Engineering Standard

SAES-L-460 30 September, 2003

Pipeline Crossings Under Roads and Railroads

Saudi Aramco DeskTop Standards

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1 Scope

1.1 This standard defines the minimum design and installation requirements governing pipeline crossings under roads, parking lots, railroads, and airport runways within Saudi Aramco jurisdiction.

1.2 This standard applies to pipelines in all services inside plants and residential areas as well as sewers and culverts of flexible materials.

1.3 This standard supplements API RP1102 "Steel Pipelines Crossing Railroads and Highways" Sixth Edition, April 1993.

1.4 Additional requirements imposed by the Saudi Arabian Government shall apply to individual crossings of Government roads and railroads.

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 of the references listed below, unless otherwise noted.

3.1 Saudi Aramco References

Saudi Aramco Engineering Procedure

SAEP-302	*Instructions for Obtaining a Waiver of a Mandatory Saudi Aramco Engineering Requirement*

Saudi Aramco Engineering Standards

SAES-H-002	*Internal and External Coatings for Steel Pipelines and Piping*
SAES-L-440	*Anchors for Cross-Country Pipelines*
SAES-L-450	*Construction of on-Land and Near-Shore Pipelines*
SAES-S-070	*Installation of Utility Piping Systems*
SAES-W-012	*Welding Requirements for Pipelines*
SAES-X-400	*Cathodic Protection of Buried Pipelines*

Saudi Aramco Standard Drawing

AB-036255	*Plan and Detail Concrete Slabs for Road Crossing*

Saudi Aramco Engineering Report

SAER-5809	*Behavior Analysis & Design of Buried Pipelines*

3.2 Industry Codes and Standards

American Petroleum Institute

API RP1102	*Steel Pipelines Crossing Railroads and Highways*

American Society for Testing and Materials

ASTM E515	*Testing for Leaks Using Bubble Emission Techniques*

American Railway Engineering Association

3.3 Other References

Soil Engineering by M.G. Spangler and R.L. Handy

Principles of Calculation for Underground Plastic Pipes - Loads, Deflection, Strain (Jan Molin, ISO/TC 138/WG 6 (Sweden-3) 47)

Safe Height of Sand Cover on Pipelines- Professor Sahel N. Abduljawad; Kind Fahad University of Petroleum & Minerals (June, 1996)

4 Definitions

Camel Crossing: Minor road crossing of aboveground or bermed pipelines in remote areas to provide passage of grazing herds and light vehicles.

Carrier Pipe: The pipe used for transporting liquids or gas.

Casing: The pipe through which the carrier pipe is installed.

Flexible Casing: Casing that may undergo permanent deformation or change of shape without fracture of the wall, for example, steel pipe.

Rigid Casing: Casing that does not undergo permanent deformation or change of shape without fracture of the wall, for example, cast iron or concrete pipe.

Road: Any paved or unpaved passageway or track that may be used by any vehicular traffic, including the strips adjacent to the pavement where cars may be parked and other designated parking areas.

Traffic Load Classifications: The following traffic load classifications are used by Saudi Aramco:

AR-2: Roads on which vehicles heavier than 2 metric tons are prohibited. The design wheel load (i.e. basic wheel load) is 0.8 metric ton. AR-2 applies mostly to patrol roads along security fences, some roads in plants and residential areas and some parking lots.

AR-10: Roads on which trucks are limited to 10 metric tons except on very rare occasions. The design wheel load is 4 metric tons. AR-10 applies mostly to main roads in plants and residential areas, and to unpaved camel crossings.

AR-20: Roads which are frequently used by heavy cranes and tanker trailers in industrial areas. The design wheel load is 7 metric tons. AR-20 applies mostly to major roads in shipping terminals.

AR-40: Loads which are frequently used by 40 metric ton trucks. The design wheel load is 9 metric tons. AR-40 applies to main thoroughfares and government highways.

