Memorandum
Attachment # 5
10/25/21

10/7/21
Deposition
Exhibit 2

Steel Pipelines Crossing Railroads and Highways

API RECOMMENDED PRACTICE 1102
SEVENTH EDITION, DECEMBER 2007

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energy API

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Foreword

The need for an industry-recommended practice to address installation of pipeline crossings under railroads was first recognized by the publication of American Petroleum Institute (API) Code 26 in 1934. This code represented an understanding between the pipeline and railroad industries regarding the installation of the relatively small-diameter lines then prevalent.

The rapid growth of pipeline systems after 1946 using large-diameter pipe led to the reevaluation and revision of API Code 26 to include pipeline design criteria. A series of changes were made between 1949 and 1952, culminating in the establishment in 1952 of Recommended Practice 1102. The scope of Recommended Practice 1102 (1952) included crossings of highways in anticipation of the cost savings that would accrue to the use of thin-wall casings in conjunction with the pending construction of the Defense Interstate Highway System.

Recommended Practice 1102 (1968) incorporated the knowledge gained from known data on uncased carrier pipes and casing design and from the performance of uncased carrier pipes under dead and live loads, as well as under internal pressures. Extensive computer analysis was performed using Spangler's Iowa Formula [1] to determine the stress in uncased carrier pipes and the wall thickness of casing pipes in instances where cased pipes are required in an installation.

The performance of carrier pipes in uncased crossings and casings installed since 1934, and operated in accordance with API Code 26 and Recommended Practice 1102, has been excellent. There is no known occurrence in the petroleum industry of a structural failure due to imposed earth and live loads on a carrier pipe or casing under a railroad or highway. Pipeline company reports to the U.S. Department of Transportation in compliance with 49 *Code of Federal Regulations* Part 195 corroborate this record.

The excellent performance record of uncased carrier pipes and casings may in part be due to the design process used to determine the required wall thickness. Measurements of actual installed casings and carrier pipes using previous Recommended Practice 1102 design criteria demonstrate that the past design methods are conservative. In 1985, the Gas Research Institute (GRI) began funding a research project at Cornell University to develop an improved methodology for the design of uncased carrier pipelines crossing beneath railroads and highways. The research scope included state-of-the-art reviews of railroad and highway crossing practices and performance records [2, 3]. three-dimensional finite element modeling of uncased carrier pipes beneath railroads and highways, and extensive field testing on full-scale instrumented pipelines. The results of this research are the basis for the new methodology for uncased carrier pipe design given in this edition of Recommended Practice 1102. The GRI summary report, *Technical Summary and Database for Guidelines for Pipelines Crossing Railroads and Highway* by Ingraffea et al. [4], includes the results of the numerical modeling, the full derivations of the design curves used in this recommended practice, and the data base of the field measurements made on the experimental test pipelines.

This recommended practice contains tabular values for the wall thickness of casings where they are required in an installation. The loading values that were employed are Cooper E-80 with 175% impact for railroads and 10,000 lbs (44.5 kN) per tandem wheel with 150% impact for highways. Due notice should be taken of the fact that external loads on flexible pipes can cause failure by buckling. Buckling occurs when the vertical diameter has undergone 18% to 22% deflection. Failure by buckling does not result in rupture of the pipe wall, although the metal may be stressed far beyond its elastic limit. Recommended Practice 1102 (1993) recognizes this performance of a properly installed flexible casing pipe, as opposed to heavy wall rigid structures, and has based its design criteria on a maximum vertical deflection of 3% of the vertical diameter. Measurement of actual installed casing pipe using Recommended Practice 1102 (1981) design criteria demonstrates that the Iowa Formula is very conservative, and in most instances, the measures long-term vertical deflection has been 0.65% or less of the vertical diameter.

Recommended Practice 1102 has been revised and improved repeatedly using the latest research and experience in measuring actual performance of externally loaded uncased pipelines under various environmental conditions and using new materials and construction techniques developed since the recommended practice was last revised. The current Recommended Practice 1102 (2007) is the seventh edition and reflects the most recent design criteria and technology.

The seventh edition of Recommended Practice 1102 (2007) has been reviewed by the API Pipeline Operations Technical Committee utilizing the extensive knowledge and experiences of qualified engineers responsible for design construction, operation and maintenance of the nation’s petroleum pipelines. API appreciatively acknowledges their contributions.

This document was produced under API standardization procedures that ensure appropriate notification and participation in the developmental process and is designated as an API standard. Questions concerning the interpretation of the content of this publication or comments and questions concerning the procedures under which this publication was developed should be directed in writing to the Director of Standards, American Petroleum Institute, 1220 L Street, N.W., Washington, D.C. 20005. Requests for permission to reproduce or translate all or any part of the material published herein should also be addressed to the director.

Generally, API standards are reviewed and revised, reaffirmed, or withdrawn at least every five years. A one-time extension of up to two years may be added to this review cycle. Status of the publication can be ascertained from the API Standards Department, telephone (202) 682-8000. A catalog of API publications and materials is published annually and updated quarterly by API, 1220 L Street, N.W., Washington, D.C. 20005.

Suggested revisions are invited and should be submitted to the Standards Department, API, 1220 L Street, NW, Washington, D.C. 20005, standards@api.org.

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Steel Pipelines Crossing Railroads and Highways

1 Scope

1.1 General

This recommended practice, *Steel Pipelines Crossing Railroads and Highways*, gives primary emphasis to provisions for public safety. It covers the design, installation, inspection, and testing required to ensure safe crossings of steel pipelines under railroads and highways. The provisions apply to the design and construction of welded steel pipelines under railroads and highways. The provisions of this practice are formulated to protect the facility crossed by the pipeline, as well as to provide adequate design for safe installation and operation of the pipeline.

1.2 Application

The provisions herein should be applicable to the construction of pipelines crossing under railroads and highways and to the adjustment of existing pipelines crossed by railroad or highway construction. This practice should not be applied retroactively. Neither should it apply to pipelines under contract for construction on or prior to the effective date of this edition. Neither should it be applied to directionally drilled crossings or to pipelines installed in utility tunnels.

1.3 Type of Pipeline

This practice applies to welded steel pipelines.

1.4 Provisions for Public Safety

The provisions give primary emphasis to public safety. The provisions set forth in this practice adequately provide for safety under conditions normally encountered in the pipeline industry. Requirements for abnormal or unusual conditions are not specifically discussed, nor are all details of engineering and construction provided. The applicable regulations of federal [5, 6], state, municipal, and regulatory institutions having jurisdiction over the facility to be crossed shall be observed during the design and construction of the pipeline.

1.5 Approval for Crossings

Prior to the construction of a pipeline crossing, arrangements should be made with the authorized agent of the facility to be crossed.

2 Symbols, Equations, and Definitions

2.1 Symbols

A_p	Contact area for application of wheel load, in in.^{2} or m^2.
B_d	Bored diameter of crossing, in in. or mm.
B_e	Burial factor for circumferential stress from earth load.
D	External diameter of pipe, in in. or mm.
E	Longitudinal joint factor.
E'	Modulus of soil reaction, in kips/in.^{2} or MPa.

E_{e}	Excavation factor for circumferential stress from earth load.
E_{r}	Resilient modulus of soil, in kips/in.^{2} or MPa.
E_{s}	Young's modulus of steel, in psi or kPa.
F	Design factor chosen in accordance with standard practice or code requirement.
F_{i}	Impact factor.
G_{Hh}	Geometry factor for cyclic circumferential stress from highway vehicular load.
G_{Hr}	Geometry factor for cyclic circumferential stress from rail load.
G_{Lh}	Geometry factor for cyclic longitudinal stress from highway vehicular load.
G_{Lr}	Geometry factor for cyclic longitudinal stress from rail load.
H	Depth to top of pipe, in ft or m.
HVL	Highly volatile liquid.
K_{He}	Stiffness factor for circumferential stress from earth load.
K_{Hh}	Stiffness factor for cyclic circumferential stress from highway vehicular load.
K_{Hr}	Stiffness factor for cyclic circumferential stress from rail load.
K_{Lh}	Stiffness factor for cyclic longitudinal stress from highway vehicular load.
K_{Lr}	Stiffness factor for cyclic longitudinal stress from rail load.
L	Highway axle configuration factor.
L_{G}	Distance of girth weld from centerline of track, in ft or m.
$MAOP$	Maximum allowable operating pressure for gases, in psi or kPa.
MOP	Maximum operating pressure for liquids, in psi or kPa.
N_{H}	Double track factor for cyclic circumferential stress.
N_{L}	Double track factor for cyclic longitudinal stress.
N_{t}	Number of tracks at railroad crossing
P	Wheel load. in lb or kN.
P_{s}	Single axle wheel load, in lb or kN.
P_{t}	Tandem axle wheel load, in lb or kN.
p	Internal pipe pressure, in psi or kPa.

R	Highway pavement type factor.
R_F	Longitudinal stress reduction factor for fatigue.
S_{eff}	Total effective stress, in psi or kPa.
S_{FG}	Fatigue resistance of girth weld, in psi or kPa.
S_{FL}	Fatigue resistance of longitudinal weld in psi or kPa.
S_{He}	Circumferential stress from earth load, in psi or kPa.
S_{Hi}	Circumferential stress from internal pressure calculated using the average diameter, in psi or kPa.
S_{Hi} (Barlow)	Circumferential stress from internal pressure calculated using the Barlow formula, in psi or kPa.
S_1, S_2, S_3	Principal stresses in pipe, in psi or kPa: S_1 = maximum circumferential stress; S_2 = maximum longitudinal stress; S_3 = maximum radial stress.
$SMYS$	Specified minimum yield strength, in psi or kPa.
T	Temperature derating factor.
T_1, T_2	Temperatures (°F or °C).
t_w	Pipe wall thickness, in in. or mm.
w	Applied design surface pressure, in psi or kPa.
α_T	Coefficient of thermal expansion, per °F or per °C.
γ	Unit weight of soil, in lb/in.^{3} or kN/m^3.
ΔS_H	Cyclic circumferential stress, in psi or kPa.
ΔS_{Hh}	Cyclic circumferential stress from highway vehicular load, in psi or kPa.
ΔS_{Hr}	Cyclic circumferential stress from rail load in psi or kPa.
ΔS_L	Cyclic longitudinal stress, in psi or kPa.
ΔS_{Lh}	Cyclic longitudinal stress from highway vehicular load, in psi or kPa.
ΔS_{Lr}	Cyclic longitudinal stress from rail load, in psi or kPa.
ν_s	Poisson's ratio of steel.

2.2 Equations

NOTE All stresses below have units of psi or kPa.

Equation No.

