Engineering Standard

SAES-L-620 21 March 2010

Design of Nonmetallic Piping
in Hydrocarbon and Water Injection Systems

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Previous Issue: 10 February 2009 Next Planned Update: 21 March 2015

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1 Scope

1.1 This Design Standard provides design requirements for Reinforced Thermosetting Resins (RTR) pipe and pipeline for use in the following applications:

- Flowlines and testlines
- Water injection systems

1.2 This Design Standard applies to:

- Buried piping systems.
- Above ground piping systems with prior approval from the Manager, Consulting Services Department and the Manager, Loss Prevention Department.
- High pressure piping systems (MAOP ≥ 500 psi) and low pressure piping systems (MAOP < 500 psi).
- Flowlines, testlines and water injection systems in location Class 1.
- Road crossing in location Class 2 with a population density index for any kilometer segment is 10 or less.
- Table 1.2-1 gives the recommended temperature limits for reinforced thermosetting resins pipe.

1.3 The following services are excluded from the scope of this standard:

- In-plant piping systems

- Pipelines in location Class 2 with a population density index of more than 10.
- Pipelines in locations Class 3 and 4.
- Potable water systems, fire and raw combined water systems, irrigation water systems, well water systems, and gravity draining systems in Saudi Aramco facilities, shall be designed in accordance with Saudi Aramco Plumbing and Utilities Standards.
- Oily water systems shall be designed in accordance with SAES-L-610.

2 Conflicts and Deviations

2.1 Any conflicts between this standard and other applicable Saudi Aramco Engineering Standards (SAESs), Materials System Specifications (SAMSSs), Standard Drawings (SASDs), or industry standards, codes, and forms shall be resolved in writing by the Company or Buyer Representative through the Manager, Consulting Services Department of Saudi Aramco, Dhahran.

2.2 Direct all requests to deviate from this standard in writing to the Company or Buyer Representative, who shall follow internal company procedure SAEP-302 and forward such requests to the Manager, Consulting Services Department of Saudi Aramco, Dhahran.

3 References

The selection of material and equipment, and the design, construction, maintenance, and repair of equipment and facilities covered by this standard shall comply with the latest edition (at the project cut-off date) of the references listed below, unless otherwise noted.

3.1 Saudi Aramco References

Saudi Aramco Engineering Procedures

SAEP-13	*Environmental Assessment*
SAEP-14	*Project Proposal*
SAEP-27	*Pipelines/Piping Hydraulic Surge Analysis*
SAEP-122	*Project Records*
SAEP-302	*Instructions for Obtaining a Waiver of a Mandatory Saudi Aramco Engineering Requirement*
SAEP-334	*Retrieval, Certification and Submittal of Saudi Aramco Engineering & Vendor Drawings*

SAEP-363	*Pipelines Simulation Model Development and Support*

Saudi Aramco Engineering Standards

SAES-A-004	*General Requirements for Pressure Testing*
SAES-B-062	*Onshore Wellsite Safety*
SAES-B-064	*Onshore and Nearshore Pipeline Safety*
SAES-J-600	*Pressure Relief Devices*
SAES-J-601	*Emergency Shutdown and Isolation Systems*
SAES-J-605	*Surge Relief Protection Systems*
SAES-L-100	*Applicable Codes & Standards for Pressure Piping Systems*
SAES-L-101	*Regulated Vendor List for Pipes, Fittings and Gaskets*
SAES-L-102	*Regulated Vendor List for Valves*
SAES-L-105	*Piping Materials Specifications*
SAES-L-108	*Selection of Valves*
SAES-L-109	*Flanges, Bolts and Gaskets*
SAES-L-110	*Limitation on Piping Components & Joints*
SAES-L-120	*Piping Flexibility*
SAES-L-125	*Safety Instruction Sheet for Piping and Pipelines*
SAES-L-132	*Material Selection of Piping Systems*
SAES-L-140	*Thermal Expansion Relief in Piping*
SAES-L-460	*Pipeline Crossings under Roads and Railroads*
SAES-L-650	*Construction of Reinforced Thermosetting Resins (RTR) Piping in Hydrocarbon and Water Injection Systems*

Saudi Aramco Materials System Specification

01-SAMSS-042	*Reinforced Thermoset Resin (RTR) Pipe and Fittings in Water and Hydrocarbon Services*

Saudi Aramco Standard Drawing

AD-036973	*Marker Plates for Pipeline Kilometer Marker*

3.2 Industry Codes and Standards

American Society of Mechanical Engineers

ASME B31.3	*Process Piping*
ASME B31.4	*Pipeline Transportation Systems for Liquid Hydrocarbons and Other Liquids*
ASME B31.8	*Gas Transmission and Distribution Piping Systems*

American Petroleum Institute

API 15 HR	*Specification for High Pressure Fiberglass Line Pipe*
API 15 LR	*Specification for Low Pressure Fiberglass Line Pipe and Fittings*

International Organization for Standardization

ISO 14692	*Petroleum and Natural Gas Industries – Glass-Reinforced Pastics (GRP) Piping*

American Water Works Association

AWWA M45	*Fiberglass Pipe Design*

American Institute of Steel Construction

AISC	*Manual of Steel Construction*

American Concrete Institute

ACI 318	*Building Code Requirements for Structural Concrete, Appendix D Anchorage to Concrete*

Ductile Iron Pipe Research Association

DIPRA	*Thrust Restraint Design for Ductile Iron Pipe*

Instrument Society of America.

ISA 75.01	*Flow Equations for Sizing Control Valves*

3.3 Technical Books

Antaki, G.A., Piping and Pipeline Engineering, M. Dekker publisher, New York, NY.

Tullis, J.P., Hydraulics of Pipelines, Pumps, Valves, Cavitation, Transients, Wiley Inter-Science, Hoboken, NJ.

3.4 Saudi Government

SSD-29 *Saudi Security and Safety Directives*

4 Pipeline Optimization Study

4.1 Each new application of RTR pipeline shall be thoroughly studied to evaluate its safety, technical and economical feasibility. The economic analysis shall include a Life Cycle Cost Analysis. The study shall be conducted no later than the Project Proposal stage and shall address the following as a minimum:

a) Pipe diameter, wall thickness and material type and grade.

b) Pipeline routing, construction method (i.e., aboveground or buried) and their impact on initial capital, operation, and maintenance expense.

c) Pipeline area classification.

d) The maximum allowable operating pressure, the available inlet pressure and the minimum required delivery pressure.

e) Requirements for future expansion.

f) Constructability of the pipelines.

g) Design flow rate (and future needs), velocity limitations (upper and lower) imposed by the fluid composition and flow pattern for multi-phase fluid.

h) Management of Change (MOC) package shall be prepared as required in accordance with Saudi Aramco Safety Management System (SMS) Element 5.

i) Calculation of Rupture Exposure Radius (RER) is required unless the default RER values in SAES-B-064 are to be used. Population density index shall be calculated along with the RER values to determine the location class of the area.

4.2 Production pipelines in gas or crude may not require detailed pipeline optimization study. For pipelines in this category, consult the Production & Facilities Development Department of E&P which is the responsible organization for the development of these pipelines.

4.3 Pipeline hydraulic and surge studies should be conducted as needed and in accordance with SAEP-27 and SAEP-363.

5 Design Process

- The steps of the design process are outlined in Appendix A, Section A1.
- The design input is listed in Appendix A, Section A2.

- The design output to be specified to the manufacturer is specified in the Materials System Specification 01-SAMSS-042.

6 Pressure Design

6.1 Internal Pressure Design

6.1.1 System Design Pressure

6.1.1.1 The system design pressure P_D shall be established by the Design Engineer and provided to the pipe and fitting manufacturer.

6.1.1.2 The system design pressure is the maximum pressure that can be achieved in the system given all operating conditions, including postulated abnormal operating conditions.

6.1.1.3 The system design pressure shall be increased by the ASME B31.8 Location Class Factor LCF, where

$$P_{D.LCF} = P_D \times LCF$$

With

$$LCF = \frac{0.72}{LCF_{B31.8}} \text{ but not less than 1.0}$$

<u>Example</u>:

- For a pipeline installed in a Location Class 4 (high population density, ASME B31.8 Table 841.114A).

  $LCF_{B31.8} = 0.4$

  Then the design pressure of the system should be defined as

  $P_D \times (0.72/0.4) = P_D \times 1.8.$

- For a pipeline installed in a Location Class 1 (remote desert, ASME B31.8 Table 841.114A).

  $LCF_{B31.8} = 0.72$

  Then the design pressure of the system should be defined as

  $P_D \times (0.72 / 0.72) = P_D.$

6.1.2 Pressure Rating

6.1.2.1 Based on the parameters specified by the design engineer, the manufacturer shall provide the pressure rating Pr in accordance with API 15 HR for high pressure RTR pipe and fittings and API 15 LR for low pressure pipe and fittings.

6.1.2.2 The pressure rating of the pipe and fitting shall be equal to or larger than the system design pressure:

$$Pr \geq P_D$$

For gas service:

$$Pr \geq P_{D \cdot Gas}$$

6.1.2.3 In establishing the pressure rating, the manufacturer shall account for the magnitude (psig) and frequency (occurrences/year) of pressure transients (waterhammer) provided by the Design Engineer (Appendix A). Refer to Appendix B for guidance to calculate the pressure surge.

6.1.2.4 The manufacturer shall submit a Pressure Rating Report to document the basis for the pressure rating, including pressure transients, in accordance with API Spec. 15HR and 15LR.

6.1.2.5 The API 15 equations for pressure rating of straight pipe: High pressure equations (API 15HR), if D/t ≤ 10 (thick wall) [API 15 HR]:

$$P_r = S_S(T) \times S_f \times \frac{R_o^2 - R_i^2}{R_o^2 + R_i^2}$$

if D/t > 10[API 15 HR eq.2 corrected]

$$P_r = S_S(T) \times S_f \times \frac{2 \times t}{D}$$

Low pressure equations (API 15LR): Low pressure cyclic-test based (ASTM D2992 Procedure A) [API 15 LR]

$$P_r = HDB_C \times \frac{2 \times t}{D}$$

Low pressure static-test based (ASTM D2992 Procedure B) [API 15 LR]

$$P_r = S_S(T) \times S_f \times \frac{2 \times t}{D}$$

6.1.3 MAOP

6.1.3.1 The maximum allowable operating pressure (MAOP) is the maximum pressure permitted during operation, excluding pressure transients, based on the wall thickness and pressure rating of the pipe, fittings and components.

6.1.3.2 The MAOP shall not exceed the fitting or joint pressure rating at maximum operating temperature.

$$MAOP \leq Pr$$

6.2 Permitted Fittings

6.2.1 High Pressure

6.2.1.1 High pressure fittings and joints shall be threaded.

6.2.1.2 Threads shall be in accordance with API 5B.

6.2.1.3 Flanges shall be threaded to the pipe and have steel bolts with metallic washers.

6.2.1.4 A steel backing ring shall be used if required by the flange manufacturer.

6.2.1.5 Only spiral wound gaskets rated for the fluid, pressure and temperature shall be used, unless permitted otherwise by the flange manufacturer.

6.2.2 Low Pressure

Low pressure fittings and joints shall be selected from the manufacturer catalog, for the applicable pressure rating, temperature and service.

6.3 Over-Thickness Allowance

6.3.1 Where the service contains suspended solids (such as sand) at high flow rate, bends and tees may require an additional thickness (over-thickness allowance) for erosion-wear of the inner surface.

6.3.2 The over-thickness allowance for erosion shall be determined by the pipe and fitting manufacturer, given the suspended solids and flow rates specified by the Design Engineer (Appendix A).

6.3.3 As an alternative to the over-thickness allowance:

6.3.3.1 One 90-degree elbow may be replaced by three 30-degree or four 22.5-degree elbows, or

6.3.3.2 An erosion-resistant liner may be applied to the pipe inner diameter.

6.4 External Differential Pressure

6.4.1 The external differential pressure on the pipe shall not exceed the following limit [ISO 14692-3]

$$P_{ext} = \text{smaller of } \frac{2 \times E_h}{F_e} \times \left(\frac{t}{D}\right)^3 \text{ and } P_{ext\text{-}mfr}$$

6.4.2 F_e = 1.5 for an occasional short-time transient external differential pressure, and F_e = 3 for a sustained external differential pressure.

6.4.3 $P_{ext\text{-}mfr}$ is the maximum differential external pressure permitted by the manufacturer, for the concurrent temperature.

6.5 Pressure Cycling

6.5.1 Pressure cycles are permitted if they are within the pressure surge allowance P_s.

6.5.2 If the system is subjected to more than 7000 pressure cycles, within its lifetime, the fatigue analysis requirements of Section 11 shall apply.

6.6 Overpressure Protection

6.6.1 Over-pressure protection (relief devices) shall be provided in accordance with the design code (ASME B31.3, ASME B31.4, ASME B31.8).

