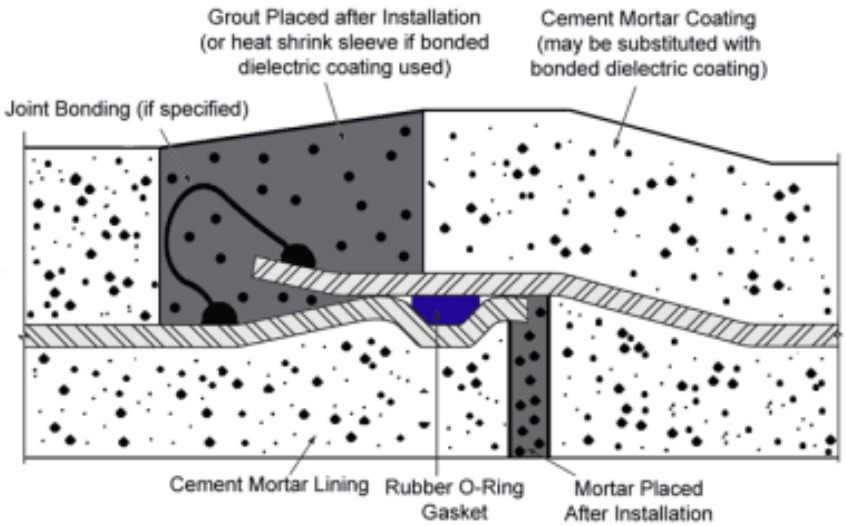


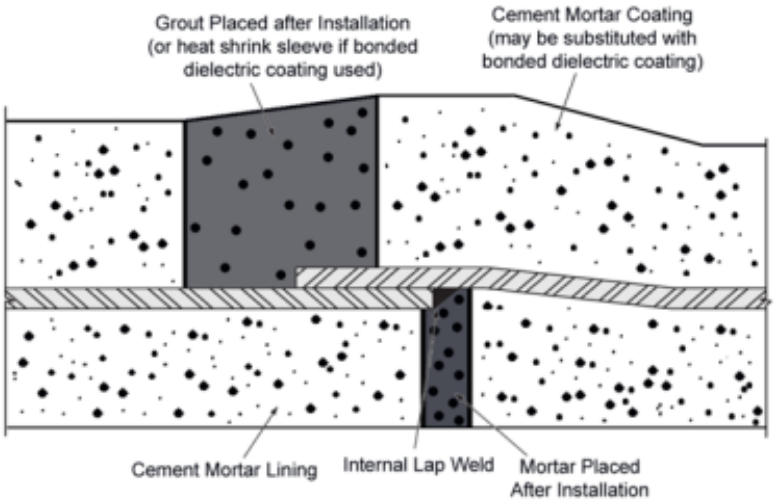
RUBBER GASKET JOINT



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

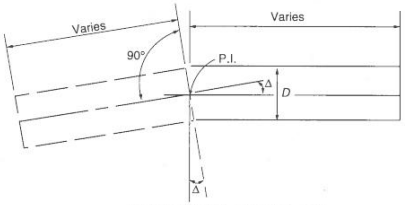
- Fittings and specials
  - Short pipe for closures or station adjustments
  - Mitered end pipes
  - Outlets
  - Manways
  - Bends/elbows
  - Wyes
  - Tees
- Manufactured and designed per AWWA C200, C208, and M11
- Made from same plate steel as pipe and can require fittings be made from all hydrostatically tested pipe



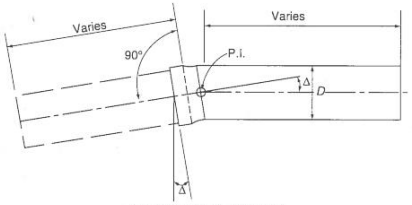
Fittings

Bends or Elbows

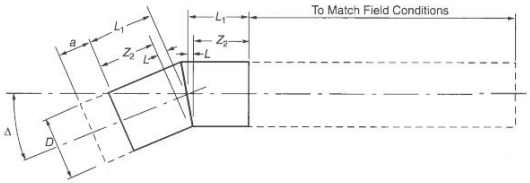
- Mitered end pipe up to 5°
- Two-piece elbows up to 22.5°
- Three-piece elbows >22.5° to 45°
- Four-piece elbows >45° to 67.5°
- Five-piece elbows >67.5° to 90°