Earth Load:

$$S_{\mathrm{He}} = K_{\mathrm{He}} B_{\mathrm{e}} E_{\mathrm{e}} \gamma D \tag{1}$$

Live Load:

$$w = P / A_{\mathrm{P}} \tag{2}$$

$$\Delta S_{\mathrm{Hr}} = K_{\mathrm{Hr}} G_{\mathrm{Hr}} N_{\mathrm{H}} F_{\mathrm{i}} w \tag{3}$$

$$\Delta S_{\mathrm{Lr}} = K_{\mathrm{Lr}} G_{\mathrm{Lr}} N_{\mathrm{L}} F_{\mathrm{i}} w \tag{4}$$

$$\Delta S_{\mathrm{Hh}} = K_{\mathrm{Hh}} G_{\mathrm{Hh}} R L F_{\mathrm{i}} w \tag{5}$$

$$\Delta S_{\mathrm{Lh}} = K_{\mathrm{Lh}} G_{\mathrm{Lh}} R L F_{\mathrm{i}} w \tag{6}$$

Internal Load:

$$S_{\mathrm{Hi}} = p(D - t_{\mathrm{w}}) / 2t_{\mathrm{w}} \tag{7}$$

Natural gas:

$$[S_{\mathrm{Hi}}(\mathrm{Barlow}) = pD / 2t_{\mathrm{w}}] \le F \times E \times T \times SMYS \tag{8a}$$

Liquids:

$$[S_{\mathrm{Hi}}(\mathrm{Barlow}) = pD / 2t_{\mathrm{w}}] \le F \times E \times T \times SMYS \tag{8b}$$

Limits of Calculated Stresses:

Circumferential:

$$S_1 = S_{\mathrm{He}} + \Delta S_{\mathrm{H}} + S_{\mathrm{Hi}} \tag{9}$$

Longitudinal:

$$S_2 = \Delta S_{\mathrm{L}} - E_{\mathrm{s}} \alpha_{\mathrm{T}} (T_2 - T_1) + \nu_{\mathrm{s}} (S_{\mathrm{He}} + S_{\mathrm{Hi}}) \tag{10}$$

Radial:

$$S_3 = -p = -MAOP \text{ or } -MOP \tag{11}$$

$$S_{\mathrm{eff}} = \sqrt{\frac{1}{2}[(S_1 - S_2)^2 + (S_2 - S_3)^2 + (S_3 - S_1)^2]} \tag{12}$$

$$S_{\mathrm{eff}} \le SMYS \times F \tag{13}$$

$$\Delta S_{\mathrm{L}} \le S_{\mathrm{FG}} \times F \tag{14}$$

$$\Delta S_{\mathrm{Lr}}/N_{\mathrm{L}} \le S_{\mathrm{FG}} \times F \tag{15}$$

$$R_{\mathrm{F}}\Delta S_{\mathrm{Lr}}/N_{\mathrm{L}} \le S_{\mathrm{FG}} \times F \tag{16}$$

$$\Delta S_{\mathrm{Lh}} \le S_{\mathrm{FG}} \times F \tag{17}$$

$$\Delta S_{H} \le S_{\mathrm{FL}} \times F \tag{18}$$

$$\Delta S_{\mathrm{Hr}}/N_{\mathrm{H}} \le S_{\mathrm{FL}} \times F \tag{19}$$

$$\Delta S_{\mathrm{Hh}} \le S_{\mathrm{FL}} \times F \tag{20}$$

2.3 Definitions

The following definitions of terms apply to this practice:

2.3.1
carrier pipe
A steel pipe for transporting gas or liquids.

2.3.2
cased pipeline or **cased pipe**
A carrier pipe inside a casing that crosses beneath a railroad or highway.

2.3.3
casing
A conduit through which the carrier pipe may be placed.

2.3.4
flexible casing
Casing that may undergo permanent deformation or change of shape without fracture of the wall.

NOTE Steel pipe is an example of a flexible casing.

2.3.5
flexible pavement
A highway surface made of viscous asphaltic materials.

2.3.6
girth weld
A full circumferential butt weld joining two adjacent sections of pipe.

2.3.7
highly volatile liquid (HVL)
A hazardous liquid that will form a vapor cloud when released to the atmosphere and that has a vapor pressure exceeding 40 psia (276 kPa) at 100 °F (37.8 °C).

2.3.8
highway
Any road or driveway that is used frequently as a thoroughfare and is subject to self-propelled vehicular traffic.

2.3.9
longitudinal weld
A full penetration groove weld running lengthwise along the pipe made during fabrication of the pipe.

2.3.10
maximum allowable operating pressure (*MAOP*) or **maximum operating pressure (*MOP*)**
The maximum pressure at which a pipeline or segment of a pipeline may be operated with limits as determined by applicable design codes and regulations.

2.3.11
percussive moling
A construction method in which a device is used to advance a hole as sections of pipe are jacked simultaneously into place behind the advancing instrument.

2.3.12
pipe jacking with anger boring
A construction method for pipeline crossings in which the excavation is performed by a continuous auger as sections of pipe are welded and then jacked simultaneously behind the front of the advancing auger.

2.3.13
pressure testing
A continuous, uninterrupted test of specified time duration and pressure of the completed pipeline or piping systems, or segments thereof, which qualifies them for operation.

2.3.14
railroad
Rails fixed to ties laid on a roadbed providing a track for rolling stock drawn by locomotives or propelled by self-contained motors.

2.3.15
rigid pavement
Highway surface or subsurface made of Portland cement concrete.

2.3.16
split casing
A casing made of a pipe that is cut longitudinally and rewelded around the carrier pipe.

2.3.17
trenchless construction
Any construction method, other than directional dirlling, for installing pipelines by subsurface excavation without the use of open trenching.

2.3.18
uncased pipeline or **uncased pipe**
Carrier pipe without a casing that crosses beneath a railroad or highway.

3 Provisions for Safety

3.1 The applicable regulations of federal, state, municipal or other regulating bodies having jurisdiction over the pipeline or the facility to be crossed shall be observed during the installation of a crossing.

3.2 As appropriate to the hazards involved, guards (watch persons) should be posted; warning signs, lights, and flares should be placed; and temporary walkways, fences, and barricades should be provided and maintained.

3.3 Permission should be obtained from an authorized agent of the railroad company before any equipment is transported across a railroad track at any location other than a public or private thoroughfare.

3.4 The movement of vehicles, equipment, material, and personnel across a highway should be in strict compliance with the requirements of the appropriate jurisdictional authority. Precautionary and preparatory procedures should be used, such as posting flagpersons to direct traffic and equipment movement and protecting the highway from surface or structural damage. Highway surfaces should be kept free of dirt, rock, mud, oil, or other debris that present an unsafe condition.

3.5 Equipment used and procedures followed in constructing a crossing should not cause damage to, or make unsafe to operate, any structure or facility intercepted by or adjacent to the crossing.

3.6 The functioning of railroad and highway drainage ditches should be maintained to avoid flooding or erosion of the roadbed or adjacent properties.

4 Uncased Crossings

4.1 Type of Crossing

The decision to use an uncased crossing must be predicated on careful consideration of the stresses imposed on uncased pipelines, versus the potential difficulties associated with protecting cased pipelines from corrosion. This section focuses specifically on the design of uncased carrier pipelines to accommodate safely the stresses and deformations imposed at railroad and highway crossings. The provisions apply to the design and construction of welded steel pipelines under railroads and highways.

4.2 General

4.2.1 The carrier pipe should be as straight as practicable and should have uniform soil support for the entire length of the crossing.

4.2.2 The carrier pipe should be installed so as to minimize the void between the pipe and the adjacent soil.

4.2.3 The carrier pipe shall be welded in accordance with the latest approved editions of API Standard 1104, *Welding of Pipelines and Related Facilities* [7], and ASME B31.4 or B31.8 [8, 9], whichever is applicable.

4.3 Location and Alignment

4.3.1 The angle of intersection between a pipeline crossing and the railroad or highway to be crossed should be as near to 90 degrees as practicable. In no case should it be less than 30 degrees.

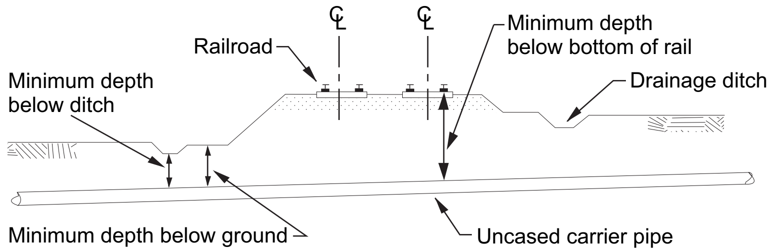
4.3.2 Crossings in wet or rock terrain, and where deep cuts are required, should be avoided where practicable.

4.3.3 Vertical and horizontal clearances between the pipeline and a structure or facility in place must be sufficient to permit maintenance of the pipeline and the structure or facility.

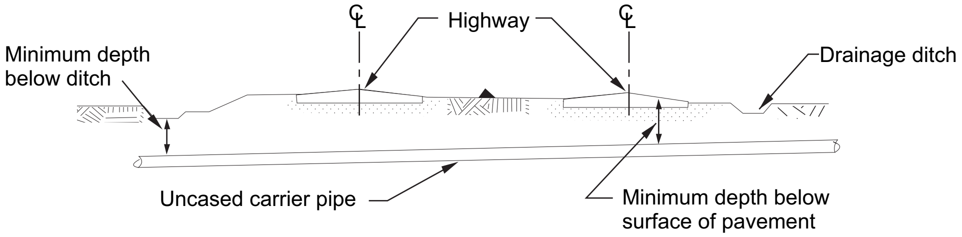
4.4 Cover

4.4.1 Railroad Crossings

Carrier pipe under railroads should be installed with a minimum of cover, as measured from the top of the pipe to the base of the rail, as follows (see Figure 1):



RAILROAD CROSSING



HIGHWAY CROSSING

Figure 1—Examples of Uncased Crossing Installations

Location	Minimum Cover
a) Under track structure proper.	6 ft (1.8 m)
b) Under all other surfaces within the right-of-way or from the bottom of ditches.	3 ft (0.9 m)
c) For pipelines transporting HVL, from the bottom of ditches.	4 ft (1.2 m)

4.4.2 Highway Crossings

Carrier pipe under highways should be installed with minimum cover, as measured from the top of the pipe to the top of the surface, as follows (see Figure 1).

Location	Minimum Cover
a) Under highway surface proper.	4 ft (1.2 m)
b) Under all other surfaces within the right-of-way.	3 ft (0.9 m)
c) For pipelines transporting HVL, from the bottom of ditches.	4 ft (1.2 m)

4.4.3 Mechanical Protection

If the minimum coverage set forth in 4.4.1 and 4.4.2 cannot be provided, mechanical protection shall be installed.

4.5 Design

To ensure safe operation, the stresses affecting the uncased pipeline must be accounted for comprehensively, including both circumferential and longitudinal stresses. The recommended design procedure is shown schematically in Figure 2. It consists of the following steps:

a) Begin with the wall thickness for the pipeline of given diameter approaching the crossing. Determine the pipe, soil, construction, and operational characteristics.

b) Use the Barlow formula to calculate the circumferential stress due to internal pressure, S_{Hi} (Barlow). Check S_{Hi} (Barlow) against the maximum allowable value.

c) Calculate the circumferential stress due to earth load, S_{He}.

d) Calculate the external live load, w, and determine the appropriate impact factor, F_i.

e) Calculate the cyclic circumferential stress, ΔS_H, and the cyclic longitudinal stress, ΔS_L due to live load.

f) Calculate the circumferential stress due to internal pressure, S_{Hi}.

g) Check effective stress, S_{eff} as follows:

  1) Calculate the principal stresses, S_1 in the circumferential direction, S_2 in the longitudinal direction, and S_3, in the radial direction.

  2) Calculate the effective stress, S_{eff}.

  3) Check by comparing S_{eff} against the allowable stress, $SMYS \times F$.

h) Check welds for fatigue as follows:

  1) Check with weld fatigue by comparing ΔS_L against the girth weld fatigue limit, $S_{FG} \times F$.