6.6.2 Pressure accumulation during relief discharge shall not exceed the pressure rating allowance P_r.

7 Above Ground Piping Systems

Above ground piping systems shall have a prior approval from the Manager, Consulting Services Department and the Manager, Loss Prevention Department.

7.1 Layout of Above Ground Piping Systems

7.1.1 Layout

7.1.1.1 Piping system layout shall be established in accordance with Section 5.1 of ISO 14692-3, and functional and constructability requirements.

7.1.1.2 Above ground RTR pipe shall be protected from impact. This may be achieved by placing barriers between the pipe and the roadway, and, in congested areas, posting caution signs to prevent impact or stepping onto the pipe.

7.1.1.3 There should be sufficient clearance around the pipe to accommodate thermal expansion calculated by stress analysis. In addition, it is common practice to provide minimum clearances around the pipe: 6 in (150 mm) clearance around 2 in and smaller pipe, 12 in (300 mm) clearance around 2 in to 6 in pipe, and 20 in (500 mm) clearance around pipe larger than 6 in.

7.1.2 Supports

7.1.2.1 Above ground piping systems in the scope of this standard shall be qualified by stress analysis.

7.1.2.2 As a first step prior to stress analysis, the layout, supports and span length guidance specified by the pipe manufacturer should be followed.

7.1.2.3 Six-way anchors may be placed at intervals in accordance with manufacturer recommendations (for example an anchor every approximately 300 ft is commonly recommended by manufacturer) and expansion loops or bends shall be provided between anchors, as necessary, to maintain the expansion-contraction stresses, displacements and loads within the limits specified in this Standard.

7.1.2.4 Longitudinal thrust blocks are not required unless:

- They are determined to be necessary by stress analysis
- They are required by the pipe or fitting manufacturer

7.1.2.5 The pipe shall not be placed directly on the ground.

7.1.2.6 Valves shall be directly supported (Figure D-1).

7.1.2.7 Other pipes shall not be supported from RTR pipes.

7.1.3 Bends

Elastic bends are not permitted in above ground piping systems.

7.1.4 UV Protection

Above ground piping systems shall be UV protected in accordance with materials system specification 01-SAMSS-042.

7.1.5 Fire Protection

Above ground piping systems shall have fire retardant coating in accordance with materials system specification 01-SAMSS-042.

7.1.6 Tie-Ins

7.1.6.1 Future connections, branch connections and instrument taps for high pressure systems shall be through threaded or flanged tees and threaded reducing couplings if required.

7.1.6.2 Future connections, branch connections and instrument taps for low pressure systems may be through tees and reducing couplings if required, or through branch saddles, rated for the system design pressure.

7.2 Design Loads

7.2.1 Design by Analysis

7.2.1.1 Above ground piping systems in the scope of this standard shall be qualified by stress analysis for weight, thermal expansion-contraction, anticipated pressure transients, differential ground settlement, and wind loads.

7.2.1.2 The span lengths (distance between weight supports), expansion loops, guide and anchor locations provided by the manufacturer may be used as an initial guide, but the final span lengths, expansion loops, guide and anchor locations shall be based on the line-specific stress analysis.

7.2.1.3 Refer to SAES-L-120 for flexibility analysis, with the additional requirements of this Standard.

7.2.2 Pipe Stress Analysis Model

7.2.2.1 The pipe shall be modeled to terminal points consisting of:

- Six-way anchors
- Equipment nozzles
- Virtual anchor at transition to buried pipe

7.2.2.2 Branch lines may be decoupled from the header pipe model under the following conditions:

- The section modulus of the branch pipe is equal to or smaller than 1/25 the section modulus Z of the header pipe (based on experience-based industry design practice), where the section modulus Z is

$$Z = \frac{2 \times I}{D}$$

- The stress intensification factor of the header-branch connection is included in the header and the branch models
- The header movements are applied to the model of the branch pipe

7.2.3 Pipe Properties for Analysis Model

7.2.3.1 The following pipe and fittings physical properties are required in preparing the stress analysis model of above ground piping systems. They shall be obtained from the pipe manufacturer for the specified direction, time (short-term or 20-year), and at ambient and maximum operating temperature.

- Linear weight (lb/ft)
- Weights of individual fittings, flanges and components (lb)
- Coefficient of thermal expansion α (1/°F)
- Modulus of elasticity in the hoop direction Eh (psi)
- Modulus of elasticity in the axial direction Ea (psi)
- Poisson ratio ν

7.2.3.2 The physical properties of the pipe and fittings may be different. If they differ by more than 10%, this difference shall be reflected in the analysis model.

7.2.3.3 The piping system stress analysis model shall be based on the pipe axial bending modulus of elasticity at temperature.

7.2.3.4 The following pipe and fittings dimensional properties are required in preparing the stress analysis model of above ground piping systems. They shall be obtained from the pipe manufacturer: Pipe outer diameter OD (in), Reinforced wall thickness t (in)

7.2.3.5 The manufacturer of bends (elbows, miters) and tees shall provide the flexibility factor (κ) and the stress intensification factors (SIF) for each fitting and size, determined in accordance with ISO 14692-3:2002 Annex D.

7.3 Applied Loads

7.3.1 Weight

7.3.1.1 The deadweight analysis of the piping system shall include the weight of the pipe, its contents, the weight of exterior coating if any, the weight of in-line fittings and components, and the portion of the weight of braces and appurtenances supported from the pipe.

7.3.1.2 The hydrostatic test case, water-filled line, shall be included in the analysis.

7.3.2 Thermal Expansion and Contraction

7.3.2.1 The flexibility analysis of the piping system for thermal expansion and contraction shall incorporate the mechanical and physical properties of the pipe at the concurrent temperature and duration for each load case.

7.3.2.2 Thermal movements (translations and rotations) of interfacing equipment nozzles shall be applied to the piping system.

7.3.2.3 The thermal expansion and contraction shall consider the range of (a) fluid temperatures, and (b) daytime to nighttime temperature experienced by the pipe.

7.3.3 Wind

7.3.3.1 The uniform lateral load due to wind, per unit length of pipe is [Antaki, G.A. Section 10.2]:

$$F_W = q_W \times D_W$$

Where the wind velocity pressure q_W is [Antaki, G.A. Section 10.2, with bounding values for the coefficients]:

$$q_W = (50 \times 10^{-6}) \times v_W^{\,2}$$

7.3.3.2 The wind load shall be applied in the East-West (EW) and North-South (NS) directions, separately, one direction at a time. The design shall be based on the envelope of results (maximum results) from the two cases (EW and NS).

7.4 Qualification Requirements

7.4.1 Pressure Design

7.4.1.1 The qualification for pressure loading, including internal pressure, external pressure and pressure transients shall be performed by the pipe and fitting manufacturer in accordance with Section 5 of this Standard.

7.4.1.2 The qualification for internal pressure shall be documented by the manufacturer in a Pressure Rating Report and provided to the Design Engineer for review and approval.

7.4.2 Stress Limits

7.4.2.1 The pipe and fitting manufacturer shall provide the design allowable stress envelope in the form of the Factored Long-Term Design Envelope for axial and hoop stress (Figure 1 of ISO 14692-3:2002), given the following parameters:

- The pipe and fittings material
- The design temperature (Appendix A) for calculating the partial factor for temperature A_1
- The fluid (Appendix A) for calculating the partial factor for chemical resistance A_2
- The cyclic pressure service for each load case (Appendix A) for calculating the partial factor for cyclic service A_3 for pressure stress cycles
- The design life (Appendix A)
- The hoop stress at pressure rating (qualified stress)

7.4.2.2 The partial factor for loads f_2 shall be in accordance with Table 3 of ISO 14692-3:2002, and described in Table 7.4.2-1.

7.4.3 Deflection Limits

7.4.3.1 The pipe sag (maximum downward deflection of a span of pipe due to weight) shall not exceed the smaller of 0.5 in or 0.5% of the span length.

7.4.3.2 The expansion and contraction movements shall not cause the pipe, fittings or components to interfere with adjacent structures, systems and components.

7.4.3.3 Pipe movements shall not cause the pipe to disengage or lift from its supports.

7.4.4 Nozzle Load Limits

The reaction loads (three forces and three moments) at equipment nozzles shall not exceed the equipment manufacturer limits.

8 Supports, Guides, Braces and Anchors for Above Ground Piping Systems

Conceptual designs of supports, guides and anchors are provided in Appendix D.

8.1 Pipe Supports

8.1.1 Pipe supports hold the pipe in the required position, with the required slope, and support its weight:

- Hangers support the pipe from above (Figures D-2)
- Bottom supports support the pipe from below (Figure D-3)

8.1.2 Support-to-pipe contact surface shall be sufficiently wide to prevent contact damage. The minimum width of wide clamps or saddles shall be [typical manufacturer recommendation]:

$$w(in) = \sqrt{D(in)}$$

8.1.3 If the support clamp is not sufficiently wide, wear pads, 120°, shall be used at pipe-to-support interface.

8.1.4 Vertical pipes may be supported by riser clamps bearing against an RTR sleeve (Figure D-4).

8.1.5 Valve or other heavy attached equipment shall be independently supported.

8.2 Pipe Guides

8.2.1 Pipe guides provide lateral restrain to the pipe (side-to-side, perpendicular to the pipe axis), prevent excessive lateral movement and buckling, but allow for free axial movement and rotation of the pipe.

8.2.2 An RTR wear pad is required at guides, with a gap of 1/16 in. (1.5 mm) to 1/8 in. (3 mm) between the guide and the sides of the wear saddle (Figure D-3).

8.2.3 For horizontal pipes, the wear saddle shall be 120° (Figure D-3).

8.2.4 For vertical pipes, a full encirclement 360° anchor sleeve shall be provided around the full circumference of the pipe, above the riser clamp (Figure D-4).

8.3 Axial Brace

If an axial brace is required (for example if the pipe is prone to pressure surge transients, Appendix B) the axial brace should be provided through a full encirclement 360° clamp with saddle (Figures D-5).

8.4 Pipe Anchors

8.4.1 Pipe anchors restrain the pipe in all six degrees of freedom, three translations and three rotations (Figure D-6).

8.4.2 An anchor may be provided by a clamp bolted snug against the pipe, with a full encirclement 360° anchor sleeve on each side of the pipe, mating uniformly with the pipe. The bolts on the anchor clamp shall be tack welded to prevent loosening in service.

8.4.3 The anchor sleeve clamp shall not be tightened against the pipe to provide axial friction, instead the axial restraint may be provided through the anchor sleeve bearing against the clamp (Figure D-6):

- Flat U-straps shall be used for pipe 6 in. (150 mm) and larger
- Flat U-straps or round U-bolts may be used for pipe smaller than 6 in. (150 mm)

8.4.4 The anchor sleeve shall be sized to prevent sliding shear failure between the pipe and the anchor sleeve.

8.5 Sizing of Supports, Guides, Braces and Anchors

8.5.1 The loads and movements at supports, guides, braces and anchors shall be determined through the pipe stress analysis.

8.5.2 The RTR portions of the load path, such as the RTR wrap sleeve on vertical risers shall be designed in accordance with the manufacturer load limits.

8.5.3 The steel and concrete anchor bolts portions of the load path shall be designed in accordance with standard procedures for steel supports [AISC, ACI318].

9 Buried Pipe Design

9.1 Pressure

Buried pipes shall meet the same pressure design requirements as above ground pipes.

9.2 Depth of Cover

9.2.1 The minimum depth of cover (from the top of the pipe to ground surface) shall be 36 in. (0.9 m) (Figure 9.2-1).

9.2.2 If the pipe does not qualify for surface loads, it shall be placed inside a steel or concrete sleeve at crossings (Figure 9.2-2).

9.2.3 The pipe shall be evenly supported on the bottom of the trench (Figure 9.2-3).

9.3 Thrust Blocks

9.3.1 High pressure buried pipe shall be constrained by thrust blocks in accordance with the requirements of the pipe and fitting manufacturer.

9.3.2 Thrust blocks may be achieved with anchored steel plates, sand bags or concrete block, as permitted by the pipe and fitting manufacturer. Thrust blocks shall be designed and sized in accordance with manufacturer recommendation or the DIPRA Standard [DIPRA].

9.3.3 Abrasion pads shall be provided at the interface between the pipe and the thrust block.

9.4 Crossing Lines

9.4.1 When the RTR pipe crosses under an existing line, there should be a 1 meter clearance minimum between the two lines for maintenance access.

9.4.2 Crossing of two buried lines shall be as near to 90 degrees as feasible.

9.5 Ovality

The criteria and equations for soil and surface loads are from AWWA M45.