AR-300: Designated crossings used by the 300 metric ton drilling platform. The design wheel loading is 60 metric tons applied on 2 loaded areas at 3.8 m centers.

B737: Saudi Aramco airport runways. Loading is based on two 49-metric-ton landing wheel sets for a Boeing 737.

E-72: Railroads per the American Railway Engineering Association. Loading is based on three cross ties each carrying 65 metric tons (72 short tons).

5 Approval of Crossings

The location of all proposed pipeline crossings outside plant areas shall be reviewed by the Facilities Planning Department to determine its jurisdiction. Crossings of Saudi Aramco roads and railroads shall be coordinated with the Roads and Wellsites Division prior to construction. Crossings of Government roads and railroads shall be coordinated with the Government Affairs Department for proper authorization prior to construction.

6 Crossing Design Criteria

6.1 For new pipelines as well as existing pipelines under rehabilitation and provided that the stresses are within the limit stated in Section 7, the carrier pipes without casings shall be used as the normal installation method at crossings, when that is possible.

For uncased pipe installed by thrust boring, the pipe shall be coated in accordance with paragraph 9.4, and a 13 mm larger outside diameter lead end shall be used during thrust boring and cut off afterwards.

For new road crossings over existing pipelines, the carrier pipe may be reinforced by installing sleeves, such as repair sleeves, if required, without casings. The sleeve shall extend at least 1 m beyond the edge of the road shoulders.

6.2 Casings shall be used for all railroad crossings and when required by the Saudi Arabian Government.

6.3 Access space for inspection and maintenance is required around pipelines that cross elevated roads inside culverts or under bridges. The length of the restricted access area (i.e., culvert length or bridge width) shall not exceed 20 times the clearance between the top of the highest pipeline in a culvert and the ceiling of the culvert, or from the top of a pipeline to the bottom of the bridge beams.

6.4 Box culverts shall not be used in areas where moving sand can bury the pipeline unless the pipeline is coated in accordance with SAES-H-002.

6.5 Deleted.

6.6 When sufficient cover cannot be provided over the carrier pipe or the casing for a road crossing to meet design requirements per section 7, a reinforced concrete slab shall be installed over the pipe or the casing to transmit the traffic load to the adjacent soil. The concrete slab standard drawing AB-036255 Sheet 1 should be used as guidelines.

Commentary Note:

It is always advisable to avoid these concrete slabs because they create future maintenance difficulties and may shield the cathodic protection.

6.7 The casing or the portion of the carrier pipe with heavier wall shall extend under the railroad bed, the surfaced road, the road shoulders, and not less than 1 m beyond the edge of the road shoulders.

6.8 The crossing for all roads shall be made as nearly perpendicular to the road or railroad axis and as straight as practicable. The crossing angle shall not be less than 45 degrees. If this requirement can not be met, the routing of the pipeline shall be reviewed and approved by the Chairman of Piping Standards Committee in Consulting Services Department.

6.9 For all roads, traveled by motorized vehicles having four wheels or more, the pipeline shall be protected against vehicle collision by means of suitable traffic barriers, walls, earth berms, or stabilized berm over the pipe beyond the edge of the road (measured at a 90-degree angle to the road):

6.9.1 Saudi Government maintained railroads and paved roads, pipeline protection shall extend for a distance of at least 30 m from the edge of the road. If a stabilized berm is used for protection, the berm shall provide at least 1 m cover over the top of the pipe.

6.9.2 For Saudi Aramco maintained paved roads or unpaved rig roads and camel crossings, pipeline protection shall extend for a distance of at least 15 m from the edge of the road. If a stabilized berm is used for protection, the berm shall provide at least 1 m cover over the top of the pipe.

7 Crossing Design Calculations

7.1 General

7.1.1 Crossings shall be designed for the highest total loading expected.

7.1.2 The maximum expected long-term radial deflection of the pipe due to dead and live loads shall be calculated using appropriate equations. SAER-5809 or other references can be used to conduct the calculations.