  2) Check longitudinal weld fatigue by comparing, ΔS_H against the longitudinal weld fatigue limit, $S_{FL} \times F$.

i) If any check fails, modify the design conditions in Item a appropriately and repeat the steps in Items b through h.

Recommended methods for performing the steps in Items b through h, above, are described in 4.6 through 4.8. In 4.6 through 4.8, several figures give design curves for specific material properties or geometric conditions. *Interpolations between the design curves may be done. Extrapolations beyond the design curve limits are not recommended.*

4.6 Loads

4.6.1 General

4.6.1.1 A carrier pipe at an uncased crossing will be subjected to both internal load from pressurization and external loads from earth forces (dead load) and train or highway traffic (live load). An impact factor should be applied to the live load. Recommended methods for calculating these loads and impact factors are described in the following subsections.

4.6.1.2 Other loads may be present as a result of temperature fluctuations caused by changes in season; longitudinal tension due to end effects; fluctuations associated with pipeline operating conditions, unusual surface loads associated with specialized equipment; and ground deformations arising from various sources, such as shrinking and swelling soils, frost heave, local instability, nearby blasting, and undermining by adjacent excavations.

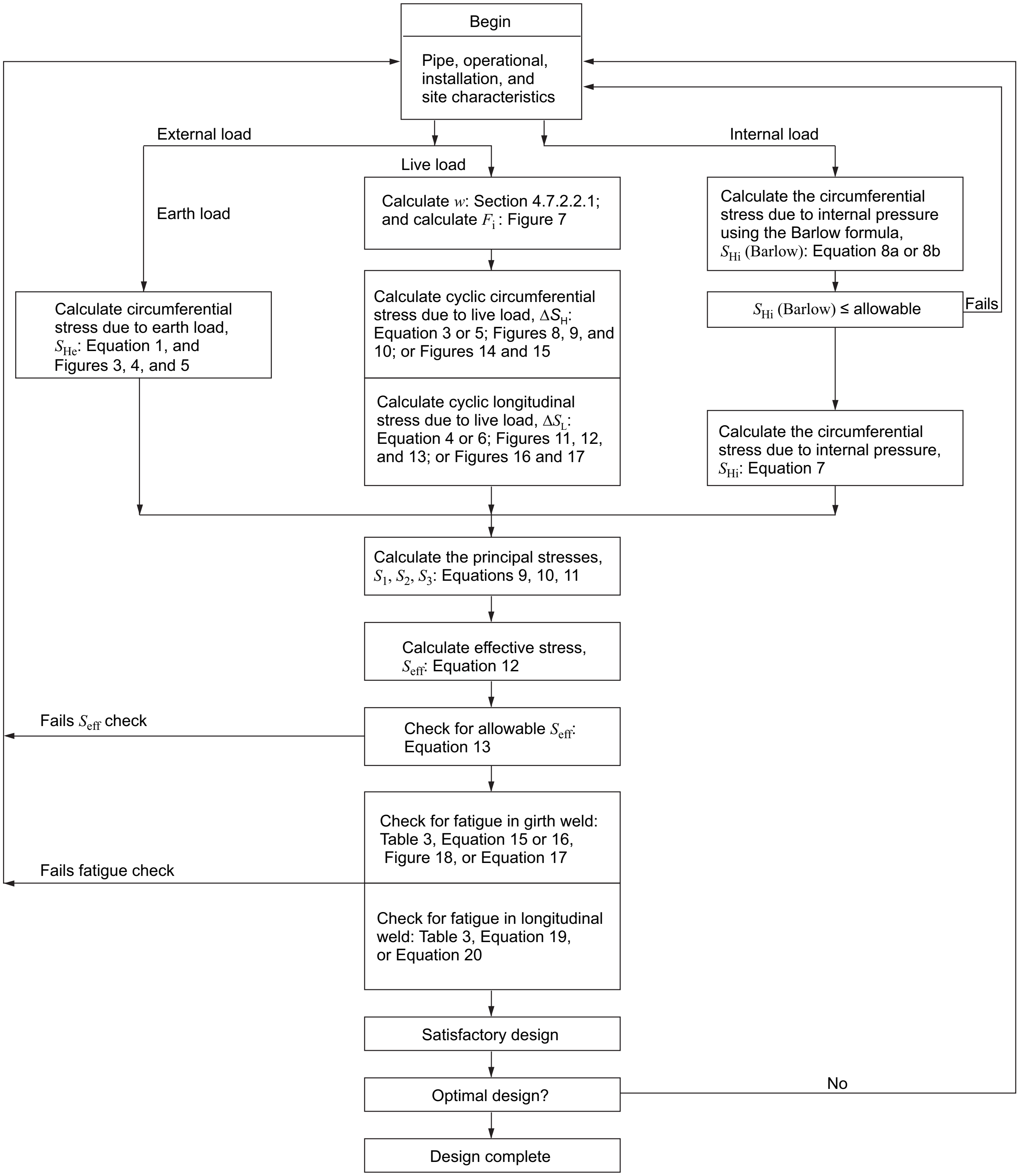


Figure 2—Flow Diagram of Design Procedure for Uncased Crossings of Railroads and Highways

Pipe stresses induced by temperature fluctuations can be included. All other loads are a result of special conditions. Loads of this nature must be evaluated on a site-specific basis and, therefore, are outside the scope of this recommended practice. Ingraffea et al. [4] describe how pipeline stresses can be influenced by longitudinal bends and tees in the vicinity of the crossing, and they give equations to evaluate such effects.

4.6.2 External Loads

4.6.2.1 Earth Load

The earth load is the force resulting from the weight of the overlying soil that is conveyed to the top of pipe. The earth load is calculated according to the procedures widely adopted in practice for ditch conduits [10]. Such procedures have been used in pipeline design for many years and have been included in specifications adopted by various professional organizations [11, 12, 13].

4.6.2.2 Live Load

4.6.2.2.1 Railroad Crossing

It is assumed that the pipeline is subjected to the load from a single train as would be applied on either track shown in Figure 1. For simultaneous loading of both tracks, stress increment factors for the cyclic longitudinal and cyclic circumferential stress are used. The crossing is assumed to be oriented at 90 degrees with respect to the railroad and is an embankment-type crossing as illustrated in Figure 1. This type of orientation generally is preferred in new pipeline construction and is likely to result in pipeline stresses larger than those associated with pipelines crossing at oblique angles to the railroad.

4.6.2.2.2 Highway Crossing

It is assumed that the pipeline is subjected to the loads from two trucks traveling in adjacent lanes, such that there are two sets of tandem or single axles in line with each other. The crossing is assumed to be oriented at 90 degrees with respect to the highway and is an embankment-type crossing, as shown in Figure 1. This type of orientation generally is preferred in new pipeline construction and is likely to result in pipeline stresses larger than those associated with pipelines crossing at oblique angles to the highway.

4.6.3 Internal Load

The internal load is produced by internal pressure, p, in pounds per square inch (psi) or kilopascals (kPa). The maximum allowable operating pressure, $MAOP$ or maximum operating pressure, MOP should be used in the design.

4.7 Stresses

4.7.1 General

For detailed information on the methods used to develop the design approaches and design curves for determining stresses, see Ingraffea et al. [4].

4.7.2 Stresses Due to External Loads

External loading on the carrier pipe will produce both circumferential and longitudinal stresses. Recommended procedures for calculating each component of these stresses follow. It is assumed that all external loads are conveyed vertically across a 90 degree arc centered on the pipe crown and resisted by a vertical reaction distributed across a 90 degree arc centered on the pipe invert.

4.7.2.1 Stresses Due to Earth Load

The circumferential stress at the pipeline invert caused by earth load. S_{He} (psi or kPa), is determined as follows:

$$S_{He} = K_{He}B_eE_e\gamma D \quad (1)$$

where

K_{He} is the stiffness factor for circumferential stress from earth load.

B_e is the burial factor for earth load.

E_e is the excavation factor for earth load.

γ is the soil unit weight, in lb/in.^{3} or kN/m^3.

D is the pipe outside diameter, in in. or m.

It is recommended that γ be taken as 120 lb/ft^3 (18.9 kN/m^3) (equivalent to 0.069 lb/in.^{3}) for most soil types unless a higher value is justified on the basis of field or laboratory data.

The earth load stiffness factor, K_{He}, accounts for the interaction between the soil and pipe and depends on the pipe wall thickness to diameter ratio, t_w/D, and modulus of soil reaction, E'. Figure 3 shows K_{He} plotted for various E', as a function of t_w/D. Values of E' appropriate for auger borer construction may range from 0.2 to 2.0 kips/in.^{2} (1.4 to 13.8 mPa). It is recommended that E' be chosen as 0.5 kips/in.^{2} (3.4 mPa), unless a higher value is judged more appropriate by the designer. Table A-1 in Annex A gives typical values for E'.

The burial factor, B_e, is presented as a function of the ratio of pipe depth to bored diameter, H/B_d for various soil conditions in Figure 4. If the bored diameter is unknown or uncertain at the time of design, it is recommended that B_d be taken as D + 2 in. (51 mm). For trenched construction and new structures constructed over existing pipelines, $B_d = D$ can be assumed, recognizing that soil compaction in the trench would lead to higher E' values than those for auger bored installations.

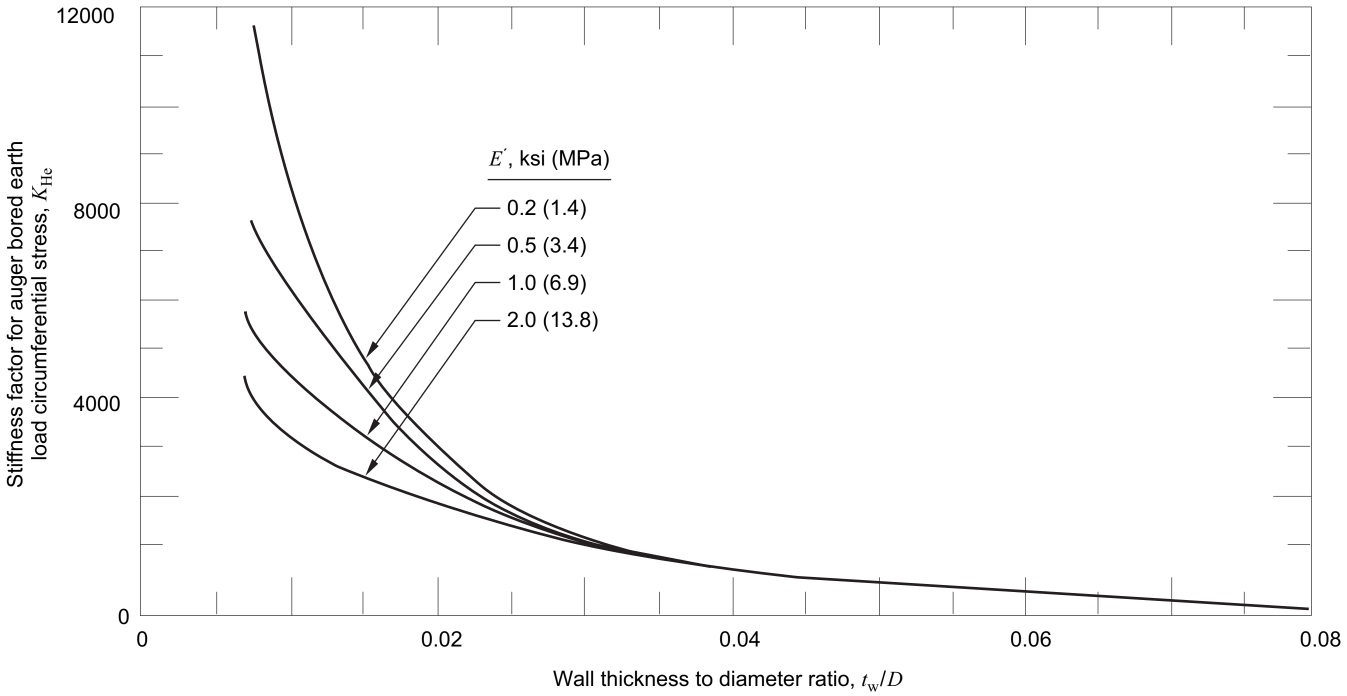
The excavation factor, E_e, is presented as a function of the ratio of bored diameter to pipe diameter, B_d/D in Figure 5. If the bored diameter is unknown or uncertain at the time of design, E_e should be assumed equal to 1.0. For trenched construction and new structures constructed over existing pipelines, E_e can be assumed equal to 1.0.