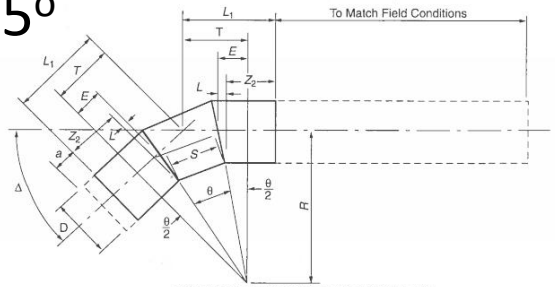
A. Miter End Cut—Weld Butt Joint



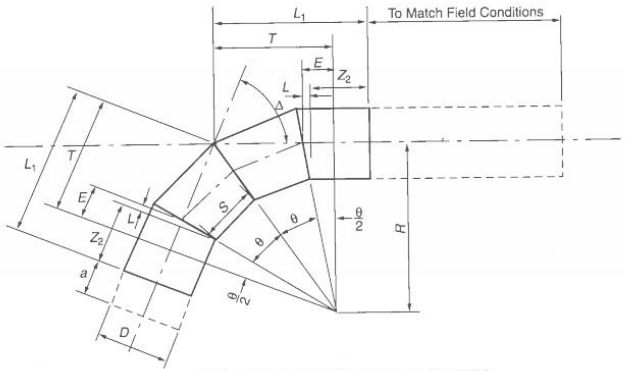
B. Miter End Cut—Lap Joint



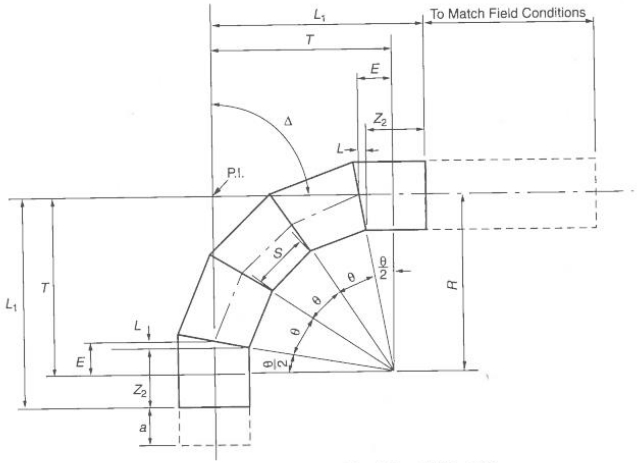
C. Two-Piece Elbow (0° to 22.5°)