9.5.1 The ovality of the buried pipe under soil and live (surface) loads shall not exceed the manufacturer limit Ω_{mfr}, where the ovality is [AWWA M45 eq. (5-8)]:

$$\Omega = \frac{(D_L \times W_C + W_L) \times K_S}{0.149 \times PS + 0.061 \times M_S} \leq \Omega_{mfr}$$

Where

D_L = 1.5 deflection lag factor

$W_C = \gamma \times H$ weight of soil prism per unit of pipe area

$PS = \dfrac{E_{ring} \times (t^3/12)}{0.149 \times (0.53 \times D)^3}$ pipe ring stiffness [AWWA M45 eq.(5-17) and (5-18)]

K_S = 0.1 bedding constant

The composite constrained soil modulus M_S reflects the soil stiffening effect restraining the pipe ring deflection [AWWA M45 eq. (5-19)]:

$$M_S = S_{soil} \times M_{sb}$$

Note to obtain M_S [AWWA M45]

Step 1: Obtain M_{sb} from Table 7.5-1, given the depth of cover (depth for γ_S = 120 lb/ft^3) and a selected Standard Proctor Density (SPD).

Step 2: Select M_{sn} applicable to the native soil at the pipe zone elevation from Table 7.5-4.

Step 3: Calculate M_{sn}/M_{sb}.

Step 4: Calculate the ratio B_d/D of the trench width at the top of the pipe B_d to the average diameter of the pipe D.

Step 5: Enter M_{sn}/M_{sb} and B_d/D in Table 7.5-3 and read S_{soil}.

Step 6: Multiply $S_{soil} \times M_{sb}$ to obtain M_S

Step 7: Specify the selected SPD compaction in the construction drawing.

9.5.2 Alternatively, PS may be obtained from tests in accordance with ASTM D2412 at 5% reduction in pipe diameter.

9.5.3 Refer to Appendix C for calculating the live (surface) load W_L, and Appendix D for the composite soil constrained modulus M_S.

9.6 Through-Wall Bending

9.6.1 The through-wall bending stress is the bending stress across the pipe wall, along the circumferential direction, due to the ovalization of the pipe cross-section. The through-wall bending stress in the ovalized cross-section shall not exceed the long-term ring-bending stress of the material, divided by a design factor of 1.5 [AWWA M45 F_{Sb}=1.5 and Antaki, G.A. Section 14.4, with D_f > 4]:

$$\sigma_{TWB} = D_f \times E_h \times \Omega \times \frac{t}{D} \le \frac{S_{TWB}}{1.5}$$

9.6.2 The combined circumferential stress due to internal pressure and through-wall bending stress shall not exceed $S_S(T)$

$$\frac{MAOP \times D}{2 \times t} + \sigma_{TWB} \le S_S(T)$$

9.7 Constrained Expansion-Contraction

9.7.1 The longitudinal stress in the fully restrained buried pipe may be calculated as [ASME B31.4]:

$$\sigma_{EXP} = E_{longitudinal} \times \alpha \times \Delta T - \upsilon \times \frac{MAOP \times D}{2 \times t}$$

The calculated stress is based on the conservative assumption that the pipe is fully constrained by the soil or thrust blocks (if used). If the piping system does not qualify using this fully constrained approach, refer to Appendix E.

9.7.2 Where a thrust block is used, the load on the thrust block shall be the axial stress in the pipe (due to pressure and thermal expansion) multiplied by the cross sectional area of the pipe wall:

$$F_{block} = \left(\frac{MAOP \times D}{4 \times t} + \sigma_{EXP} \right) \times A_{pipe}$$

9.7.3 The same factored long-term design envelope for axial and hoop stress as used for above-ground piping systems shall be used for the qualification of sustained, thermal and occasional stresses.

9.7.4 To prevent compressive axial elastic shell buckling due to constrained thermal expansion, the axial force on the pipe shall be limited to [ISO 14692-3]:

$$F_a \leq 0.9 \times \beta \times E_{eff} \times \pi \times t^2$$

with

$$E_{eff} = \sqrt{E_a \times E_h}$$

$$\beta = 0.1887 + 0.8113 \times \beta_0$$

$$\beta_0 = \frac{0.83}{\sqrt{0.1 + 0.005 \times \frac{D}{t}}}$$

9.7.5 To prevent compressive axial column buckling (Euler buckling) of a run of straight pipe of length L, due to constrained thermal expansion, conservatively excluding the confining effect of the soil stiffness, the axial force on the pipe shall be limited to [ISO 14692-3]:

$$F_a \leq \frac{\pi^3 \times D^3 \times t \times E_a}{8 \times L^2}$$

9.8 Soil Settlement

The risk and magnitude of settlement of the trench foundation shall be determined by civil-geotechnical engineering. The pipe curvature due to settlement shall not exceed the pipe manufacturer curvature limit.

9.9 Lift Curvature

The pipe shall be analyzed for lift curvature, to determine the number of permissible lift points and their distance, as well as the height of lift, as the pipe is lifted from the side of the ditch to be lowered to the bottom of the ditch, or vice-versa.

9.10 Tie-Ins

Tie-Ins of new laterals to existing lines should be designed as for above ground piping systems (Section 7.1).

10 Three-Phase Analysis

10.1 Transient loads in three-phase pipelines (water-hydrocarbons-gas) are due to liquid slugs propelled through the line.

10.2 If the potential for slugging is known at the design stage, the slug loads at changes in direction (bends and tees) may be calculated and included in the transient analysis. The force caused by a slug at changes of direction is [Antaki, G. A.]:

$$F_X = F_Y = \frac{\rho \times A \times v^2}{g}$$

where

ρ is the density of the liquid phase,

A is he cross-sectional flow area of the pipe,

v is the gas velocity propelling the slug of liquid, and

g is gravity.

10.3 If the potential for slugging is unknown at the design stage, the line may be observed during commissioning start-up for evidence of slugging, which can then be measured and analyzed.

10.4 Cavitation (vaporization of the transported liquid and subsequent vapor bubble collapse) is a localized two-phase flow condition. Cavitation is likely to occur at points of increased flow velocity (pressure drop), including throttling valves and orifice plates. Cavitation shall be prevented through proper flow sizing of control valves and orifice plates [Tullis, J.P., ISA 75.01].

11 Fatigue Analysis

11.1 If the piping system is subject to more than 7000 pressure cycles, the fatigue life shall be qualified.

11.2 The piping system fatigue life for pressure cycling is qualified by applying the partial factor for pressure stress cycles A3 to the Factored Long-Term Design Envelope, determined by the pipe and fitting manufacturer (Section 7.4.2).

12 Maximum Flow Velocity

12.1 The maximum flow velocity in RTR pipe shall not exceed the manufacturer limit applicable to the fluid and proportion of suspended solids.

12.2 Typically, for liquid service, the maximum velocity in RTR pipe is in the order of 5 m/s with intermittent excursions up to 10 m/s [ISO 14692-3].

12.3 Typically, for gas service, the maximum velocity in RTR pipe is in the order of 10 m/s with intermittent excursions up to 20 m/s [ISO 14692-3].

12.4 The suspended solids (including sands) shall be specified to the manufacturer for (a) the selection of the maximum fluid velocity and (2) the determination for the need of an inner abrasion-resistant liner.

13 Sectioning Valves

13.1 Sectioning valves shall be steel valves with flanged connections to the RTR pipe.

13.2 Valves shall be independently supported vertically and laterally.

13.3 The steel valve shall be grounded to prevent the build-up of a static electrical charge.

14 Electrical Grounding

14.1 RTR pipelines that carry potentially flammable or explosive fluids shall be protected against the buildup of static electric charge.

14.2 Protection against the buildup of static electric charge can be achieved by one of the following methods:

- Direct burial of the pipe, in continuous contact with the ground
- Use of pipe with grounded and continuously wound conductive fiber. Multiple conductive strands shall be used to ground the full circumference, and the distance between strands shall not exceed twice the wall thickness. A single wound conductive wire is not acceptable
- Pipe with grounded continuous external conductive coating

14.3 Filters shall be individually grounded.

14.4 In all cases, when potentially flammable or explosive fluids are used, and for all hydrocarbon applications, the manufacturer shall be required to specify the grounding requirements for each application.

15 Design Package and Project Records

The pipeline design shall include, as a minimum, the preparation of the documents listed below and shall be given Saudi Aramco engineering drawing numbers per SAEP-122. These documents shall be prepared in accordance with SAEP-334 and will become permanent plant records:

15.1 Piping and Instrument Diagram (P&ID).

15.2 Process Flow Diagram (PFD).

15.3 Calculation sheets supporting flow and pressure drop data, surge analysis in liquid services, stress analysis of restrained and unrestrained pipelines, anchor design, supports for above ground and minimum cover for buried pipelines, etc., as applicable, (calculation sheets are not required for flowlines).

15.4 Safety Instruction Sheets (SIS) per SAES-L-125.

15.5 Pipeline route/corridor drawing.

15.6 Piping detail drawings for end connections, branches, crossings, etc.

15.7 Hydrostatic Test Diagram and pressure testing plans per SAES-A-004 and SAES-L-150.

15.8 Stress analysis reports submittal per SAES-L-120, Appendix A.

15.9 Pipe support and anchor detail drawings.

15.10 Project Scope of Work or Project Specifications covering the installation and highlighting any special features or precautions, tie-in temperature range, procedures for testing, lay-up, and commissioning as applicable.

15.11 As-built pipeline Plan and Profile drawings including pipeline data and appurtenance information such as topography, area classification and design factors, MAOP, station location of all accessories along the pipeline presented in a tabular form along the route of pipeline.

16 Design Output

16.1 Manufacturer Design Verification Calculation from the supplier in support of the API pressure rating of pipe and components.

16.2 Piping drawings, and fabrication spool drawings.

16.3 Stress analysis input and output, with stress isometrics.

16.4 Shop spool fabrication tolerances.

16.5 Field installation tolerances for pipe and pipe supports, guides and anchors.

16.6 Stress Analysis Reports Submittal shall be in accordance with SAES-L-120, Appendix A.

17 Nomenclature

A	=	flow area of the pipe cross-section, in^2
A_{pipe}	=	cross sectional area of the pipe wall (approximately $\pi \times D \times t$), in^2
A	=	speed of sound in the fluid inside the pipe, in/sec
B_d	=	trench width at top of pipe, in
D	=	average pipe diameter (OD-t or ID+t), in
D_f	=	shape factor (Table 7.5-5)
D_L	=	deflection lag factor
D_W	=	diameter exposed to wind, in
E_a	=	modulus of elasticity in the axial (longitudinal) direction, at temperature, psi
E_{eff}	=	effective modulus of elasticity, psi
E_h	=	modulus of elasticity of pipe in the hoop direction, at temperature, psi
E_{ring}	=	ring flexural modulus of elasticity, at temperature, psi
F_a	=	axial force on the pipe
F_e	=	design margin for external differential pressure
F_W	=	uniform wind force per unit of pipe length, lb/in
F_{wheel}	=	force exerted by wheel on the ground, lb
f_2	=	partial factor (Table 3.4.2-1)
g	=	gravity, 386 in/sec^2
H	=	depth of burial of pipe (depth of cover), from ground surface to top of pipe, in
H_{int}	=	depth at which load from wheels interacts, in
HDB_C	=	hydrostatic design basis of the material, in accordance with ASTM D2992 procedure A
I	=	moment of inertia of the pipe cross section, in^4
I_f	=	impact factor
ID	=	inside diameter of the reinforced wall, in

K_S	=	bedding coefficient, use 1.0 as bounding value
L	=	length, in
L_1	=	load width parallel to direction of travel, in
L_2	=	load width perpendicular to direction of travel, in
LCF	=	location class factor
$LCF_{B31.8}$	=	location class factor in accordance with ASME B31.8
M_S	=	composite soil constrained modulus, psi
M_{sb}	=	constrained soil modulus of the pipe zone embedment, psi (Tables 5.5-1, 5.5-2)
MAOP	=	maximum allowable operating pressure, psi
OD	=	outside diameter of the reinforced wall, in
P_D	=	system design pressure, psi
$P_{D,LCF}$	=	design pressure increased to account for the location correction factor, psi
P_{ext}	=	external differential pressure, psi
$P_{ext-mfr}$	=	limit on external differential pressure imposed by the pipe or fitting manufacturer, psi
P_r	=	pressure rating at the design temperature, psi
P_S	=	pressure surge, psi
PS	=	pipe stiffness, psi
q_W	=	velocity pressure, psi
R_i	=	radius of the pipe at the inside of the minimum reinforced wall thickness, in
R_o	=	radius of the pipe at the outside of the minimum reinforced wall thickness, in
S_f	=	service design factor = 2/3
$S_S(T)$	=	95% Lower Confidence Limit (LCL) of the Long-Term Hydrostatic Strength (LTHS) at 20 years per ASTM D 2992 Procedure B at the design temperature, psi
S_{soil}	=	soil support combining factor (Table 5.5-3)
S_{TWB}	=	Long-term allowable through-wall bending stress, psi
SIF	=	stress intensification factor in accordance with ISO 14692-3:2002, Annex D
T	=	reinforced pipe wall thickness, in