4.7.2.2 Stresses Due to Live Load

4.7.2.2.1 Surface Live Loads

The live, external rail load is the vehicular load, w, applied at the surface of the crossing. It is recommended that Cooper E-80 loading of w = 13.9 psi (96 kPa) be used, unless the loads are known to be greater. This is the load resulting from the uniform distribution of four 80-kip (356-kN) axles over an area 20 ft by 8 ft (6.1 m by 2.4 m).

The live external highway load, w, is due to the wheel load, P, applied at the surface of the roadway. For design, only the load from one of the wheel sets needs to be considered. The design wheel load should be either the maximum wheel load from a truck's single axle, P_s, or the maximum wheel load from a truck's tandem axle set, P_t. Figure 6 shows the methods by which axle loads are converted into equivalent single wheel loads P_s and P_t. For example, a truck with a single axle load of 24 kips (106.8 kN) would have a design single wheel load of P_s = 12 kips (53.4 kN) and a truck with a tandem axle load of 40 kips (177.9 kN) would have a design tandem wheel load of P_t = 10 kips (44.5 kN). The maximum single axle wheel load recommended for design is P_s = 12 kips (53.4 kN). The maximum tandem axle wheel load recommended for design is P_t = 10 kips (44.5 kN). The decision as to whether single or tandem axle loading is more critical depends on the carrier pipe diameter, D; the depth of burial, H; and whether the



NOTE See Table A-1 for soil descriptions.

Figure 3—Stiffness Factor for Earth Load Circumferential Stress, K_{He}

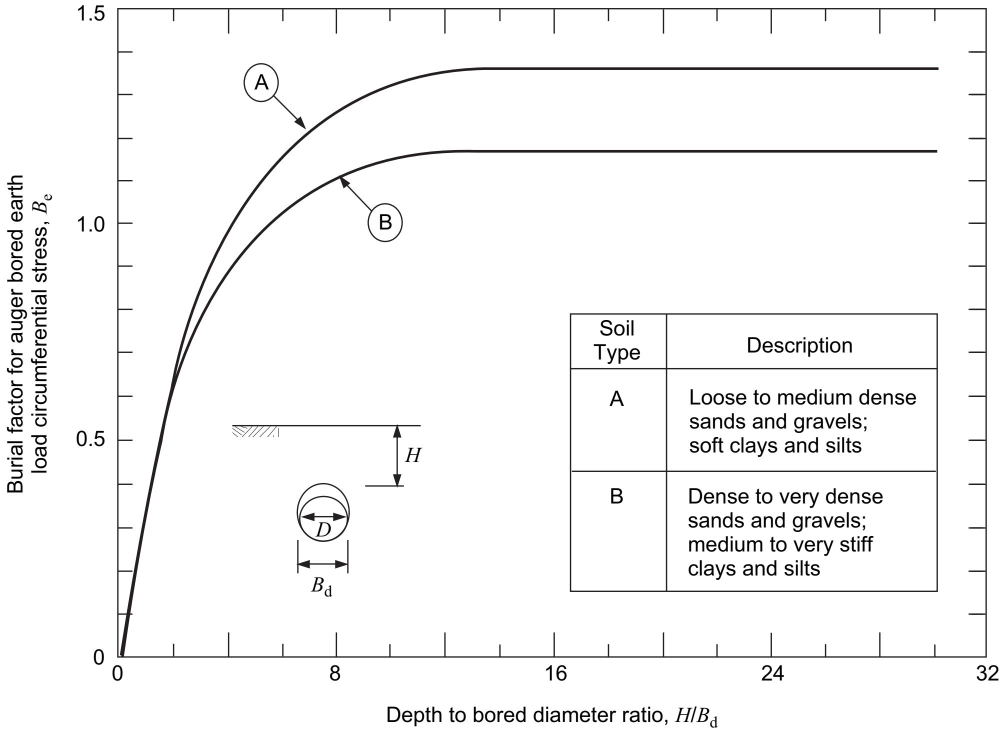


Figure 4—Burial Factor for Earth Load Circumferential Stress, B_e

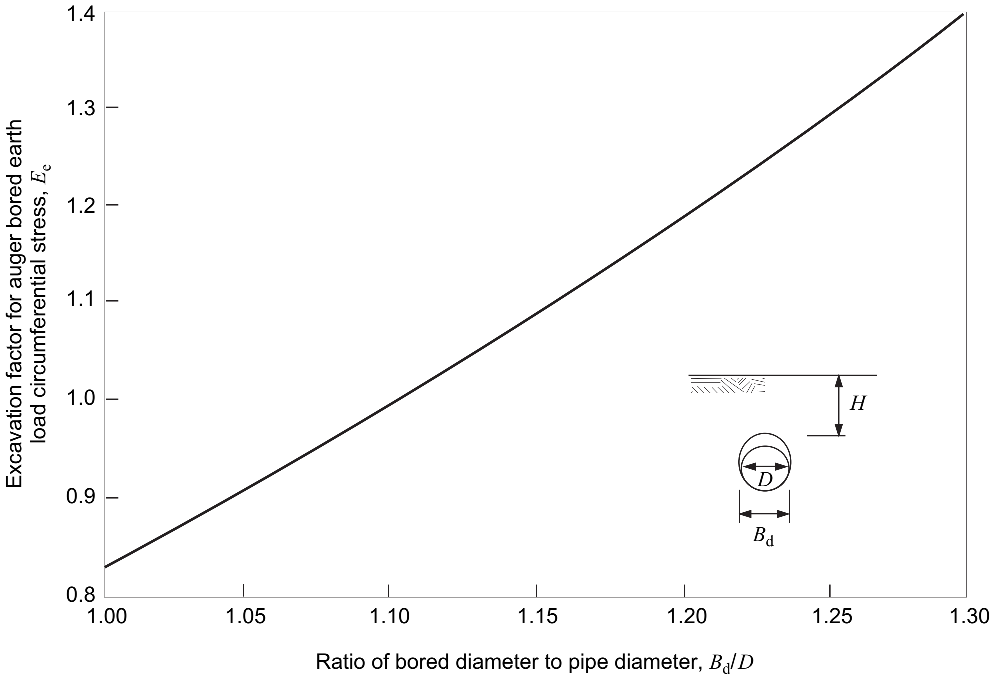


Figure 5—Excavation Factor for Earth Load Circumferential Stress, E_e

road surface has a flexible pavement, has no pavement, or has a rigid pavement. For the recommended design loads of P_s = 12 kips (53.4 kN) and P_t = 10 kips (44.5 kN), the critical axle configuration cases for the various pavement types, burial depths, and pipe diameters are given in Table 1.

The applied design surface pressure, w (lb/in.^{2} or kN), then is determined as follows:

$$w = P/A_P \tag{2}$$

where

P is the either the design single wheel load, P_s, or the design tandem wheel load, P_t, in lbs (kN).

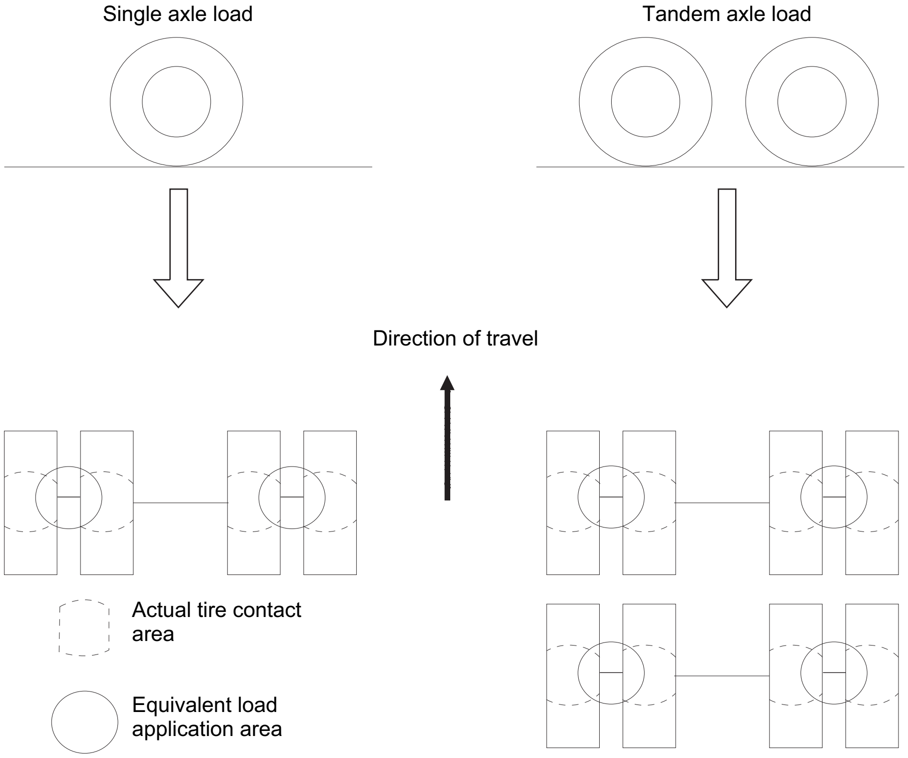
A_p is the contact area over which the wheel load is applied; A_p is taken as 144 in.^{2} (0.093 m^2).

For the recommended design loads of P_s = 12 kips = 12,000 lbs (53.4 kN) and P_t = 10 kips = 10,000 lbs (44.5 kN) the applied design surface pressures are as follows:

a) Single axle loading: w = 83.3 psi (574 kPa).

b) Tandem axle loading: w = 69.4 psi (479 kPa).