D. Three-Piece Elbow (More Than 22.5° to 45°)



E. Four-Piece Elbow (More Than 45° to 67.5°)

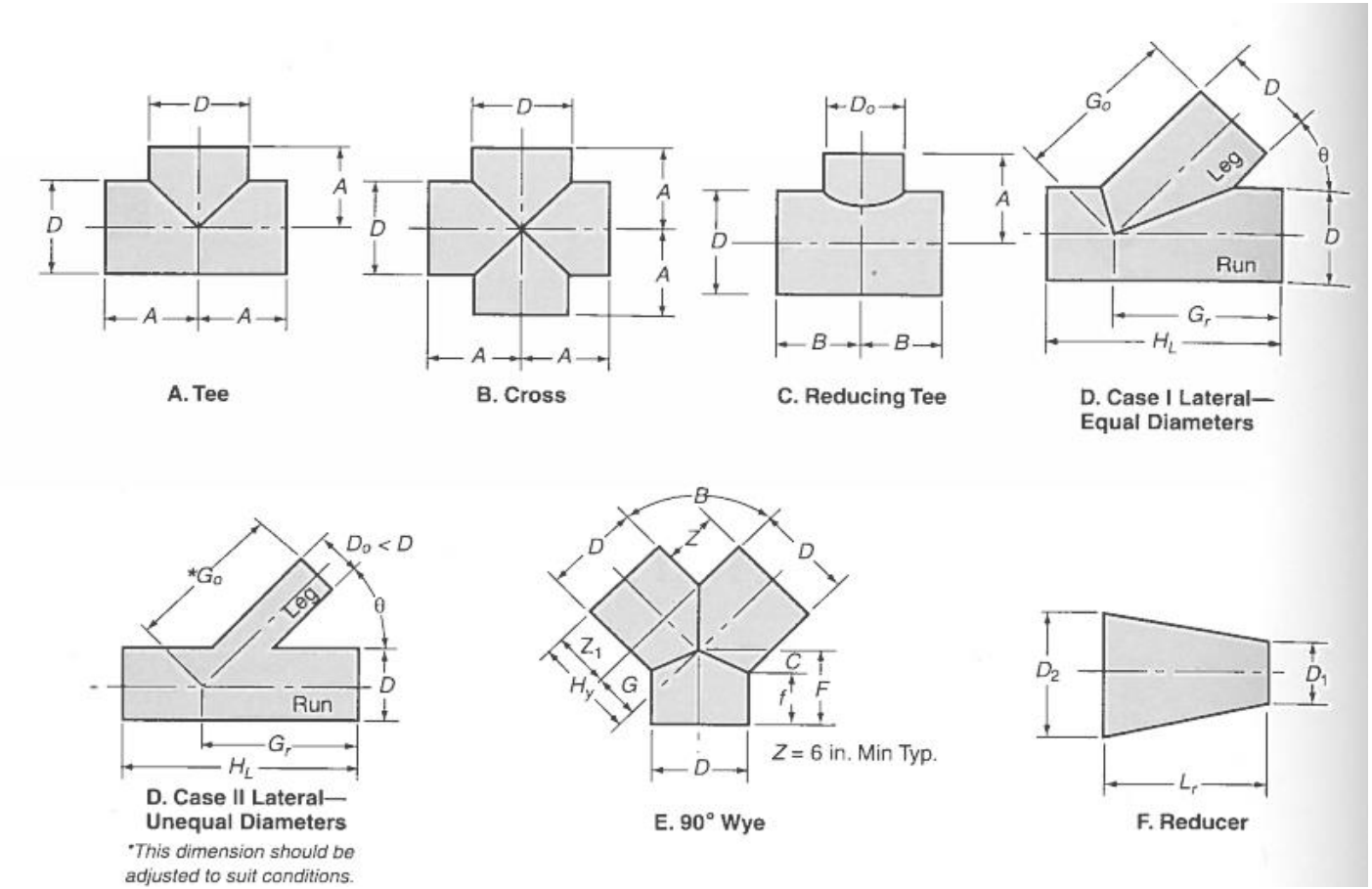


F. Five-Piece Elbow (More Than 67.5° to 90°)

M11 Manual



Fittings



M11 Manual



Fittings

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

$$PDV = \frac{P\mathrm{d}^2}{\mathrm{D}\sin^2\Delta}$$

Where *P*=Design Pressure

d=Branch pipe OD

D=Main pipe OD

Δ=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

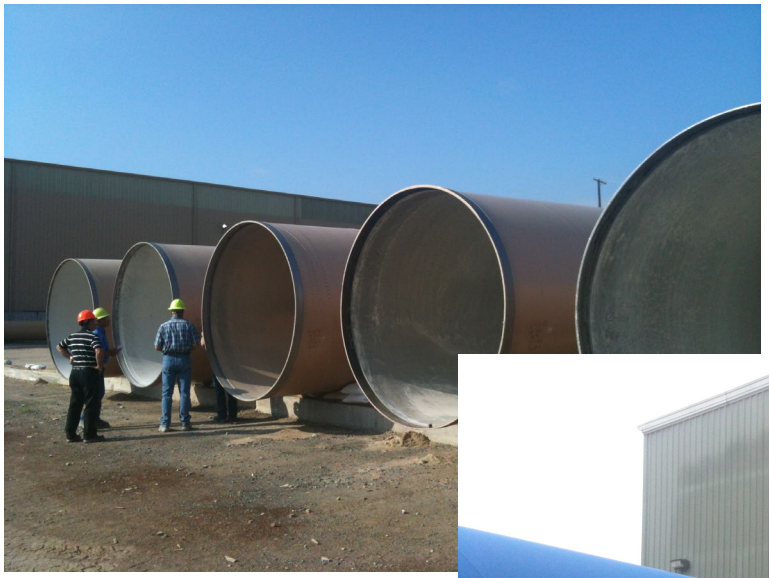


Coatings

- 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)