T_{cr} = critical time for pressure surge, sec

TL = length of tire footprint, in

TW = width of tire footprint, in

V = gas flow velocity, in/sec

v_W = wind velocity, mph

w = width of pipe-support contact saddle or clamp, in

W_C = vertical soil load on pipe, psi

W_L = live (surface) load on pipe, psi

Z = section modulus of the pipe cross section, in^3

Δv = change in flow velocity, in/sec

α = coefficient of thermal expansion, 1/°F

β = buckling coefficient

β_0 = buckling coefficient

σ_{EXP} = expansion or contraction stress, psi

σ_{TWB} = through-wall bending stress, psi

ΔT = difference between the pipe operating and installation temperatures, °F

γ = weight density of soil in pipe trench, lb/in^3

ρ = weight density, lbf/in^3

ν = Poisson ratio of pipe material

Ω = pipe ovality under soil and surface loads

Ω_{mfr} = pipe manufacturer ovality limit

Tables

Table 1.2-1 – Recommended Temperature Limits for Reinforced Thermosetting Resin Pipe [ASME B31.3:2008 Table A323.4.2C]

Materials		Recommended Temperature Limits			
		Minimum		Maximum	
Resin	Reinforcing	ºC	ºF	ºC	ºF
Epoxy	Glass fiber	-29	-20	149	300
Phenolic	Glass fiber	-29	-20	149	300
Furan	Carbon	-29	-20	93	200
Furan	Glass fiber	-29	-20	93	200
Polyester	Glass fiber	-29	-20	93	200
Vinyl ester	Glass fiber	-29	-20	93	200

Table 7.4.2-1 – Allowable Stress Partial Factor f_2 [ISO 14692-3:2002 Table 3]

Load Type	Duration	Example	f_2
Sustained excluding thermal loads	Long	Weight	0.67
Sustained including thermal loads	Long	Expansion - Contraction	0.83
Occasional	Short	Waterhammer – Wind - Lift	0.89

Table 7.5-1 – M_{sb} Based on Soil Type and Compaction Condition (inch-pound units) [AWWA M45 Table 5-4]

(Refer to Note following the Table for Soil Stiffness Categories)

Vertical Stress Level (see note 5) *psi*	Depth for γ_S = 120 pcf *ft*	Stiffness Categories 1 and 2 (SC1,SC2)			
		SPD 100 *psi*	SPD 95 *psi*	SPD 90 *psi*	SPD 85 *psi*
1	1.2	2,350	2,000	1,275	479
5	6	3,450	2,600	1,500	520
10	12	4,200	3,000	1,625	570
20	24	5,500	3,450	1,800	650
40	48	7,500	4,250	2,100	825
60	72	9,300	5,000	2,500	1,000
		Stiffness Category 3 (SC3)			
1	1.2		1,415	670	360

5	6		1,670	740	390
10	12		1,770	750	400
20	24		1,880	790	430
40	48		2,090	900	510
60	72		2,300	1,025	600
		Stiffness Category 4 (SC4)			
1	1.2		530	255	130
5	6		625	320	175
10	12		690	355	200
20	24		740	395	230
40	48		815	460	285
60	72		895	525	345

SPD = Standard Proctor Density (ASTM D 698)

***Note**: [based on AWWA M45. Refer to AWWA M45 table 5-3 for Soil Group Symbols GW, GP, etc.]*

The ovalization of the pipe under soil and surface loads depends on its soil stiffness. The stiffer soils will reduce ovalization of the pipe which will improve their long-term integrity. Soil stiffnesses are divided into five categories (SC1 best to SC5 poorest) depending on their contents and compaction.

Soil Stiffness Category SC1. SC1 soils consist of crushed rock and gravel with < 15% sand, and < 5% fines. These materials provide maximum pipe support for a given density due to low content of sand and fines. They are recommended for foundation, bedding and backfill.

With minimum effort these materials can provide high soil stiffness over a wide range of moisture contents. Minimum density is generally achieved by dump placements with minimum vibration using surface plate vibrators, vibratory rollers, or internal vibrators. The compacted lift thickness should not exceed 12 in. (300 mm) when compacted with surface plate vibrators, vibratory rollers, or should not exceed the length of the internal vibrator.

In addition, the high permeability of SC1 materials may aid in the control of water and are often desirable for embedment in rock cuts where water is frequently encountered. However, when groundwater flow is anticipated, consideration should be given to the potential for migration of fines from adjacent materials into the open-graded SC1 materials.

Soil Stiffness Category SC2. SC2 soils consist of groups GW, GP, SW, SP, and dual symbol soils containing one of these designations such as GW-GC containing ≤ 12%

fines. These materials, when compacted, provide a relatively high level of pipe support; however, open-graded groups may allow migration and the sizes should be checked for compatibility with adjacent material.

A standard Proctor compaction of 85% minimum shall be achieved (ASTM D 698), which typically will require moderate vibration using surface plate vibrators, vibratory rollers, or internal vibrators. The compacted lift thickness should not exceed 12 in. (300 mm) when compacted with surface plate vibrators, vibratory rollers, or should not exceed the length of the internal vibrator.

Soil Stiffness Category SC3. SC3 soils consist of GM, GC, SM, SC with > 12% fines; and ML, CL, or borderline soils beginning with one of these designations, such as MUCL, with ≥ 30% retained on the No. 200 sieve. These materials provide less support for a given density than SC1 or SC2 materials.

Higher levels of compactive effort are required and moisture content must be controlled. These materials provide reasonable levels of pipe support once proper density is achieved. A standard Proctor compaction of 90% minimum shall be achieved (ASTM D 698), which typically will require high impact compaction with impact tempers or with sheepfoot rollers. The compacted lift should not exceed 6 in. (150 mm).

Soil Stiffness Category SC4. SC4 soils consist of ML, CL, or borderline soil beginning with one of these designations, such as ML/MH, with < 30% retained on the No. 200 sieve. These materials require a geotechnical evaluation prior to use. The moisture content must be near optimum to minimize compactive effort and achieve the required density. When properly placed and compacted, SC4 materials can provide reasonable levels of pipe support; however, these materials may not be suitable under high fills, surface applied wheel loads, or high energy level vibratory compactors and tampers. Do not use where water conditions in the trench prevent proper placement and compaction. They shall not be used for foundation.

Very high levels of compactive effort are required and moisture content must be controlled. These materials provide reasonable levels of pipe support once proper density is achieved. A standard Proctor compaction of 95% minimum shall be achieved (ASTM D 698), which typically will require high impact compaction with impact tempers or with sheepfoot rollers. The compacted lift should not exceed 6 in. (150 mm).

Soil Stiffness Category SC5. SC5 soils consist of CH, MH, OL, OH, PT, CWMH, and any frozen materials. They shall not be used for bedding or backfill.

Table 7.5-2 – M_{sb} Based on Soil Type and Compaction Condition (metric units) [AWWA M45, Table 5-4]

Vertical Stress Level (see note 5) *kPa*	Depth for Soil Density = 18.8 kN/m^3, *m*	Stiffness Categories 1 and 2 (SC1,SC2)			
		SPD 100 *MPa*	SPD 95 *MPa*	SPD 90 *MPa*	SPD 85 *MPa*
6.9	0.4	16.2	13.8	8.8	3.2
34.5	1.8	23.8	17.9	10.3	3.6
69	3.7	29	20.7	11.2	3.9
138	7.3	37.9	23.8	12.4	4.5
276	14.6	51.7	29.3	14.5	5.7
414	22	64.1	34.5	17.2	6.9
		Stiffness Category 3 (SC3)			
6.9	0.4		9.8	4.6	2.5
34.5	1.8		11.5	5.1	2.7
69	3.7		12.2	5.2	2.8
138	7.3		13	5.4	3
276	14.6		14.4	6.2	3.5
414	22		15.9	7.1	4.1
		Stiffness Category 4 (SC4)			
6.9	0.4		3.7	1.8	0.9
34.5	1.8		4.3	2.2	1.2
69	3.7		4.8	2.5	1.4
138	7.3		5.1	2.7	1.6
276	14.6		5.6	3.2	2
414	22		6.2	3.6	2.4

Tables 7.5-1 and 7.5-2 Notes [AWWA M45, Table 5-4]

1. SC1 soils have the highest stiffness and require the least amount of compactive energy to achieve a given density. SC5 soils, which are not recommended for use as backfill, have the lowest stiffness and require substantial effort to achieve a given density.
2. The soil stiffness of dumped SC1 soils can be taken equivalent to SC2 soils compacted to 90% of maximum standard Proctor density (SPD90), and the soil stiffness of compacted SC1 soils can be taken equivalent to SC2 soils compacted to 100% of maximum Standard Proctor Density (SPD100). Even if dumped, SC1 materials should always be worked into the haunch zone.
3. The soil types SC1 to SC5 are defined in Table 6-1. Specific soil groups that fall into these categories, based on ASTM D2487 and AASHTO M145, are also listed Table 6-1.
4. The numerical suffix to the SPD (Standard Proctor Density) indicates the compaction level of the soil as a percentage of maximum dry density determined in accordance with ASTM D689 or AASHTO T-99.

5. Vertical stress level is the vertical effective soil stress at the springline elevation of the pipe. It is normally computed as the design soil unit weight times the depth of fill. Buoyant unit weight should be used below the groundwater level.
6. Engineers may interpolate intermediate values of M_{sb} for vertical stress levels not shown on the table.
7. For pipe installed below the water table, the modulus should be corrected for reduced vertical stress due to buoyancy and by an additional factor of 1.00 for SC1 and SC2 soils with SPD of ≥95, 0.85 for SC2 soils with SPD of 90, 0.70 for SC2 soils with SPD of 85, 0.50 for SC3 soils, and 0.30 for SC4 soils.
8. It is recommended to embed pipe with stiffness of 9 psi (62 kPa) or less only in SC1 or SC2 soils.

Table 7.5-3 – S_{soil} Soil Support Combining Factor [AWWA M45 Table 5-4]

M_{sn}/M_{sb}	B_d/D=1.25	B_d/D=1.5	B_d/D=1.75	B_d/D=2	B_d/D=2.5	B_d/D=3	B_d/D=4	B_d/D=5
0.005	0.02	0.05	0.08	0.12	0.23	0.43	0.72	1.00
0.01	0.03	0.07	0.11	0.15	0.27	0.47	0.74	1.00
0.02	0.05	0.10	0.15	0.20	0.32	0.52	0.77	1.00
0.05	0.10	0.15	0.20	0.27	0.38	0.58	0.80	1.00
0.1	0.15	0.20	0.27	0.35	0.46	0.65	0.84	1.00
0.2	0.25	0.30	0.38	0.47	0.58	0.75	0.88	1.00
0.4	0.45	0.50	0.56	0.64	0.75	0.85	0.93	1.00
0.6	0.65	0.70	0.75	0.81	0.87	0.94	0.98	1.00
0.8	0.84	0.87	0.90	0.93	0.96	0.98	1.00	1.00
1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1.5	1.40	1.30	1.20	1.12	1.06	1.03	1.00	1.00
2	1.70	1.50	1.40	1.30	1.20	1.10	1.05	1.00
3	2.20	1.80	1.65	1.50	1.35	1.20	1.10	1.00
≥5	3.00	2.20	1.90	1.70	1.50	1.30	1.15	1.00

Note: In-between values of S_{soil} may be determined by straight-line interpolation from adjacent values.

Note: B_d is the width of the trench at the top of the pipe, D is the average diameter of the pipe, M_{sn} is from Table 7.5-4, and M_{sb} is from Table 7.5-1 (7.5-2 metric).