For design wheel loads different from the recommended maximums, refer to Annex A.



$$P_s = \frac{\text{Single axle load}}{2} \qquad P_t = \frac{\text{Tandem axle load}}{4}$$

Figure 6—Single and Tandem Wheel Loads, P_s and P_t

Table 1—Critical Axle Configurations for Design Wheel Loads of P_s = 12 Kips (53.4 kN) and P_t = 10 Kips (44.5 kN)

Depth of burial, H, < 4 ft (1.2 m) and diameter, D, ≤ 12 in. (305 mm)	
Pavement Type	Critical Axle Configuration
Flexible pavement No pavement Rigid pavement	Tandem axles Single axle Tandem axles
Depth, H, < 4 ft (1.2 m) and diameter, D, > 12 in. (305 mm) Depth, H, ≥ 4 ft (1.2m) for all diameters	
Pavement Type	Critical Axle Configuration
Flexible pavement No pavement Rigid pavement	Tandem axles Tandem axles Tandem axles

4.7.2.2.2 Impact Factor

It is recommended that the live load be increased by an impact factor, F_i, which is a function of the depth of burial, H, of the carrier pipeline at the crossing. The impact factor for both railroad and highway crossings is shown graphically in Figure 7. The impact factors are 1.75 for railroads and 1.5 for highways, each decreasing by 0.03 per ft (0.1 per m) of depth below 5 ft (1.5 m) until the impact factor equals 1.0.

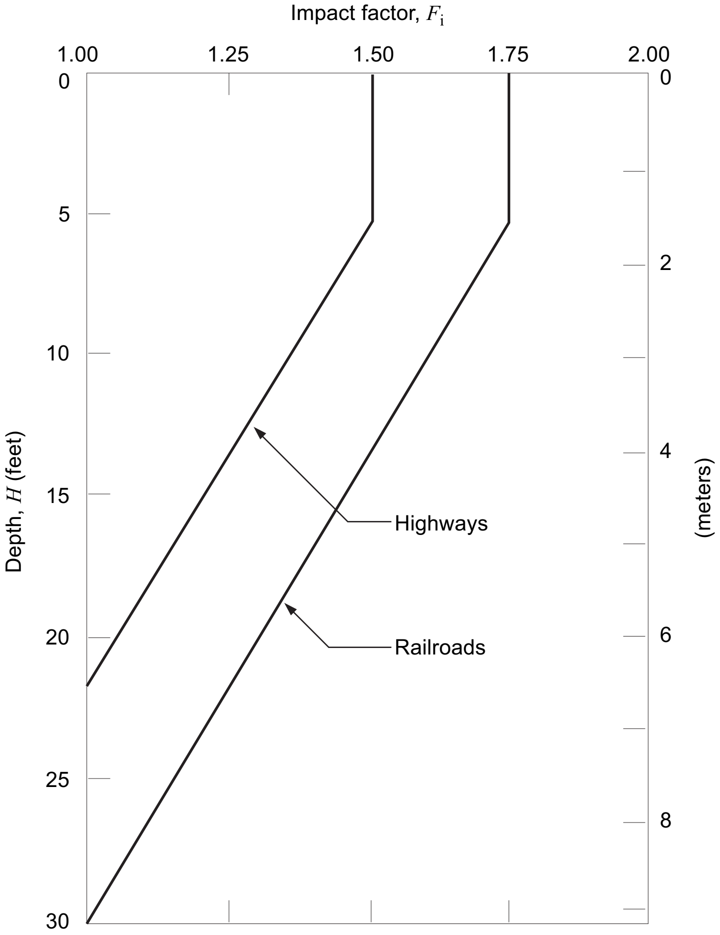


Figure 7—Recommended Impact Factor Versus Depth

4.7.2.2.3 Railroad Cyclic Stresses

4.7.2.2.3.1 The cyclic circumferential stress due to rail load, ΔS_{Hr}, (psi or kPa), may be calculated as follows:

$$\Delta S_{Hr} = K_{Hr} G_{Hr} N_H F_i w \qquad (3)$$

where

K_{Hr} is the railroad stiffness factor for cyclic circumferential stress.

G_{Hr} is the railroad geometry factor for cyclic circumferential stress.

N_H is the railroad single or double track factor for cyclic circumferential stress.

F_i is the impact factor.

w is the applied design surface pressure, in psi or kPa.

The railroad stiffness factor, K_{Hr}, is presented as a function of the pipe wall thickness to diameter ratio, t_w/D, and soil resilient modulus, E_r, in Figure 8. Table A-2 in Annex A gives typical values for E_r.

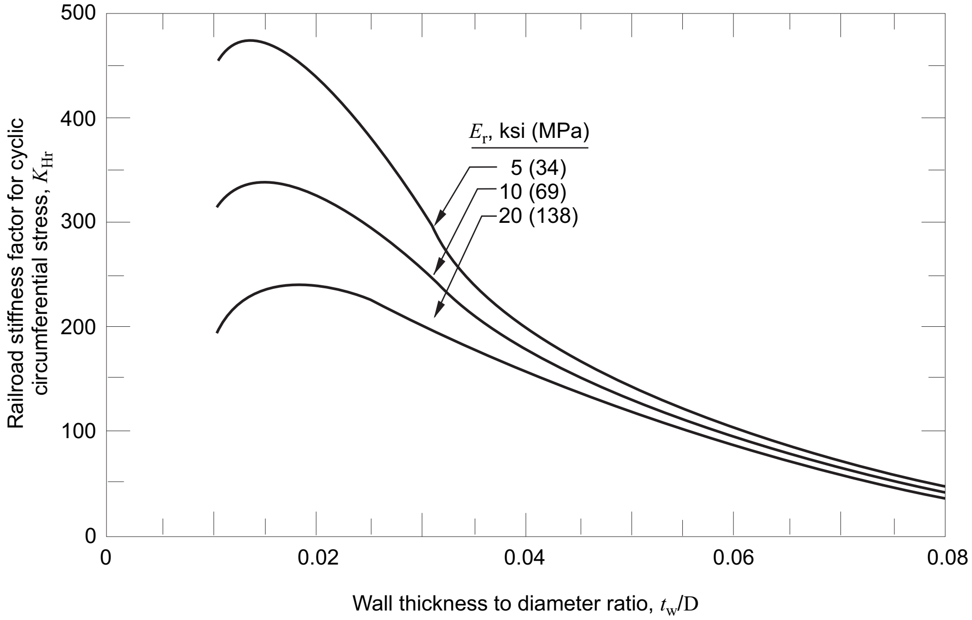


Figure 8—Railroad Stiffness Factor for Cyclic Circumferential Stress, K_{Hr}

The railroad geometry factor, G_{Hr}, is presented as a function of pipe diameter, D, and depth of burial, H, in Figure 9.

The single track factor for cyclic circumferential stress is, N_H = 1.00. The N_H factor for double track is shown in Figure 10.

4.7.2.2.3.2 The cyclic longitudinal stress due to rail load, ΔS_{Lr} (psi or kPa) may be calculated as follows:

$$\Delta S_{Lr} = K_{Lr} G_{Lr} N_L F_i w \tag{4}$$

where

K_{Lr} is the railroad stiffness factor for cyclic longitudinal stress.

G_{Lr} is the railroad geometry factor for cyclic longitudinal stress.

N_L is the railroad single or double track factor for cyclic longitudinal stress.

F_i is the impact factor.

w is the applied design surface pressure, in psi or kPa.

The railroad stiffness factor, K_{Lr}, is presented as a function of t_w/D and E_r in Figure 11.

The railroad geometry factor, G_{Lr}, is presented as a function of D and H in Figure 12.

The single track factor for cyclic longitudinal stress is N_L = 1.00. The N_L factor for double track is shown in Figure 13.

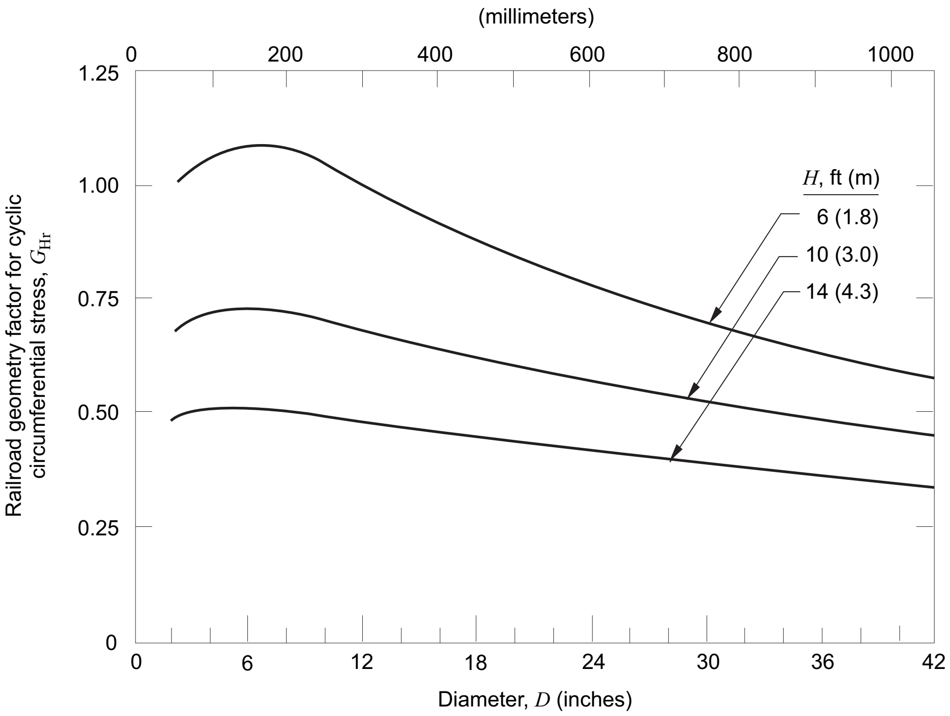


Figure 9—Railroad Geometry Factor for Cyclic Circumferential Stress, G_{Hr}

4.7.2.2.4 Highway Cyclic Stresses

4.7.2.2.4.1 The cyclic circumferential stress due to highway vehicular load, ΔS_{Hh} (psi or kPa), may be calculated from the following

$$\Delta S_{Hh} = K_{Hh} G_{Hh} R L F_i w \tag{5}$$

where

K_{Hh} is the highway stiffness factor for cyclic circumferential stress.

G_{Hh} is the highway geometry factor for cyclic circumferential stress.

R is the highway Pavement type factor.

L is the highway axle configuration factor.

F_i is the impact factor.

w is the applied design surface pressure, in psi or kPa.