Commentary Note:

The Spangler equation usually gives higher deflection values than actual.

7.1.3 The maximum circumferential fiber stress in the pipe wall due to the external load shall be calculated using appropriate equations such as those in API RP 1102.

The design shall be governed by the maximum value of the sum of hoop stress due to internal pressure and the corresponding circumferential tensile stress due to external loading.

7.1.4 The governing stress shall not exceed 72% of the specified minimum yield strength (SMYS) in steel casings and in uncased steel carrier pipes

except for cement-lined pipes. For cement-lined steel carrier pipes, the tensile stress in the steel shall not exceed 100 MPa (15 ksi).

7.1.5 A joint factor of 0.8 shall be used for split sleeves unless the halves are welded with full-penetration butt welds.

7.1.6 The governing stress shall not exceed 72% of the long term cyclic hydrostatic design basis (HDB) in uncased plastic carrier pipe.

7.2 For pipelines of 42-inch NPS and smaller and with D/t ratio of greater than 12.5 and smaller than 100; depth of cover of 1.8 to 4.3 m for railroad crossings, 0.9 to 3.0 m for highway crossings the following shall apply:

7.2.1 Design procedures shall be in accordance with API RP1102.

Commentary Note:

The limitations above on pipeline diameter and D/t ratio are the limiting value imposed by API RP-1102.

7.2.2 The design factor "F" used for computing the allowable stress in paragraphs 4.5g. 3, and 4.8.1.1 of API RP1102 shall be 0.72 regardless of the class location.

Commentary Note:

For determining the pipe wall thickness due to internal pressure, the design factor "F" shall be based on the appropriate location class.

7.3 For pipelines outside the range of paragraph 7.2 above, the following shall apply:

7.3.1 The design wheel load for trucks, except for the AR-300 traffic load classification, shall be applied as uniformly distributed loads on the road surface in a pattern for two trucks which are assumed to cross the pipeline simultaneously at minimum distance.

7.3.2 An impact factor shall be applied to the design wheel load as follows for depth of cover up to 1.5 m:

Traffic Load Classification	Impact Factor
AR-2, AR-10, AR-20, AR-40	1.5
AR-300	1.0
B-737	1.0
E-73	1.75

7.4 For depth of cover larger than 1.5 m, the above impact factors shall be reduced by not more than 0.03 per meter of extra cover and shall not be less than 1.

7.5 The deflection shall not exceed 5 percent for steel casing.

7.6 Appendix B to this standard provides crossing design procedures using CROSSI computer program for pipelines larger than 42-inch NPS. The CROSSI program is available for use on PC compatible computers. Contact Chairman of Piping Standards Committee in CSD for additional information.

Commentary Note:

The CROSSI computer software is based on Spangler approach and will result in very high stresses at load condition of 0.0 psig internal pressure, which should be ignored and the Piping Specialist should be contacted.

8 Casing Design

8.1 If a steel split sleeve is used, it shall be continuously welded in accordance with SAES-W-012 using longitudinal butt welds or side straps with fillet welds.

8.2 The inside diameter of the casing shall be large enough to facilitate installation of the carrier pipe and to prevent the transmission of external loads to the carrier pipe. The casing pipe shall be at least two nominal pipe sizes larger than the carrier pipe.

For utility lines, except for steam lines, more than one carrier pipe may be placed inside a common casing within a plant area subject to review and approval by the Chairman of Piping Standards Committee in Consulting Services Department.