Table 7.5-4 – M_{sn} Constrained Modulus of the Native Soil at Pipe Zone Elevation [AWWA M45, Table 5-6]

Native In Situ Soils *					M_{sn}	
Granular		Cohesive				
		qu				
Blows / ft[t] (0.3 m)	Description	Tons / sf	kPa	Description	psi	MPa
>0-1	very, very loose	>0-0.125	0-13	very, very soft	50	0.34
1-2	very loose	0.125-0.25	13-25	very soft	200	1.4
2-4		0.25-0.50	25-50	soft	700	4.8
4-8	loose	0.50-1.0	50-100	medium	1,500	10.3
8-15	slightly compact	1.0-2.0	100-200	stiff	3,000	20.7
15-30	compact	2.0-4.0	200-400	very stiff	5,000	34.5
30-50	dense	4.0-6.0	400-600	hard	10,000	69.0
>50	very dense	>6.0	>600	very hard	20,000	138.0

Table 7.5-5 – Shape Factor Df [AWWA M45, Table 5-1]

Pipe Stiffness PS (psi)	Gravel Fill		Sand Fill	
	Dumped to Slight(1)	Moderate to High(2)	Dumped to Slight(1)	Moderate to High(2)
9	5.5	7.0	6.0	8.0
18	4.5	5.5	5.0	6.5
36	3.8	4.5	4.0	5.5
72	3.3	3.8	3.5	4.5

1) Dumped to slight compaction = Proctor density < 85% (ASTM D 698) and relative density < 40% (ASTM D4253 and ASTM D4254)

2) Moderate to high compaction = Proctor density ≥ 85% (ASTM D 698) and relative density ≥ 40% (ASTM D4253 and ASTM D4254)

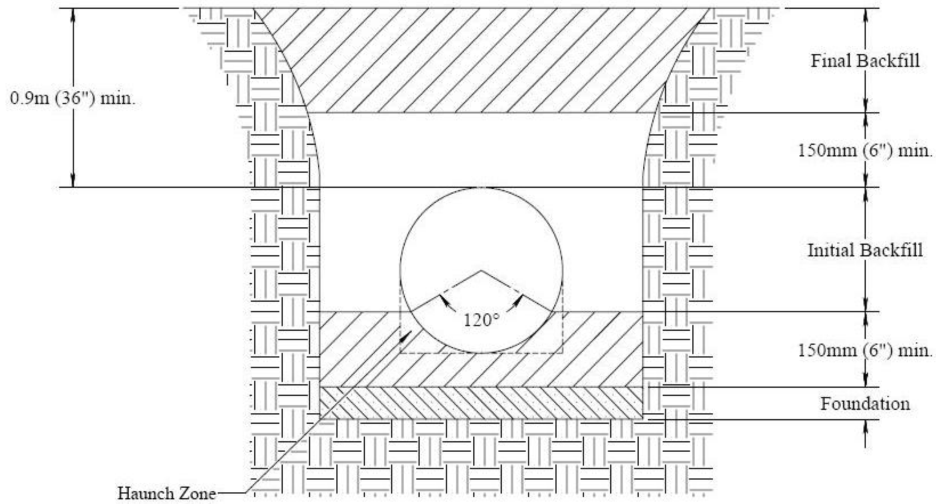


Figure 9.2-1 – Buried Pipe Trench

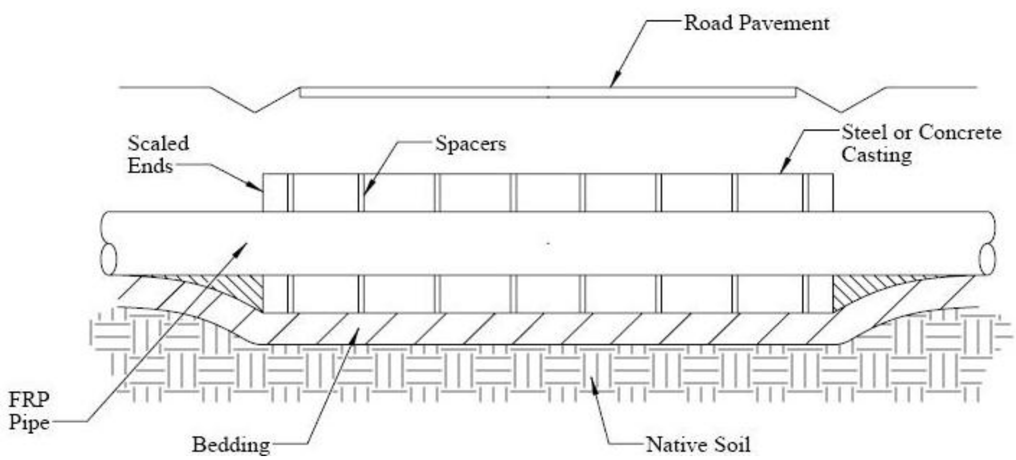


Figure 9.2-2 – Pipe Casing at Road Crossing

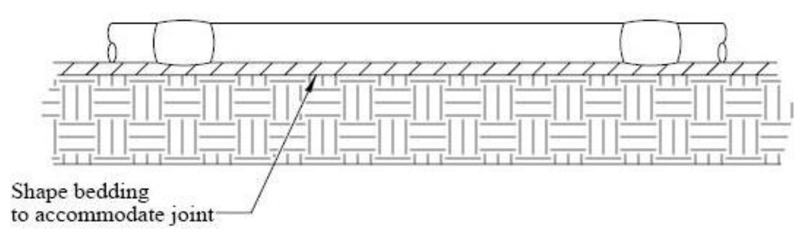


Figure 9.2-3 – Even Bedding Support

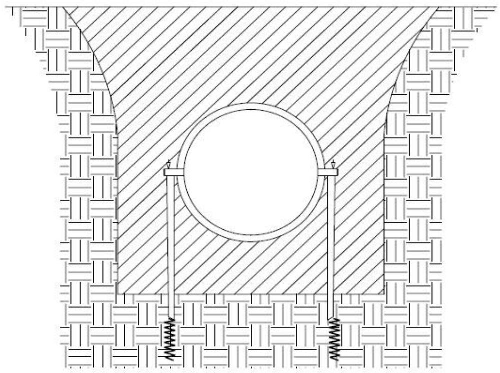
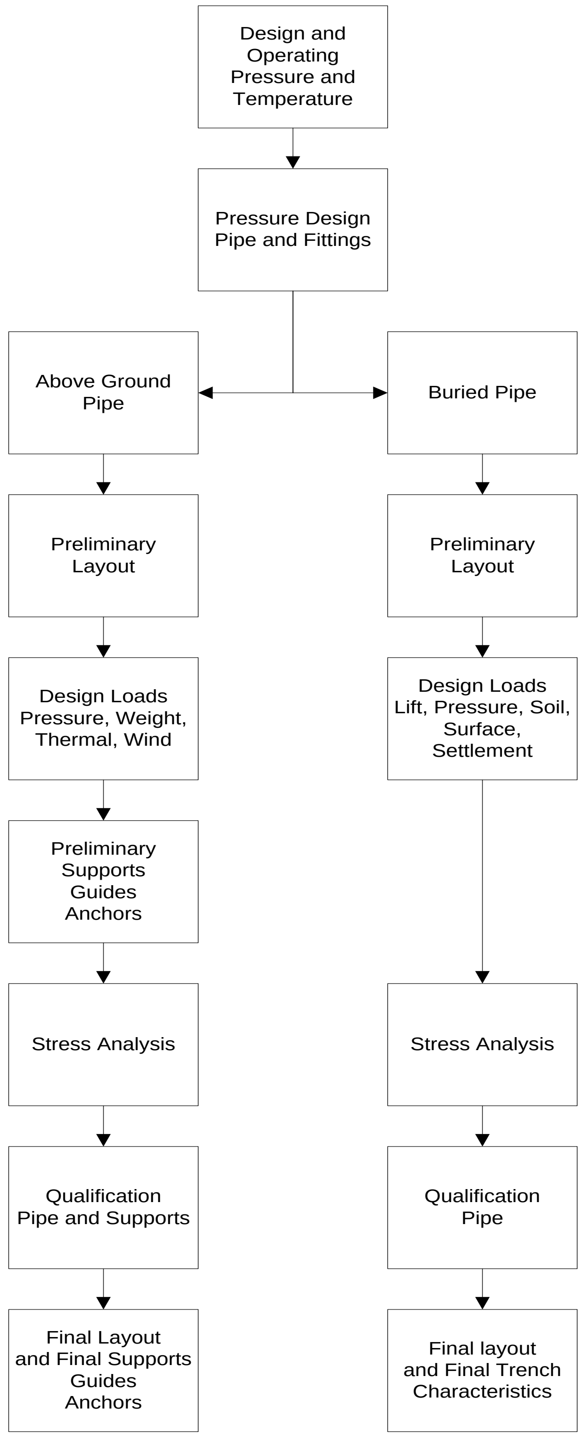


Figure 9.2-4 – Pipe Anchored Against Flotation

	Revision Summary
21 March 2010	Major revision.

Appendix A – Design Input for Analysis and Qualification

A.1 – Design Process for RTR Pipe



A.2.1 Input for Buried and Above Ground Analyses

Pressures and pressure cycles if over 7,000 in system lifetime

Temperatures (maximum and minimum)

Requirements and recommendations in this standard

Manufacturer design requirements and recommendations

Isometric of pipeline, included fittings and components

ISO 14692-3 Section 5.1 for layout guidance

D = average pipe diameter (OD-t or ID+t), in

E_a = modulus of elasticity in the axial (longitudinal) direction, at temperature, psi

E_{eff} = effective modulus of elasticity, psi

E_h = modulus of elasticity of pipe in the hoop direction, at temperature, psi

F_e = design margin for external differential pressure (1.5 for short-time transient, 3.0 for sustained external differential pressure)

HDB_C = hydrostatic design basis of the material, in accordance with ASTM D2992 procedure A

LCF = location class factor

$LCF_{B31.8}$ = location class factor in accordance with ASME B31.8

Over-thickness allowance for erosion-wear, if required

P_D = system design pressure, psi

$P_{D,LCF}$ = design pressure increased to account for the location correction factor, psi

P_{ext} = external differential pressure, psi

$P_{ext\text{-}mfr}$ = limit on external differential pressure imposed by the pipe or fitting manufacturer, psi

R_i = radius of the pipe at the inside of the minimum reinforced wall thickness, in

R_o = radius of the pipe at the outside of the minimum reinforced wall thickness, in

S_f = service design factor = 2/3

$S_S(T)$ = 95% Lower Confidence Limit (LCL) of the Long-Term Hydrostatic Strength (LTHS) at 20 years per ASTM D 2992 Procedure B at the design temperature, psi

α = coefficient of thermal expansion, 1/°F

ΔT = difference between the pipe operating and installation temperatures, °F

A.2.2 Input for Above Ground Analysis Only

Manufacturer recommended support spacing

Manufacturer recommended expansion loops spacing

Manufacturer recommended anchor spacing

Manufactured Factored long-term Design Envelope for axial and hoop stress (Figure 1 of ISO 14692-3:2002)

D_W = diameter exposed to wind, in

f_2 = partial factor (Table 7.4.2-1)

SIF = stress intensification factor in accordance with ISO 14692-3:2002, Annex D

v_W = wind velocity, mph

Z = section modulus of the pipe cross section, in^3

κ = flexibility factor of pipe fitting in accordance with ISO 14692-3:2002 Annex D

A.2.3 Input for Buried Analysis Only

Manufacturer recommended thrust block arrangement

B_d = trench width at top of pipe, in

D_f = shape factor (Table 7.5-5)

D_L = deflection lag factor

E_{ring} = ring flexural modulus of elasticity, at temperature, psi

F_{wheel} = force exerted by wheel on the ground, lb

H = depth of burial of pipe (depth of cover), from ground surface to top of pipe, in

H_{int} = depth at which load from wheels interacts, in

I_f = impact factor

K_S = bedding coefficient, use 1.0 as bounding value

L_1 = load width parallel to direction of travel, in

L_2 = load width perpendicular to direction of travel, in

TL = length of tire footprint, in

TW = width of tire footprint, in

M_S = composite soil constrained modulus, psi

M_{sb} = constrained soil modulus of the pipe zone embedment, psi (Tables 7.5-1, 7.5-2)

S_{TWB} = Long-term allowable through-wall bending stress, psi

W_L = live (surface) load on pipe, psi

γ = weight density of soil in pipe trench, lb/in^3

ν = Poisson ratio of pipe material

Ω_{mfr} = pipe manufacturer ovality limit

A.2.4 Input for Pressure Surge Analysis (Appendix B)

a = speed of sound in the fluid inside the pipe, in/sec

D = average pipe diameter (OD-t or ID+t), in

E_h = modulus of elasticity of pipe in the hoop direction, at temperature, psi

L = distance from pressure source (pump, well, tank, large header) to closing valve, in

t = reinforced pipe wall thickness, in

ρ = weight density of fluid, lbf/in^3

Δv = change in flow velocity, in/sec

ν = Poisson ratio of pipe material

A.2.5 Input for Three Phase Analysis (Section 10, where applicable)

A = flow area of the pipe cross-section, in^2

v = gas flow velocity, in/sec

ρ = weight density of fluid, lbf/in^3

Appendix B – Pressure Surge

B.1 Critical Time

A pressure surge occurs in a liquid line when the flow velocity changes rapidly. A rapid change of flow velocity is a change that occurs in a time shorter than the critical time T_{cr} where

$$T_{cr} = \frac{2 \times L}{a} \times 10$$

The factor 10 is included for conservatism. For pressure surge evaluation, L is the distance between the closing or opening flow control element (such as a valve) and the pressure source (such as a pump, a tank, a vessel or a header).