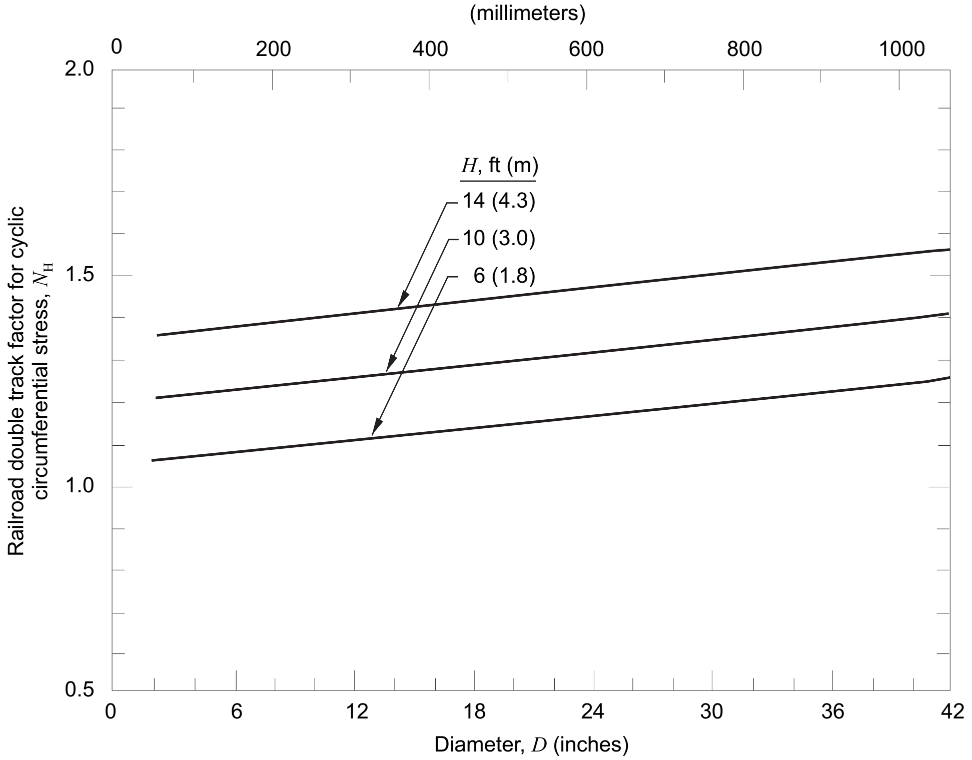


Figure 10—Railroad Double Track Factor for Cyclic Circumferential Stress, N_H

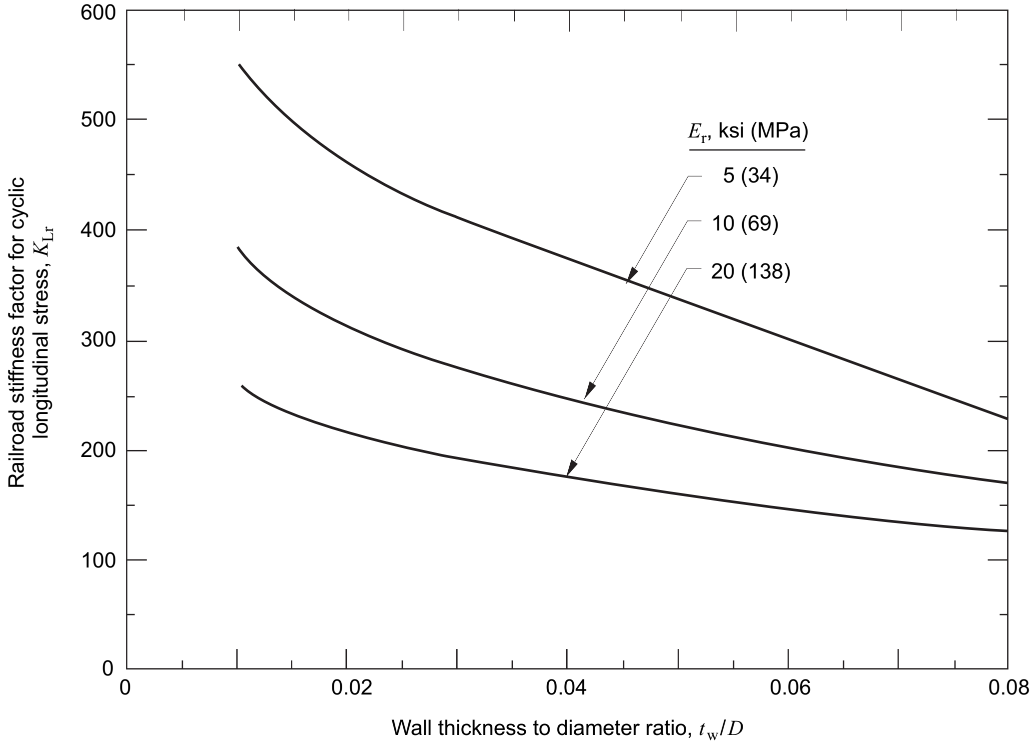


Figure 11—Railroad Stiffness Factor for Cyclic Longitudinal Stress, K_{Lr}

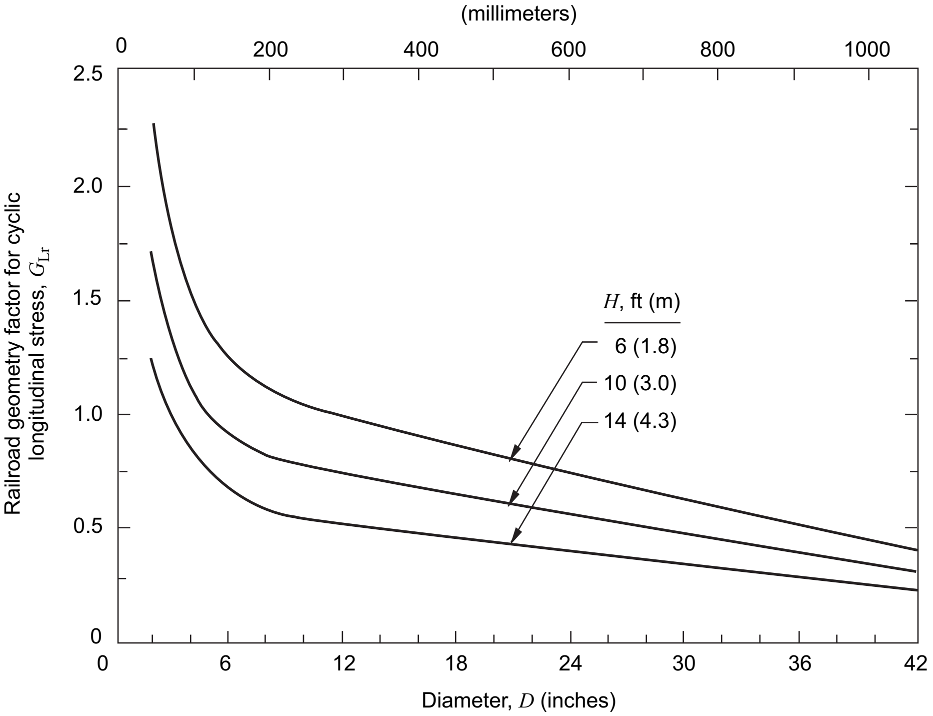


Figure 12—Railroad Geometry Factor for Cyclic Longitudinal Stress, G_{Lr}

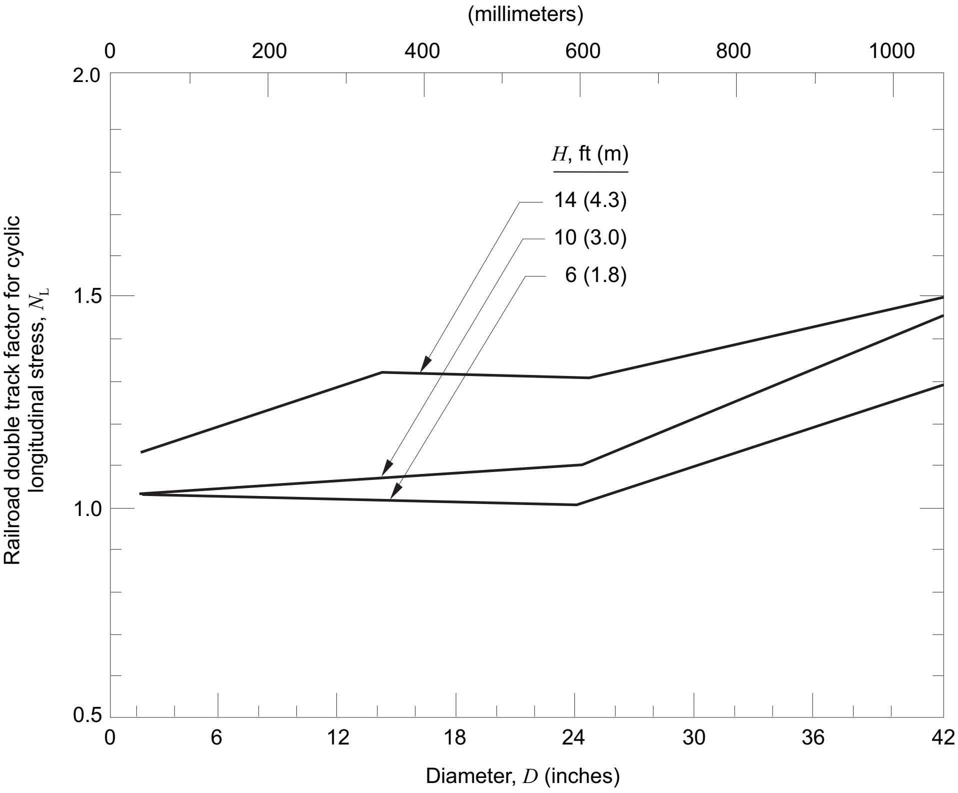


Figure 13—Railroad Double Track Factor for Cyclic Longitudinal Stress, N_L

The highway pavement type factor, R, and axle configuration factor, L, depend on the burial depth, H; pipe diameter, D; and design axle configuration (single or tandem). The decision on the design axle configuration has been described in 4.7.2.2.1. Table 2 presents the R and L factors for various H, D, pavement types, and axle configurations.

The highway stiffness factor, K_{Hh} is presented as a function of t_w/D and E_r in Figure 14.

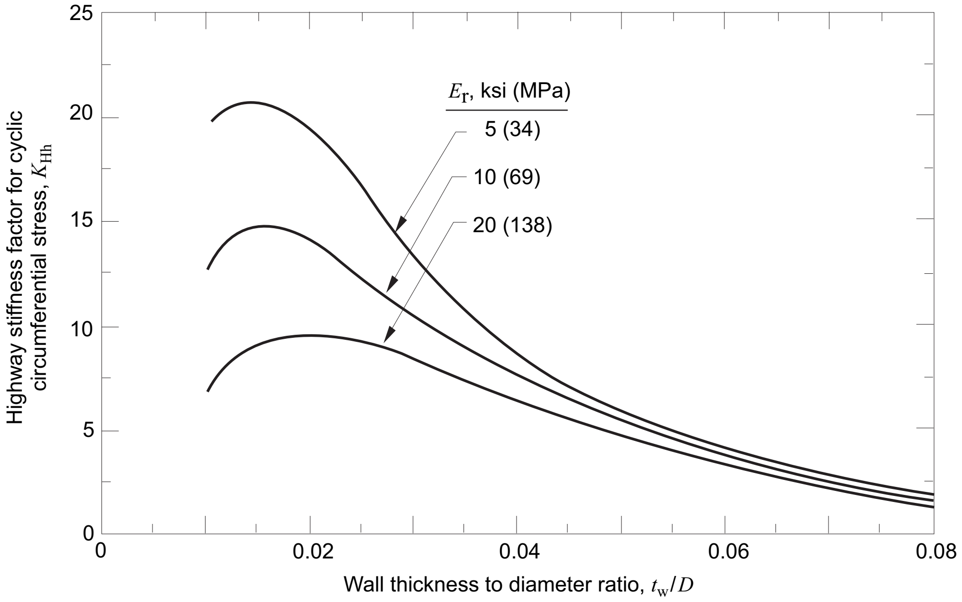


Figure 14—Highway Stiffness Factor for Cyclic Circumferential Stress, K_{Hh}

The highway geometry factor, G, is presented as a function of D and H in Figure 15.

4.7.2.2.4.2 The cyclic longitudinal stress due to highway vehicular load, ΔS_{Lh} (psi or kPa), may be calculated from the following:

$$\Delta S_{Lh} = K_{Lh} G_{Lh} R L F_i w \qquad (6)$$

where

K_{Lh} is the highway stiffness factor for cyclic longitudinal stress.