8.3 The minimum nominal wall thickness of steel casing shall be in accordance with Table 1.

Table 1 - Steel Casing Wall Thickness

	Minimum Nominal Wall Thickness	
Nominal Pipe Diameter(inches)	Railroads (mm)	Highways (mm)
14 and Under	4.77	3.40
16	5.56	3.40
18	6.35	3.40
20	7.14	3.40
22	7.14	4.17
24	7.92	4.17
26	8.74	4.17
28	9.53	4.17
30	10.31	4.17
32	11.13	4.17
34	11.91	4.17
36	11.91	4.17
38	12.70	4.78
40	13.49	4.78
42	14.27	4.78
44	15.09	4.78
46	15.09	5.56
48	15.88	5.56
50	16.66	6.35
52	17.48	6.35
54	18.26	6.35
56	19.05	6.35
60	19.84	6.35

8.4 For fully restrained steel pipelines in hydrocarbon service, if the pipeline operates at a hoop stress greater than 50 percent of SMYS or if groundwater can be within 450 mm below the bottom of the casing, the ends of the casing shall be water-tight seal welded with split reducers using longitudinal butt welds. The split reducers shall be butt welded to the casing at the large ends and fillet welded to the carrier pipe at the small ends. Welding shall be performed in accordance with SAES-W-012.

8.5 The ends of casings which are not designed per paragraph 8.4 above shall be sealed with flexible non-metallic material to keep out soil and water. The casing end seals shall accommodate the maximum axial movement of the carrier pipe without being torn or cut. The sealing material shall be resistant to ultraviolet light.

8.6 The annulus between the casing and carrier pipe shall be clean (no debris) and dry when the seals are installed.

8.7 Except for casing designed per paragraph 8.4 above, steel casing shall be electrically isolated from the metallic carrier pipe. Where electrical isolation is required, the carrier pipe shall be supported within the casing by means of coated supports or insulators installed at regular intervals. When insulators are used, double insulators are required at each end with the first insulator within one foot of the casing end.

9 Corrosion Protection

9.1 The external surface of steel casing and casing to be thrust bored shall be coated in accordance with SAES-H-002.

9.2 Steel carrier pipe inside casing with flexible end seals shall have a holiday free fusion-bonded-epoxy coating and heat-shrink sleeves at girth welds. The coating shall be holiday tested just before insertion into the casing.

9.3 Steel pipe encased in concrete shall have additional coating or heat-shrink sleeves, or welded sleeves extending beyond the concrete to approximately 300 mm inside the concrete.

9.4 Uncased carrier pipe and/or steel pipe to be installed by thrust boring shall be coated in accordance with SAES-H-002.

9.5 Cathodic protection is required in accordance with SAES-X-400. Casing welded to the carrier pipe shall be considered part of the pipeline. Casing electrically isolated from the carrier pipe shall have a separate dedicated Cathodic Protection system.

10 Installation

10.1 The design shall include construction specifications covering method of installation, use of a temporary bypass, protection of the pipeline, and protection of the road or the railroad.

10.2 Backfill shall be free of material that may damage coatings of steel casing or carrier pipe in accordance with SAES-L-051. Backfill shall be placed in layers of 300 mm or less and compacted to a density matching the surrounding soil.

10.3 Except for crossings with concrete slabs, concrete encasement, bridges, or culverts, the minimum cover over carrier pipe or steel casing shall be in accordance with Table 2, unless otherwise specified by the Saudi Arabian Government.

Table 2 - Minimum Cover for Pipeline Crossings Under Railroads and Highways

	Minimum Cover (1)	
Railroad Crossings Location	**Cased**	**Uncased**
Under track structure proper, except secondary and industry track	1.7 m	(3)
Under track structure proper for secondary and industry track	1.4 m	(3)
Under all other surfaces within the right-of-way or from bottom of ditches	0.9 m	(3)
For pipelines transporting highly volatile liquid (HVL)	1.2 m	(3)
	Minimum Cover (2)	
Highway Crossings Location	**Cased**	**Uncased**
Under highway surface proper	1.2 m	1.2 m
Under all other surfaces within the right-of-way	0.9 m	0.9 m
For pipelines transporting highly volatile liquid (HVL) (4)	1.2 m	1.2 m

Notes:

(1) Measured from the top of the casing pipe to the base of the rail.

(2) Measured from the top of the pipe to the top of the final finished ground surface, such as asphalt road surface.