B.2 Speed of Sound

For RTR pipe, the speed of sound in the liquid inside the pipe is

$$a = \sqrt{\frac{E_h}{(1-\upsilon^2) \times \rho} \times \frac{t}{D}}$$

B.3 Pressure Surge

If the change in flow velocity Δv occurs more rapidly (in a shorter time) than T_{cr} then the pressure surge in the line will be

$$P_S = 2 \times \frac{\rho \times a \times \Delta v}{g}$$

The factor 2 is included to account for dynamic effect. If the change in flow velocity Δv occurs more slowly (in a longer time) than T_{cr} then the pressure surge is negligible.

Appendix C – Live Surface Loads

The live load is calculated for a single-axle truck traveling perpendicular to the pipe on an unpaved surface or a road with flexible pavement

$$W_L = 1.2 \times \frac{F_{wheel} \times I_f}{L_1 \times L_2}$$

$$I_f = 1 + 0.33 \times \frac{96 - H}{96} \geq 1.0$$

The load widths L_1 and L_2 are a function of the depth of cover H and the tire footprint length TL and width TW

$$L_1 = TL + 1.15 \times H$$

$$L2 = TW + 1.15 \times H \quad \text{if } H \leq Hint$$

$$L_2 = \frac{TW + 72 + 1.15 \times H}{2} \quad \text{if } H > Hint$$

Where the depth at which load from wheels interacts H_{int} is

$$H_{int} = \frac{72 - TW}{1.15}$$

Appendix D – Conceptual Support Designs

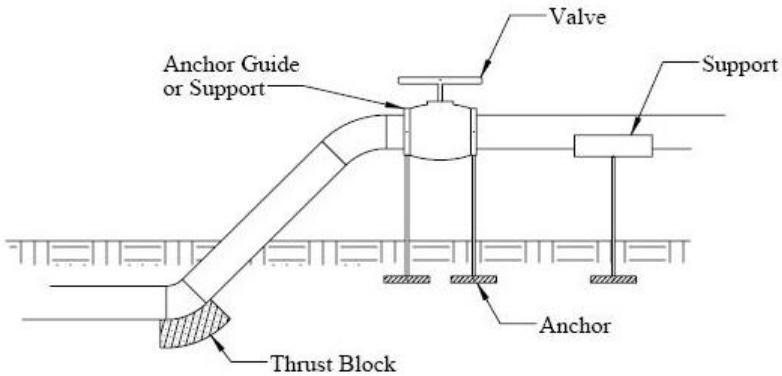


Figure D-1 – Supported Valve

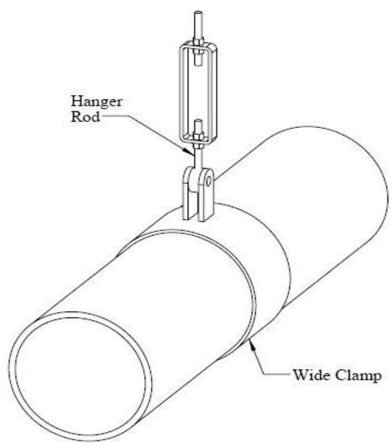


Figure D-2 – Hanger Support

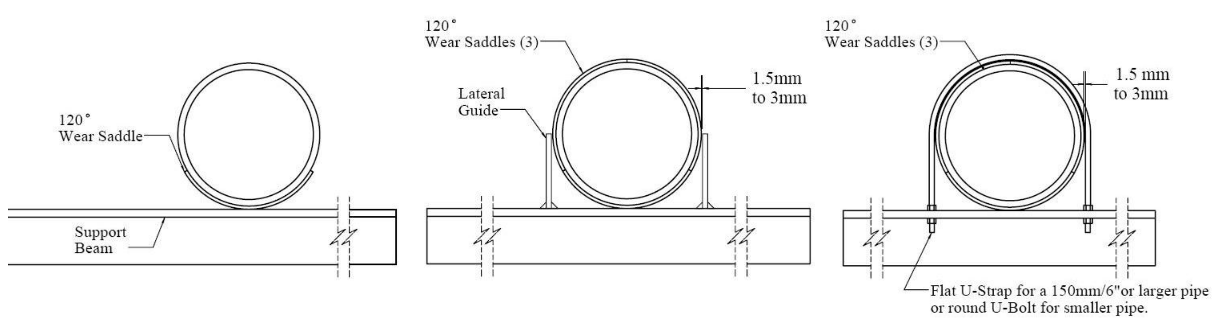


Figure D-3 – Bottom Support (left) and Lateral Guides (middle and right)

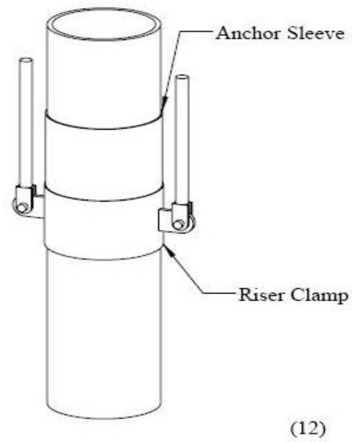


Figure D-4 – Riser Clamp

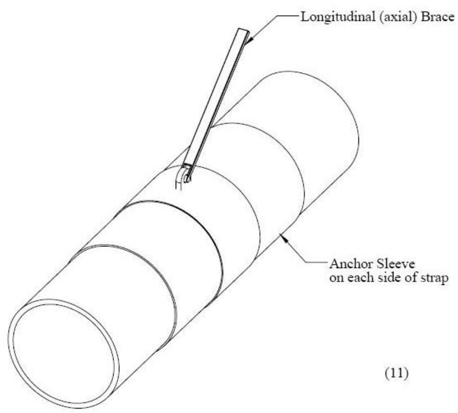


Figure D-5 – Axial Brace

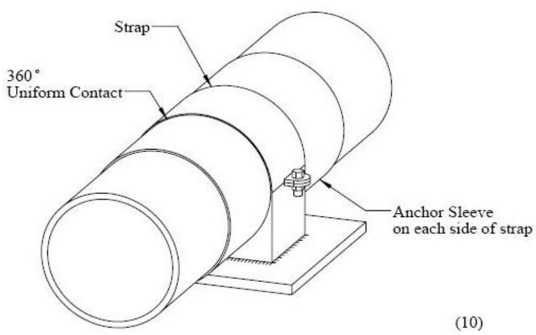
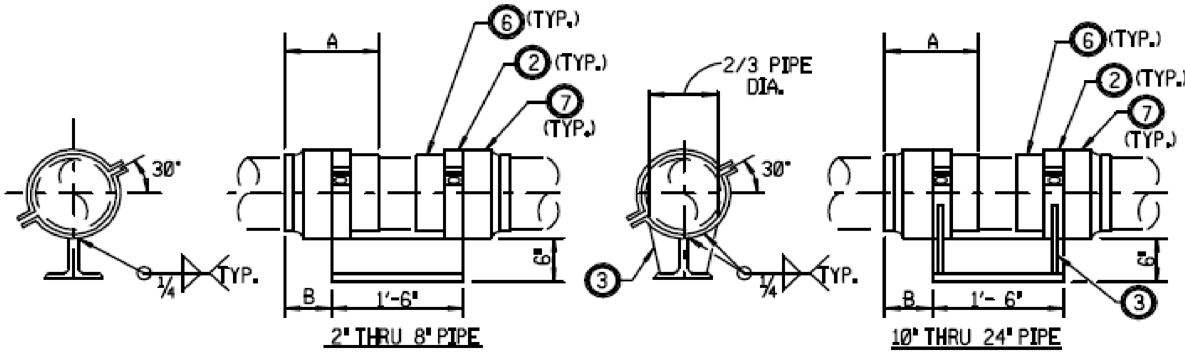


Figure D-6 – Anchor



STRUCTURAL SHAPE				
2" THRU 6" PIPE	8" THRU 10" PIPE	12" THRU 14" PIPE	16" THRU 18" PIPE	20" THRU 24" PIPE
ST6 X 15.9	ST6 X 17.5	WT6 X 15	WT6 X 22.5	WT6 X 25

"A" AND "B" DIMENSIONS			
2" THRU 4"	6" THRU 10"	12" THRU 16"	18" THRU 24"
A = 7¼" B = 4¼"	A = 9½" B = 6½"	A = 12" B = 9"	A = 14" B = 11"

Figure D-7 – 6" High Clamp Pipe Shoe, 1'-6" Long for RTR Pipe (Pipe Sizes 2"-24")

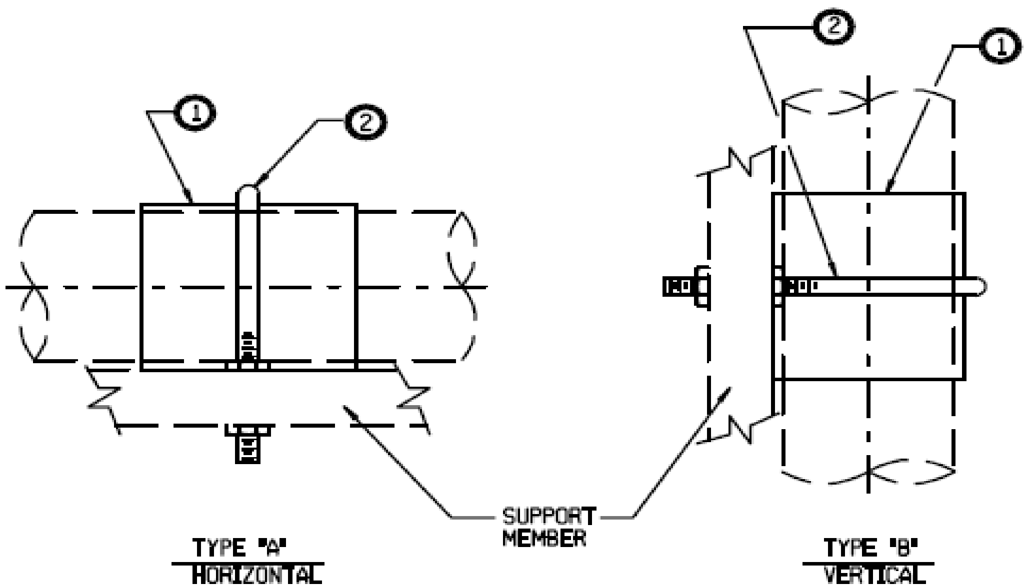
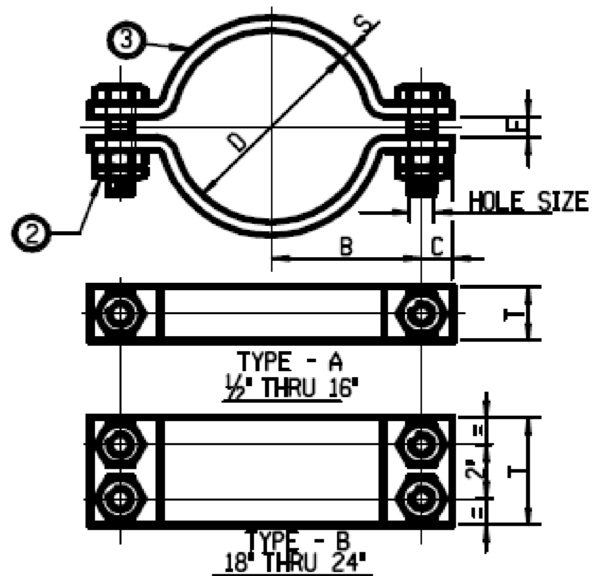


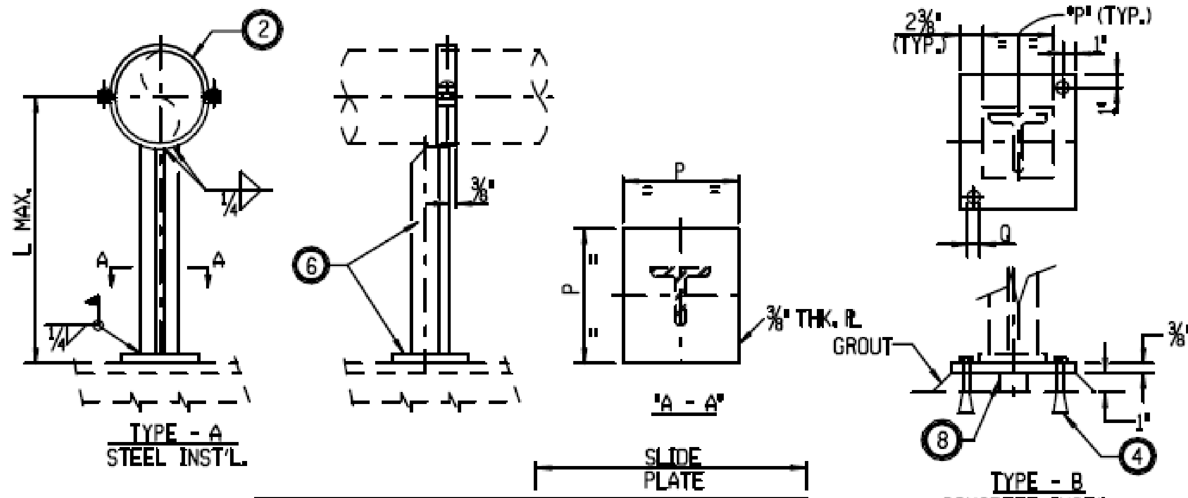
Figure D-8 – Vertical or Horizontal Guide for RTR Pipe