G_{Lh} is the highway geometry factor for cyclic longitudinal stress.

R is the highway pavement type factor.

L is the highway axle configuration factor.

F_i is the impact factor.

w is the applied design surface pressure, in psi or kPa.

The pavement type factor, R, and axle configuration factor, L, are the same as given in Table 2.

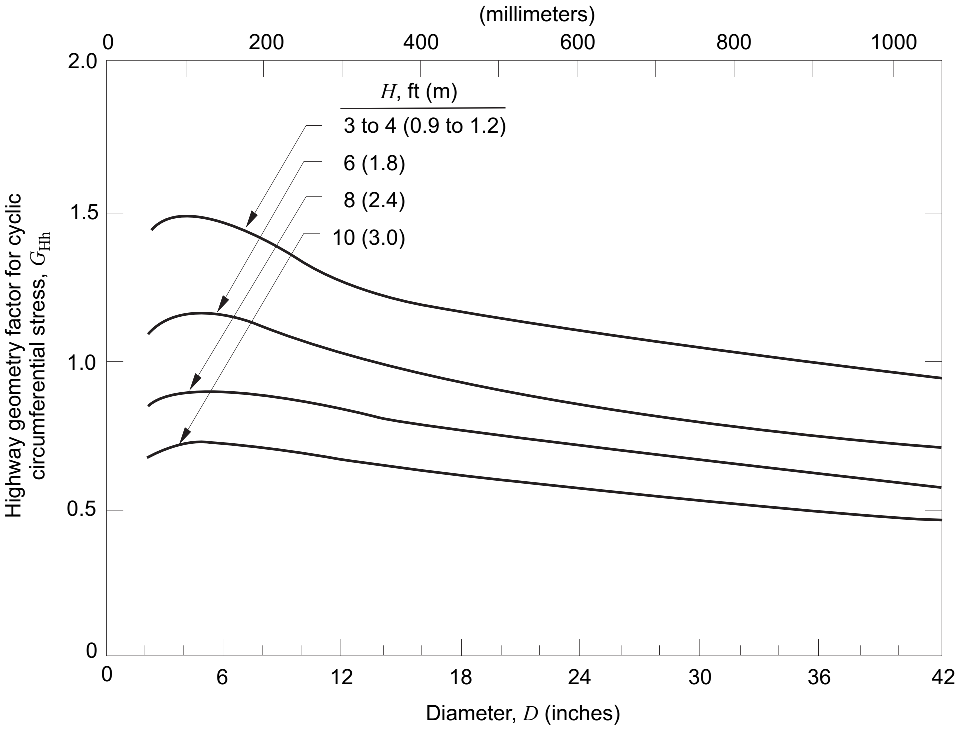


Figure 15—Highway Geometry Factor for Cyclic Circumferential Stress, G_{Hh}

The highway stiffness factor, K_{Lh}, is presented as a function of t_w/D and E_r in Figure 16.

The highway geometry factor, G_{Lh}, is presented as a function of D and H in Figure 17.

4.7.3 Stresses Due to Internal Load

The circumferential stress due to internal pressure, S_{Hi} (psi or kPa), may be calculated from the following:

$$S_{Hi} = p(D - t_w)/2t_w \tag{7}$$

where

p is the internal pressure, taken as the $MAOP$ or MOP, in psi or kPa.

D is the pipe outside diameter, in in. or mm.

t_w is the wall thickness, in in. or mm.

4.8 Limits of Calculated Stresses

The stresses calculated in 4.7 may not exceed certain allowable values. The allowable stresses for controlling yielding and fatigue in the pipeline are described in the following subsections.

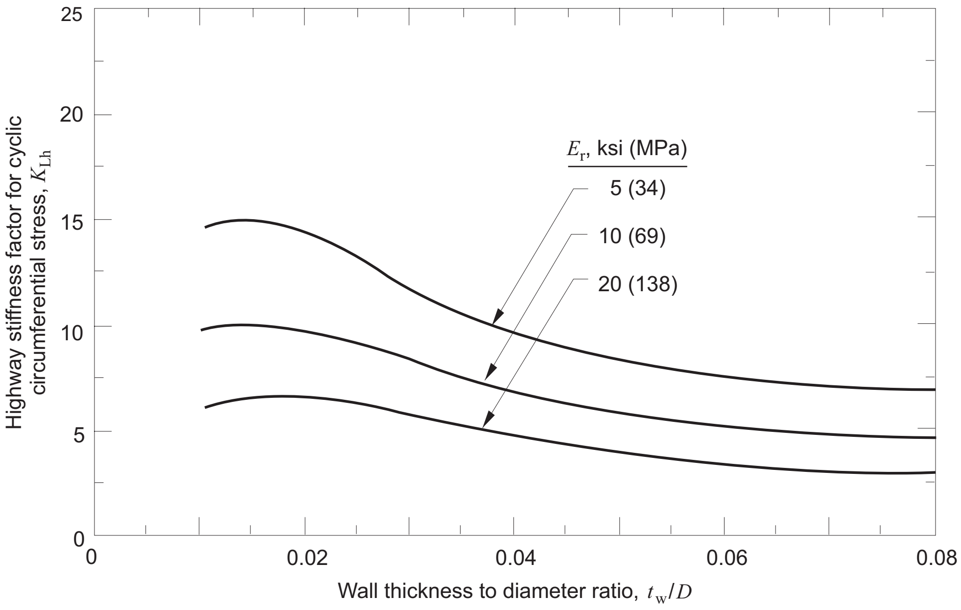


Figure 16—Highway Stiffness Factor for Cyclic Longitudinal Stress, K_{Lh}

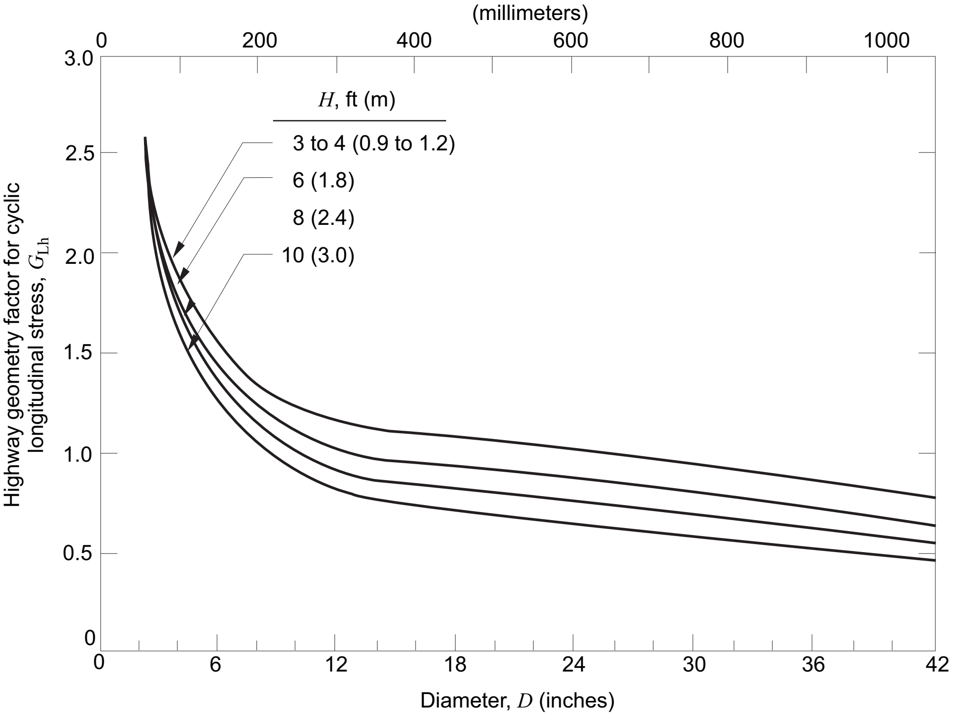


Figure 17—Highway Geometry Factor for Cyclic Longitudinal Stress, G_{Lh}

Table 2—Highway Pavement Type Factors, R, and Axle Configuration Factors, L

Depth, H, < 4 ft (1.2 m) and diameter, D, ≤ 12 in. (305 mm)			
Pavement Type	Design Axle Configuration	R	L
Flexible pavement	Tandem axle	1.00	1.00
	Single axle	1.00	0.75
No pavement	Tandem axle	1.10	1.00
	Single axle	1.20	0.80
Rigid pavement	Tandem axle	0.90	1.00
	Single axle	0.90	0.65
Depth, H, < 4 ft (1.2 m) and diameter, D, > 12 in. (305 mm) Depth H, ≥ 4 ft (1.2 m) for all diameters			
Pavement Type	Design Axle Configuration	R	L
Flexible pavement	Tandem axle	1.00	1.00
	Single axle	1.00	0.65
No pavement	Tandem axle	1.10	1.00
	Single axle	1.10	0.65
Rigid pavement	Tandem axle	0.90	1.00
	Single axle	0.90	0.65

4.8.1 Check for Allowable Stresses

4.8.1.1 Two checks for the allowable stress are required. The first is specified by 49 *Code of Federal Regulations* Part 192 or Part 195 [5, 6]. The circumferential stress due to internal pressurization, as calculated using the Barlow formula, S_{Hi} (Barlow) (psi or kPa), must be less than the factored specified minimum yield strength. This check is given by the following:

$$[S_{Hi}(\text{Barlow}) = pD/2t_w] \le F \times E \times T \times SMYS$$

for natural gas, and (8a)

$$[S_{Hi}(\text{Barlow}) = pD/2t_w] \le F \times E \times T \times SMYS$$

for liquids and other products (8b)

where

p is the internal pressure, taken as the $MAOP$ or MOP, in psi or kPa.

D is the pipe outside diameter, in in. or mm.

t_w is the wall thickness. in in. or mm.

F is the design factor chosen in accordance with 49 *Code of Federal Regulations* Part 192.111 or Part 195.106.

E is the longitudinal joint factor.

T is the temperature derating factor.

$SMYS$ is the specified minimum yield strength, in psi or kPa.

4.8.1.2 The second check for the allowable stress is accomplished by comparing the total effective stress, S_{eff} (psi or kPa), against the specified minimum yield strength multiplied by a design factor, F. Principal stresses, S_1, S_2, and S_3, (psi or kPa), are used to calculate S_{eff}. The principal stresses are calculated from the following:

$$S_1 = S_{\mathrm{He}} + \Delta S_{\mathrm{H}} + S_{\mathrm{Hi}} \tag{9}$$

where

S_1 is the maximum circumferential stress.

ΔS_{H} is ΔS_{Hr}, in psi or kPa, for railroads, and

is ΔS_{Hh}, in psi or kPa for highways.

$$S_2 = \Delta S_{\mathrm{L}} - E_{\mathrm{s}}\alpha_{\mathrm{T}}(T_2 - T_1) + \nu_{\mathrm{s}}(S_{\mathrm{He}} + S_{\mathrm{Hi}}) \tag{10}$$

where

S_2 is the maximum longitudinal stress.

ΔS_{L} is ΔS_{Lr} in psi or kPa, for railroads, and

is ΔS_{Lh} in psi or kPa, for highways.

E_{s} is Young's modulus of steel, in psi or kPa.

α_{T} is the coefficient of thermal expansion of steel, per °F or per °C.