(3) Uncased crossings under railroads are not permitted. See paragraph 6.2.

(4) For the purpose of this standard, HVL is a hazardous liquid that will form a vapor cloud when released to the atmosphere and that has a vapor pressure exceeding 276 kPa (40 psia) at 37.8°C.

10.4 Bedding, backfill, and minimum cover over plastic and reinforced thermosetting resin carrier pipe shall be in accordance with SAES-S-070.

10.5 The road pavement and sub-base shall be restored. The surface shall be compacted and finished flush with the adjoining pavement.

10.6 An intermediate plate anchor shall be designed in accordance with SAES-L-044 for uncased crossings of above ground unrestrained steel pipelines if the buried length is not long enough to provide the friction force required to anchor the pipeline.

10.7 Elevation of pipelines under crossings shall not be lower than the adjacent length of the pipeline. This is to minimize acceleration of potential internal corrosion.

When this is not feasible, a review and approval from the Chairman of Piping Standards Committee in the Consulting Services Department is required. Oil

flowlines, test lines and water lines 24" NPS and smaller are excluded from this requirement.

11 Testing and Inspection

11.1 The carrier pipe shall be visually inspected prior to installation.

11.2 Externally coated carrier pipe shall be holiday tested prior to installation.

11.3 Welds in carrier pipe shall be inspected by non-destructive test methods prior to installation.

11.4 After installation of a cased crossing with non-metallic casing seals, a test shall show that the steel carrier pipe is electrically isolated from the steel casing pipe.

11.5 The carrier pipe shall be hydrostatically tested at the same pressure as the overall pipeline.

11.6 The welds of casings that do not have flexible seal at the ends shall be tested for leaks with air at 20 to 35 kPa (3 to 5 psi) and soap suds or other liquid application technique. (Refer to ASTM E515).

Revision Summary

30 September, 2003 New Saudi Aramco Engineering Standard replaces SAES-L-046.

Appendix A – Crossing Design Calculations

A.1 The computer program CROSSI calculates stresses and Deflection for buried pipe subject to live loads and dead loads. The program incorporates Saudi Aramco's traffic load classifications in accordance with paragraph 4, or can accept any other surface load for special cases. CROSSI incorporates the impact factors specified in paragraph 7.3.2.

CROSSI determines the dead load due to soil weight for total depth of cover (with or without surcharge above original grade) based on the given soil density.

CROSSI determines the effect of a loaded surface area of a rectangle on an area of one pipe diameter by one pipe diameter at the depth of the top of the pipe. These calculations use Boussinesq factors to predict the effect of the surface loads and integrate to find the total live load on the pipe. One source of the Boussinesq factors is Soil Engineering by M.G. Spangler and R.L. Handy. Newmark's integration of the Boussinesq formula yields the following formula for the unit pressure at a point at depth H under one corner of a loaded rectangular area with dimensions of A times B:

$$\sum P = \frac{1}{4\pi}\left(\frac{(F1)(F3)(F5)}{(H^2)F2 + F4} + \arcsin\left[\frac{(F1)(F3)}{(H^2)(F2) + F4}\right]\right) \qquad (1)$$

where

$\sum$ = unit pressure at depth H

P = unit load applied over the rectangular area

F1 = $2ABH$

F2 = $A^2 + B^2 + H^2$

F3 = $\sqrt{(F2)}$

F4 = $(A^2)(B^2)$

F5 = $\frac{(F2 + H^2)}{F2}$

CROSSI calculates deflections and stresses in several ways. For steel pipe, Spangler's derivation of the Iowa formula is applicable.