PIPE SIZE	B	C	F	HOLE SIZE	CLAMP TYPE	BOLT SIZE	No. OF HOLES	S	T
½"	Ø.5D +¾"	⅝"	5/16"	½"	A	⅜"	2	3/16"	1⅝"
¾"	Ø.5D +¾"	⅝"	5/16"	½"	A	⅜"	2	3/16"	1⅝"
1"	Ø.5D +¾"	⅝"	5/16"	½"	A	⅜"	2	3/16"	1⅝"
1½"	Ø.5D +¾"	⅝"	5/16"	½"	A	⅜"	2	3/16"	1⅝"
2"	2 1/16"	⅝"	⅜"	½"	A	⅜"	2	3/16"	1⅝"
3"	2⅝"	⅝"	⅜"	½"	A	⅜"	2	3/16"	1⅝"
4"	3⅛"	⅝"	7/16"	½"	A	⅜"	2	3/16"	1⅝"
6"	4 3/16"	⅝"	7/16"	½"	A	⅜"	2	¼"	2"
8"	5 3/16"	⅝"	7/16"	½"	A	⅜"	2	¼"	2"
10"	6¼"	⅝"	9/16"	½"	A	⅜"	2	¼"	2"
12"	7½"	11/16"	9/16"	9/16"	A	½"	2	5/16"	2⅜"
14"	8⅛"	11/16"	9/16"	9/16"	A	½"	2	5/16"	2⅜"
16"	9⅛"	11/16"	11/16"	9/16"	A	½"	2	5/16"	2⅜"
18"	10⅛"	11/16"	11/16"	9/16"	B	½"	4	5/16"	3⅛"
20"	11⅛"	11/16"	11/16"	9/16"	B	½"	4	5/16"	3⅛"
24"	13⅛"	11/16"	1"	9/16"	B	½"	4	5/16"	3½"

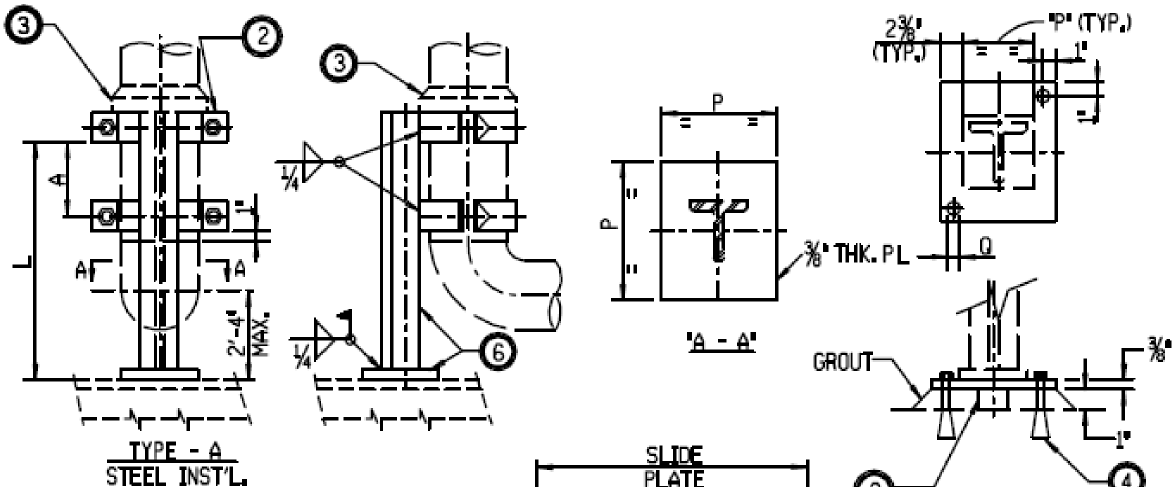
NOTES:
1. FOR SURFACE FINISH (PAINTING, GALVANIZING, ETC.) SEE TECHNICAL JOB INSTRUCTIONS.
2. JAM NUT (TYPICAL).
3. CLAMP MATERIAL, ASTM A-285, GRADE C.
4. FASTENER MATERIALS ASTM A-193, GR. B7, WITH ASTM A194, GRADE 2H NUTS.
5. FABRICATOR SHALL BREAK SHARP EDGES.
6. THIS PRACTICE IS CONTRACTOR FABRICATED AND FURNISHED.
7. D= O.D. OF PIPE.
8. INSTALL A ⅛" RUBBER GASKET BETWEEN THE O.D. OF THE PIPE AND THE CLAMP.

Figure D-9 – Fabricated Pipe Clamp
(Pipe Sizes ½"–24")



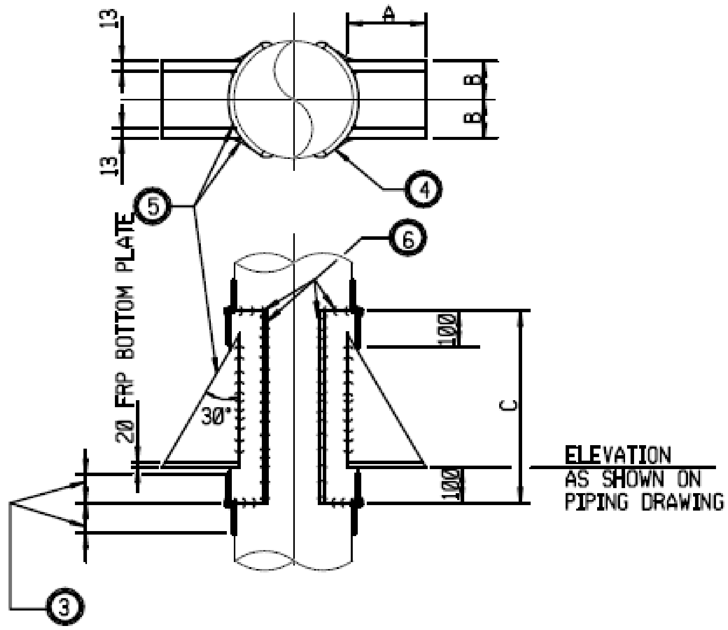
			SLIDE PLATE			
PIPE SIZE	T - SHAPE	L MAX (3)	P	Q	BOLT SIZE	NO. HOLES
2" - 4"	ST3X6.25	2'4"	8"	7/8"	3/4"	2
6",8"	ST3X6.25	2'4"	8"	7/8"	3/4"	2
10"	ST4X11.5	2'4"	10"	7/8"	3/4"	2
12"	ST4X11.5	2'4"	10"	7/8"	3/4"	2
14",16"	ST6X25	4'0"	10"	7/8"	3/4"	2
18"	ST6X25	4'0"	12"	7/8"	3/4"	2
20"	ST6X25	4'0"	12"	7/8"	3/4"	4
24"	ST6X25	4'0"	12"	7/8"	3/4"	4

Figure D-10 – Clamp Floor Support for Horizontal RTR Pipe
(Pipe Sizes 2”–24”)



PIPE SIZE	T - SHAPE	A	L MAX (4)	SLIDE PLATE P	Q	BOLT SIZE	NO. HOLES
2"	ST3X6.25	6"	3'-3"	8"	7/8"	3/4"	2
3"	ST3X6.25	6"	3'-5"	8"	7/8"	3/4"	2
4"	ST3X6.25	6"	3'-6"	8"	7/8"	3/4"	2
6"	ST3X6.25	10"	4'-2"	8"	7/8"	3/4"	2
8"	ST3X6.25	10"	4'-4"	8"	7/8"	3/4"	2
10"	ST4X11.5	10"	4'-8"	10"	7/8"	3/4"	2
12"	ST4X11.5	10"	5'-0"	10"	7/8"	3/4"	2

Figure D-11 – Clamp Floor Support for Vertical RTR Pipe
(Pipe Sizes 2"–24")

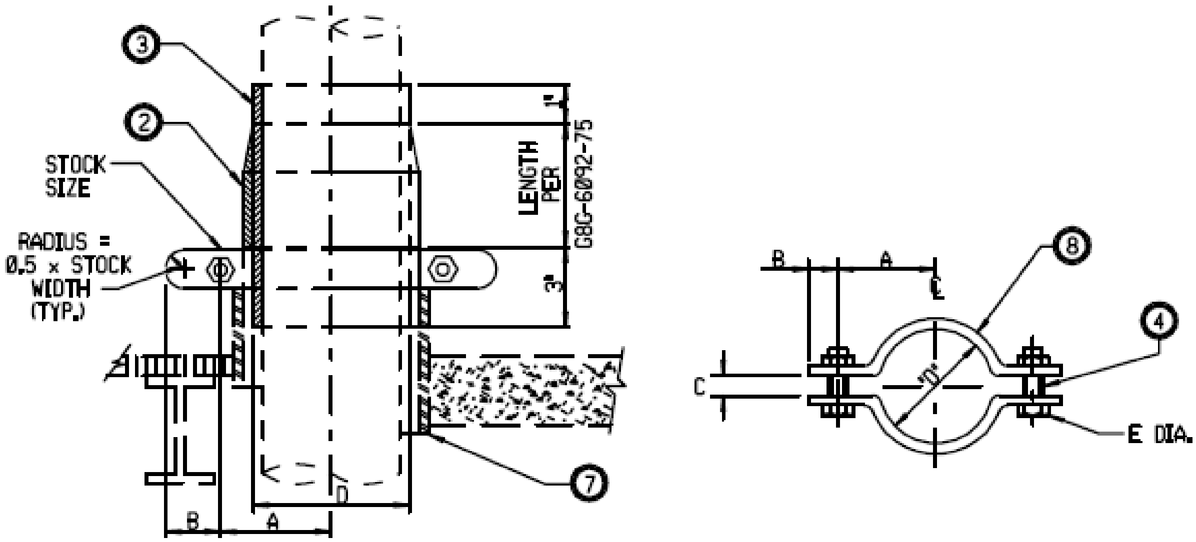


PIPE SIZE	A	B	C
4" THRU 10"	150	50	470
12" THRU 16"	150	75	470
18" THRU 24"	250	75	645

NOTES:

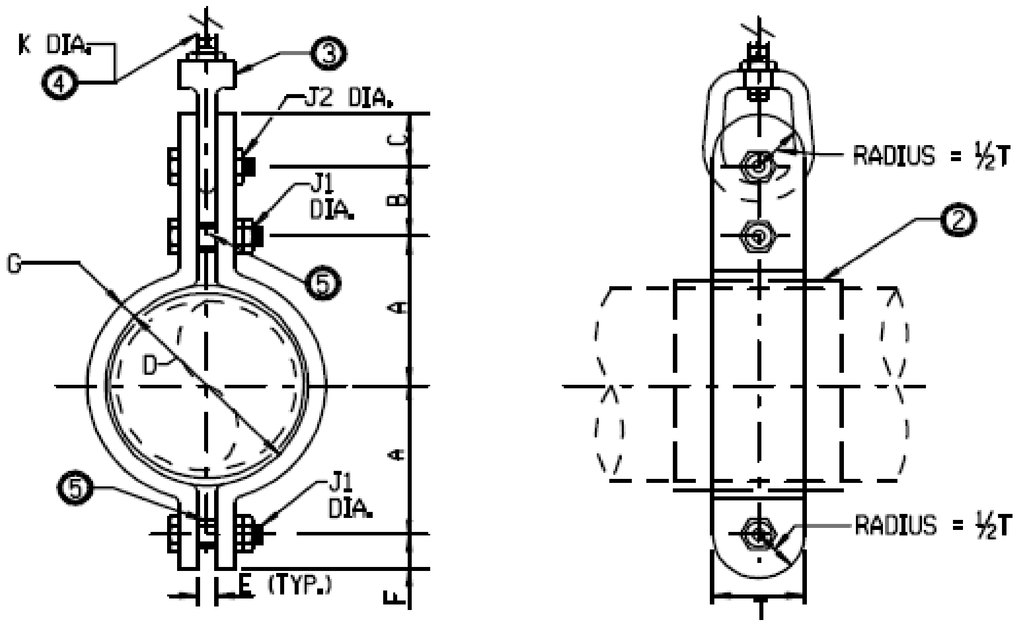
1. GUSSETS AND PLATES SAME MATERIAL AS PIPE.
2. ALL BONDING TO BE MADE WITH PIPE SPEC RESIN THICKENED WITH CAB-0-SIL.
3. MIN. LENGTH OF REINFORCEMENT OVERLAP IS 100mm (TOP & BOTTOM) BY CONTRACTOR.
4. FABRICATOR SHALL USE 120° SECTION OF PIPE WITH I.D. THE SAME AS O.D. OF PIPE TO BE SUPPORTED TO FORM PAD. THICKNESS OF PAD 6mm.
5. FABRICATOR SHALL BOND AND FIBERGLASS REINFORCE GUSSETS AND BOTTOM PLATE TO PAD.
6. INSTALLER SHALL BOND PAD TO PIPE IN THE FIELD AT ELEVATION REQUIRED. BOND PADS WITH THE SAME TYPE RESIN SPECIFIED IN PIPE SPEC & FIBERGLASS REINFORCE TO A MIN. THICKNESS OF 6mm.
7. GRIND AND DE-GREASE, WITH DOW APPROVED SOLVENT, ALL SURFACES TO BE BONDED.
8. UNLESS OTHERWISE NOTED, ALL DIMENSIONS ARE IN MILLIMETERS.