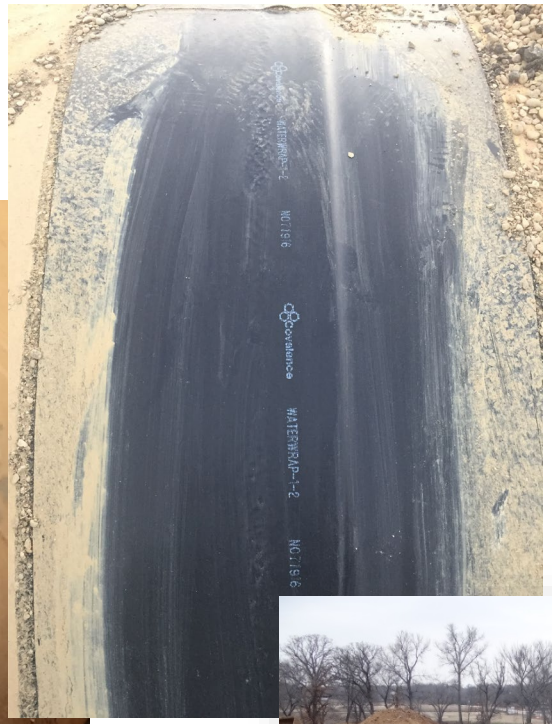




Tape Coatings (AWWA C214)



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

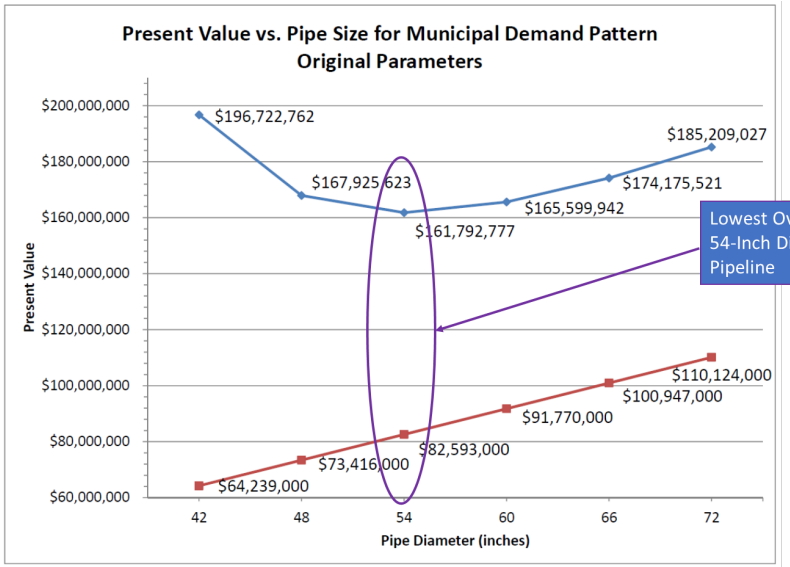
Best Practice for Linings

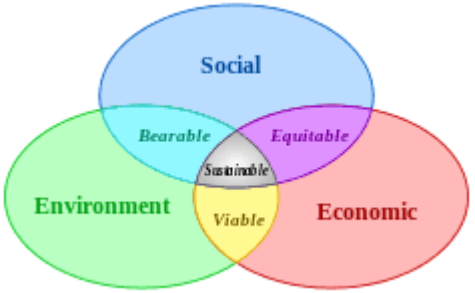
- Mortar lining for buried pipe and some plant piping
- Epoxy linings for exposed pipe and some plant piping



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





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