$$dX = \frac{(D1)(K)(WC)(r^3)}{(E)(I) + 0.061(EPRIME)(r^3)} \qquad (2)$$

where:

dX	=	horizontal deflection or change in diameter, inch
D1	=	deflection lag factor = 1.5
K	=	bedding constant = 0.083 for a bedding angle of 180º
WC	=	total load per unit length of pipe, lb/inch
D	=	pipe diameter, inch
H	=	depth of soil cover measured from top of the pipe to the road surface (inches)
r	=	mean radius of pipe = (D/2) inch
E	=	pipe modulus of elasticity, psi
T	=	pipe wall thickness, inch
I	=	moment of inertia per unit length = $(T^3)/12$ inch^3
EPRIME	=	modulus of soil reaction = 700 psi for fine-grained soils with an average compaction of 85 to 95%

Substituting the values noted above, the equation becomes the following in CROSSI:

$$dX = \frac{0.1868(WC)(D^3)}{E(T^3)+64.05(D^3)} \qquad (3)$$

A typical limit on deflection is 5 percent of the original diameter for casings.

Stresses for steel pipe are based on the equation from Appendix I of API RP1102 (1981 Edition):

Commentary Note:

The 1981 Edition was current at the time CROSSI was developed and is not in conflict with paragraph 1.3.

$$S = \frac{6(Kb)(W)(E)(R)(T)}{(E)(T^3)+24(K2)(P)(R^3)} \qquad (4)$$

where:

S	=	circumferential stress due to external loads, psi
P	=	internal pressure, psi
D	=	outside diameter, inch

R = outside radius = (D/2) inch

T = pipe wall thickness, inch

Kb = bending parameter = 0.138 for a bored hole

K2 = deflection parameter = 0.089 for a bored hole

E = pipe modulus of elasticity, psi

W = total vertical load including impact factor, lb/inch

Substitution of the values above for R, Kb, and K2 gives the following equation:

$$S = \frac{0.414(W)(E)(D)(T)}{(E)(T^3) + 0.267(P)(D^3)} \quad (5)$$

The typical deflection limits are 2 to 5 percent of the original diameter.

The deflection equation of Jan Molin is:

$$\frac{dV}{D} = \frac{(W)(.083)}{(EPRIMES)(S + 0.122)} \quad (6)$$

where:

dV = shortening of the diameter in the vertical direction

D = original mean diameter

r = D/2

T = wall thickness

E = pipe modulus of elasticity

S = stiffness factor = $\frac{(E)(I)}{(EPRIMES)(r^3)}$

or

$$S = \frac{2(E)(T^3)}{3(EPRIMES)(D^3)} \quad (7)$$

EPRIMES = secant modulus of fill determined by compression tests in a hollow cylinder apparatus

CROSSI uses a modification which accounts for depth of burial as follows:

$$\text{deflection} = \frac{(W)(0.083)}{(M8)(M9 + 0.122)} \quad (8)$$

where:

H = total depth of cover

M8 = 140 + 0.64H = EPRIMES

$$M9 = \frac{2(E)(T^3)}{3(M8)} \quad (9)$$

The stress equation of Jan Molin as used in CROSSI is the following:

$$\text{Stress} = \frac{W(D)(0.375M9 + 0.0045)}{(M9 + 0.122)(T^2)} \quad (10)$$

Molin's equations can be obtained from Principles of Calculation for Underground Plastic Pipes - Loads, Deflection, Strain (Jan Molin, ISO/TC 138/WG 6 (Sweden-3) 47) translated by British Standards Institute October, 1971. This publication is available from Owens/Corning Fiberglass.

CROSSI also predicts deflections and stresses using equations based on work by Watkins.

$$\text{deflection} = \frac{W}{2(P) + (16.66 * 10 ** 7)(T^3) \div (D^3)} \text{inch} \quad (11)$$

$$\text{stress} = \frac{3ET(\text{deflection})}{D(D - 2 * \text{deflection})} \text{ psi} \quad (12)$$

where:

W = total load, lb/inch

P = internal pressure, psi

T = pipe wall thickness, inch

D = pipe outside diameter, inch

E = pipe modulus of elasticity, psi

CROSSI is available at the Consulting Services Department for use on PC compatible computers.