Figure D-12 – Vertical Support for RTR Pipe



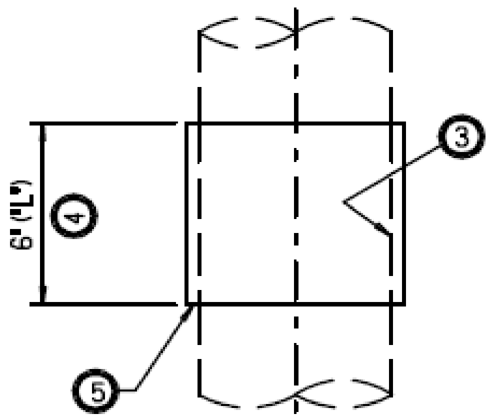
PIPE SIZE	A	B	C	E	STOCK SIZE
2"	0.5D+4"	¾"	⅝"	7/16"	3/16" x 1"
3"	0.5D+4"	¾"	⅝"	7/16"	¼" x 1"
4"	0.5D+4"	1⅛"	⅝"	½"	¼" x 1"
6"	0.5D+4½"	1⅜"	⅝"	½"	¼" x 1½"
8"	0.5D+4½"	1⅜"	⅝"	⅝"	⅜" x 1½"

Figure D-13 – Riser Clamp Support for RTR Pipe (Pipe Sizes 2"–8")



PIPE SIZE	A	B	C	E	F	G	BOLT DIA. J1	BOLT DIA. J2	ROD DIA. K	T
2"	0.5D+1"	3"	5/8"	5/8"	5/8"	1/4"	5/8"	5/8"	3/8"	1 1/4"
3"	0.5D+1"	3"	5/8"	5/8"	5/8"	1/4"	5/8"	5/8"	3/8"	1 1/4"
4"	0.5D+1 1/4"	3 1/4"	1 1/8"	5/8"	1 1/8"	5/16"	3/4"	3/4"	5/8"	2"
6"	0.5D-1 3/8"	3 5/8"	1 1/8"	5/8"	1 1/8"	3/8"	7/8"	7/8"	5/8"	2 1/2"
8"	0.5D-1 3/8"	3 5/8"	1 1/8"	5/8"	1 1/8"	3/8"	7/8"	7/8"	3/4"	2 1/2"
10"	0.5D+1 5/8"	3 5/8"	1 3/8"	5/8"	1 3/8"	1/2"	1"	1"	3/4"	2 1/2"
12"	0.5D+1 3/4"	3 5/8"	1 9/16"	7/8"	1 9/16"	1/2"	1"	1"	7/8"	2 1/2"
14"	0.5D+2"	3 3/4"	1 5/8"	7/8"	1 5/8"	5/8"	1 1/4"	1 1/4"	7/8"	3"
16"	0.5D+2"	3 3/4"	1 5/8"	7/8"	1 5/8"	5/8"	1 1/4"	1 1/4"	1"	3"
18"	0.5D+2"	3 3/4"	1 5/8"	7/8"	1 5/8"	5/8"	1 1/4"	1 1/4"	1"	3"
20"	0.5D+2 1/4"	3 3/4"	1 3/4"	1 1/8"	1 3/4"	3/4"	1 3/8"	1 3/8"	1 1/4"	3"
24"	0.5D+2 1/4"	3 3/4"	1 3/4"	1 1/8"	1 3/4"	3/4"	1 3/8"	1 3/8"	1 1/4"	3"

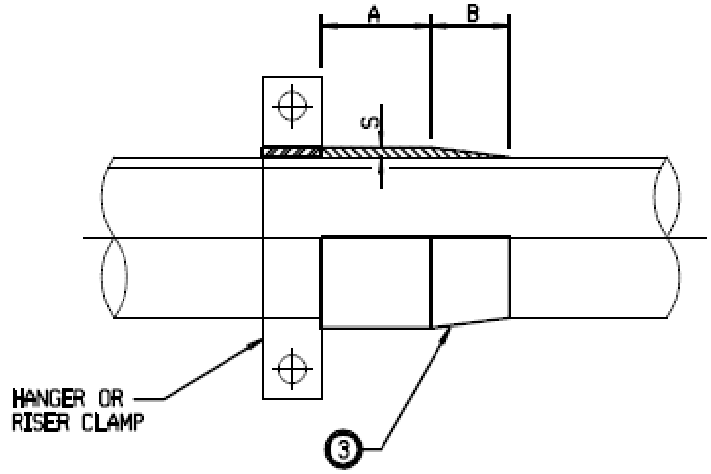
Figure D-14 – Pipe hanger for Uninsulated RTR Pipe (Pipe Sizes 2”-24”)



NOTES:

1. FABRICATE COLLAR IN TWO (2) 180° PIECES.
2. COLLARS WILL BE SHIPPED LOOSE, INSTALL IN FIELD.
3. GRIND AND DE-GREASE, WITH A DOW APPROVED SOLVENT, ALL SURFACES TO BE BONDED.
4. 6" IS STANDARD LENGTH. FOR LENGTHS LONGER THAN 6", "L" MUST BE SPECIFIED ON THE PIPING DRAWING.
5. ¼" THK. COLLAR WITH I.D. TO FIT O.D. OF PIPE. MATERIAL AND METHOD OF FABRICATION TO BE SAME AS PIPE. BOND TO PIPE WITH A PASTE MADE FROM PIPE SPEC. RESIN THICKENED WITH CAB-O-SIL.

Figure D-15 – Reinforcing Collar for RTR Pipe

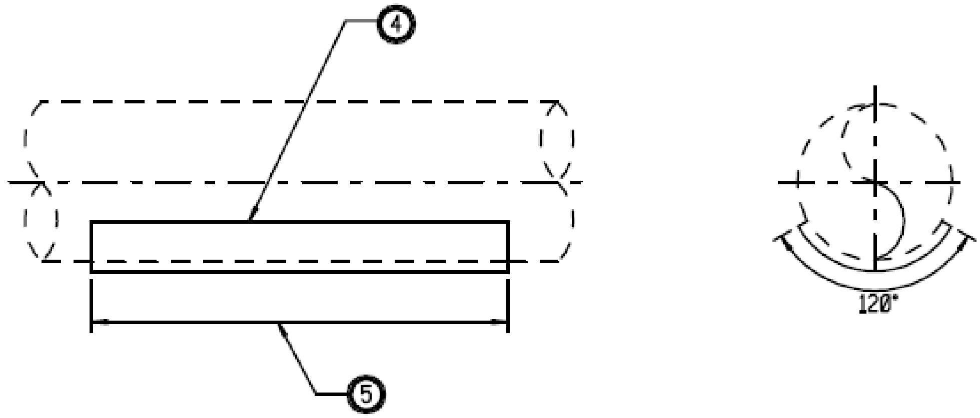


PIPE SIZE	2"	3"	4"	6"	8"	10"	12"	14"	16"	18"	20"	24"
A	2"	2"	2"	4"	4"	4"	6"	6"	6"	8"	8"	8"
B	1¼"	1¼"	1¼"	1½"	1½"	1½"	2"	2"	2"	2"	2"	2"
S	¼"	¼"	¼"	¼"	¼"	¼"	⅜"	⅜"	⅜"	⅜"	⅜"	⅜"

NOTES:

1. GRIND AND DE-GREASE, WITH DOW APPROVED SOLVENT, ALL SURFACES TO BE BONDED.
2. FABRICATE COLLAR USING WET LAY-UP.

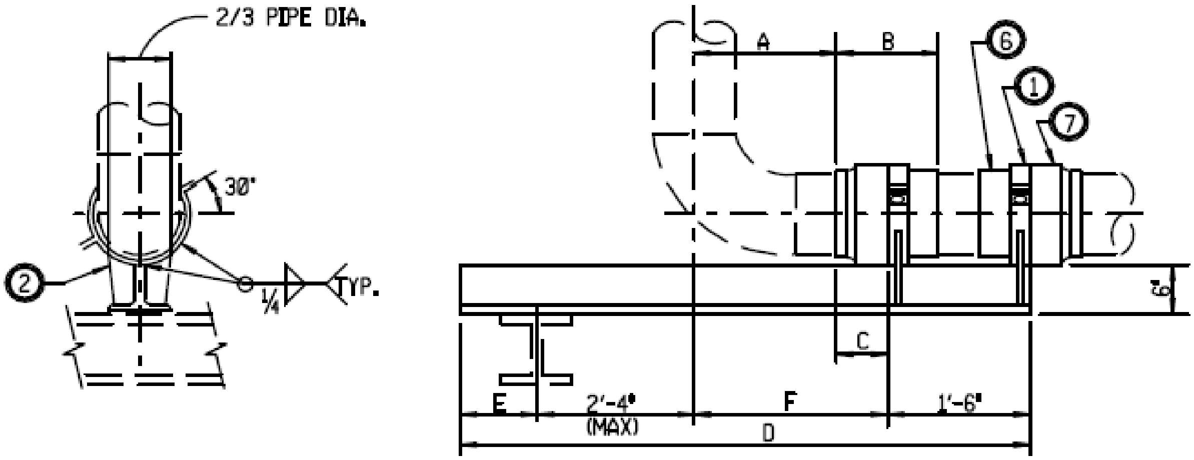
Figure D-16 – Stop Collar for RTR Pipe
(Pipe Sizes 2”-24”)



NOTES:

1. CENTER WEAR PAD ON ℄ OF SUPPORT STEEL UNLESS NOTED OTHERWISE.
2. WEAR PADS WILL BE SHIPPED LOOSE, INSTALL IN FIELD.
3. GRIND AND DE-GREASE WITH DOW APPROVED SOLVENT ALL SURFACES TO BE BONDED.
4. ¼" THK. WEAR PAD, RADIUS TO FIT O.D. OF PIPE. MATERIAL TO BE SAME SPECIFICATION AS PIPE. BOND TO PIPE WITH A PASTE MADE FROM PIPE SPEC RESIN THICKENED WITH CAB-O-SIL.
5. 1'-4" LONG, UP TO 6" PIPE; 1'-8" LONG, 8" & LARGER PIPE.

Figure D-17 – Wear Pad for RTR Pipe



STRUCTURAL SHAPE		
2" THRU 6" PIPE	8" THRU 10" PIPE	12" PIPE
ST6 X 15.9	ST6 X 17.5	WT6 X15

PIPE SIZE	"A"	"B"	"C"	"D" MAX	"E"	"F"
2"	8"	7¼"	4¼"	5' - 6"	8"	1' - 0"
3"	9"	7¼"	4¼"	5' - 7"	8"	1' - 1"
4"	11"	7¼"	4¼"	5' - 9"	8"	1' - 3"
6"	1' - 6"	9½"	6½"	6' - 3"	8"	2' - 0"
8"	1' - 8"	9½"	6½"	6' - 7"	10"	2' - 2"
10"	1' - 11"	9½"	6½"	6' - 10"	10"	2' - 5"
12"	2' - 2"	1'-0"	9"	7' - 4"	10"	2' - 11"

Figure D-18 – 6" High Structural Dummy Leg for RTR Pipe (Pipe Sizes 2"-12")

Appendix E – Alternative Thermal Expansion-Contraction Analysis

If the buried piping system does not qualify using the fully constrained assumption of Section 9.7, it may be analyzed and qualified in accordance with this Appendix.

1. The piping system shall be modeled as if above-ground.
2. The pipe springs shall be added to the model, along the entire length of the system, in each of the three directions: axial, lateral sideways, lateral vertical.
3. The temperature shall be applied to the pipe model.
4. The output stresses shall be evaluated using the same pipe stress limits as above ground piping systems (Section 7.4).

For modeling of soil springs, refer to Guidelines for the Design of Buried Steel Pipe, American Lifelines Alliance, www.americanlifelinesalliance.org.