T_1 is the temperature at time of installation, in °F or °C.

T_2 is the maximum or minimum operating temperature, in °F or °C.

v_{s} is Poisson's ratio of steel.

NOTE Table A-3, in Annex A gives typical values for E_{s}, v_{s} and α_{T}.

$$S_3 = -p = -MAOP \text{ or } -MOP \tag{11}$$

where

S_3 is the maximum radial stress.

NOTE The Poisson effects from S_{He} and S_{Hi} are reflected in S_2 as v_{s} (S_{He} + S_{Hi}). The Poisson effect of ΔS_{L} on S_1 is not directly represented in the equation for S_1. The values of ΔS_{H} and ΔS_{L} in this recommended practice were derived from finite element analyses, thus they already embody the appropriate Poisson effects.

4.8.1.3 The total effective stress, S_{eff} (psi or kPa), may be calculated from the following:

$$S_{\mathrm{eff}} = \sqrt{\frac{1}{2}[(S_1 - S_2)^2 + (S_2 - S_3)^2 + (S_3 - S_1)^2]} \tag{12}$$

The check against yielding of the pipeline may be accomplished by assuring that the total effective stress is less than the factored specified minimum yield strength, using the following equation:

$$S_{\mathrm{eff}} \leq SMYS \times F \tag{13}$$

where

$SMYS$ is the specified minimum yield strength, in psi or kPa.

F is the design factor.

The designer should use values for the design factor, F, consistent with standard practice or code requirements.

4.8.2 Check for Fatigue

The check for fatigue is accomplished by comparing a stress component normal to a weld in the pipeline against an allowable value of this stress, referred to as a fatigue endurance limit. These limits have been determined from S-N (fatigue strength versus number of load cycles) data [14, 15], and the minimum ultimate tensile strengths as given in API Specification 5L [16].

4.8.2.1 Girth Weld

The cyclic stress that must be checked for potential fatigue in a girth weld located beneath a railroad or highway crossing is the longitudinal stress due to live load. The design check is accomplished by assuring that the live load cyclic longitudinal stress is less than the factored fatigue endurance limit. The fatigue endurance limit of girth welds is taken as 12,000 psi (82,740 kPa), as shown in Table 3 for all steel grades and weld types..

Table 3—Fatigue Endurance Limits, S_{FG}, and S_{FL}, for Various Steel Grades

Steel Grade	$SMYS$ (psi)	Minimum Ultimate Tensile Strength (psi)	S_{FG} (psi)	S_{FL} (psi)	
			All welds	Seamless and ERW	SAW
A25	25000	45000	12000	21000	12000
A	30000	48000	12000	21000	12000
B	35000	60000	12000	21000	12000
X42	42000	60000	12000	21000	12000
X46	46000	63000	12000	21000	12000
X52	52000	66000	12000	21000	12000
X56	56000	71000	12000	23000	12000
X60	60000	75000	12000	23000	12000
X65	65000	77000	12000	23000	12000
X70	70000	82000	12000	25000	13000
X80	80000	90000	12000	27000	14000
NOTE 1 pound per square inch (psi) = 6.895 kilopascals (kPa).					

The general form of the design check against girth weld fatigue is given by the following:

$$\Delta S_L \leq S_{FG} \times F \tag{14}$$

where

ΔS_L is ΔS_{Lr}, in psi or kPa, for railroads, and

is ΔS_{Lh} in psi or kPa, for highways.

S_{FG} is the fatigue endurance limit of girth yield = 12,000 psi (82,740 kPa).

F is the design factor

4.8.2.1.1 Railroad Crossing

4.8.2.1.1.1 Equation 14 is the general form of the girth weld fatigue check. Since the value of $\Delta S_L = \Delta S_{Lr}$ is influenced by whether a single or double track crossing was selected, this must be accounted for in the fatigue checks. It is overly conservative to assume that all of the applied load cycles will be those generated by simultaneous loading of both tracks, with the train wheel sets always in phase directly above the crossing. Therefore, the cyclic longitudinal stress used in the girth weld fatigue check at railroad crossings is based on the live load stress from a single track loading situation. The resulting equation is given by the following:

$$\Delta S_{Lr}/N_L \leq S_{FG} \times F \tag{15}$$

where

ΔS_{Lr} is the cyclic longitudinal stress determined from Equation 4, in psi or kPa.

N_L is the single or double track factor used in Equation 4 (see note).

S_{FG} is the fatigue endurance limit of girth weld = 12,000 psi (82,740 kPa).

F is the design factor.

NOTE N_L = 1.00 for single track crossings.

4.8.2.1.1.2 Equation 15 is applicable to railroad crossings in which a girth weld is located at a distance, L_G less than 5 ft (1.5 m) from the centerline of the track. For other locations of a girth weld. Equation 15 is replaced by the following:

$$R_F \Delta S_{Lr}/N_L \leq S_{FG} \times F \tag{16}$$

where

R_F is the longitudinal stress reduction factor for fatigue.

R_F is obtained from Figures 18-A and 18-B. Figure 18-A is for values of L_G greater than or equal to 5 ft (1.5 m) but less than 10 ft (3 m). Figure 18-B is for values of L_G greater than or equal to 10 ft (3 m).

4.8.2.1.2 Highway Crossing

Longitudinal stress reduction factors to account for girth weld locations are not used, nor are double lane factors used, since adjacent truck loadings already are considered in the design curves. The cyclic longitudinal stress for highway crossings is determined using Equation 6. The girth weld fatigue check is given by the following:

$$\Delta S_{Lh} \leq S_{FG} \times F \tag{17}$$

4.8.2.2 Longitudinal Weld

4.8.2.2.1 The cyclic stress that must be checked for potential fatigue in a longitudinal weld located beneath a railroad or highway crossing is the circumferential stress due to live load. The check may be accomplished by assuring that the live load cyclic circumferential stress is less than the factored fatigue endurance limit.

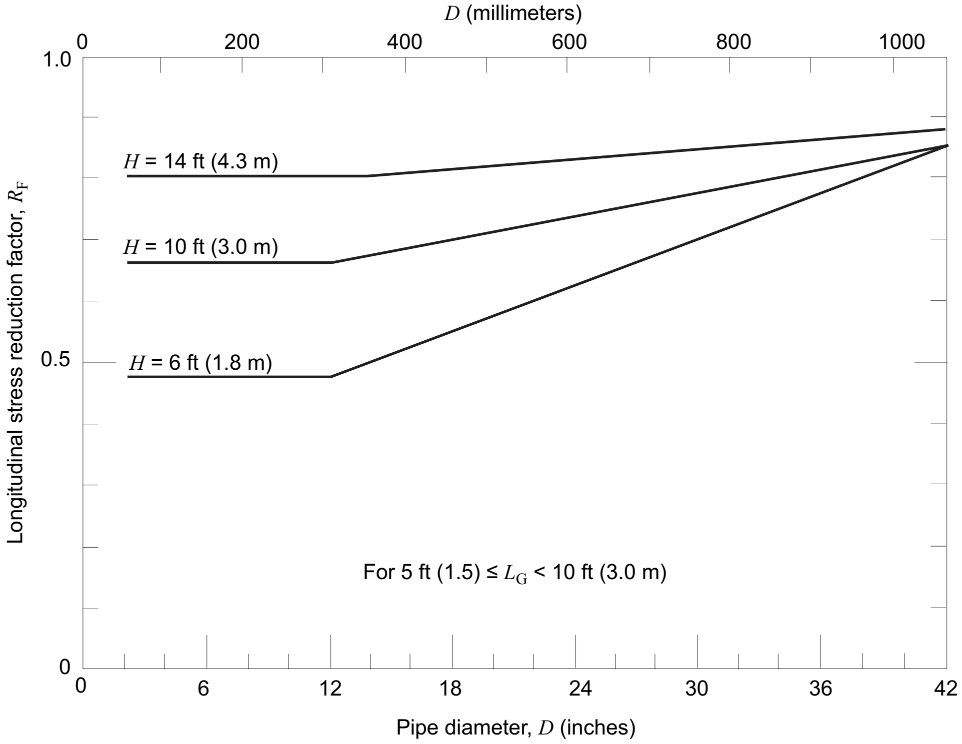


Figure 18-A—Longitudinal Stress Reduction Factors, R_F, for L_G Greater Than or Equal to 5 ft (1.5 m) but Less Than 10 ft (3 m)

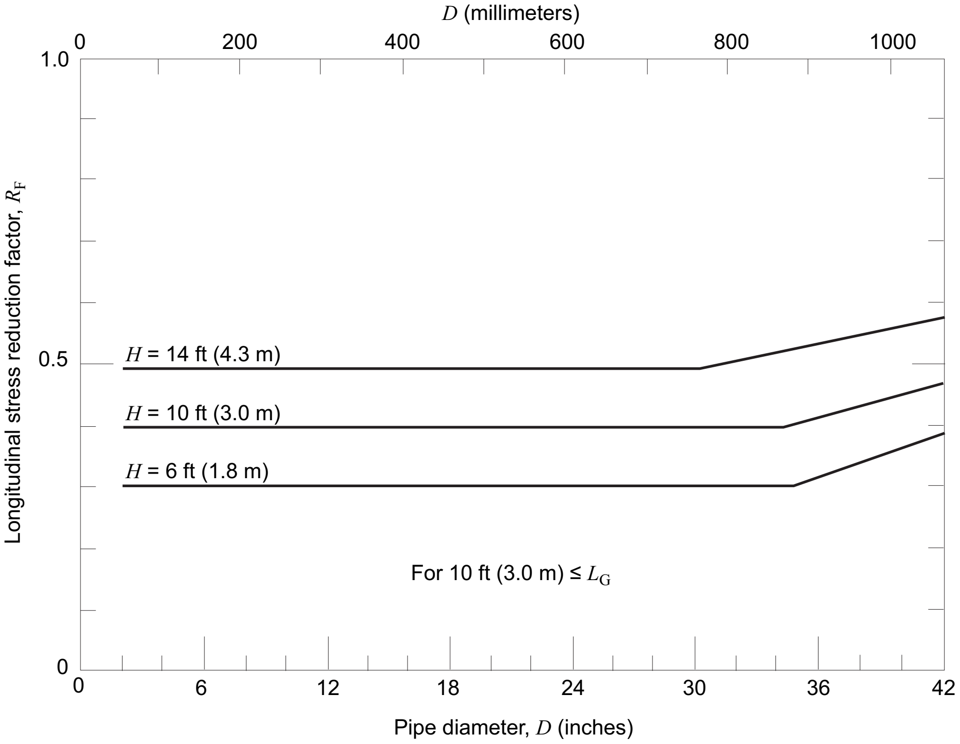


Figure 18-B—Longitudinal Stress Reduction Factors, R_F, for L_G Greater Than or Equal to 10 ft (3 m)

The fatigue endurance limit of longitudinal welds, S_{FL}, is dependent on the type of weld and the minimum ultimate tensile strength. Table 3 gives the fatigue endurance limits for seamless, ERW, and SAW longitudinal welds made in various grade steels. For $SMYS$ values intermediate to those listed in Table 3, the fatigue endurance limits for the closest $SMYS$ listed that is lower than the particular intermediate value should be used. For example, if the $SMYS$ is 54,000 psi (372 mPa), the fatigue endurance limits for X52 grade steel would be used.

The general form of the design check most longitudinal weld fatigue is as follows:

$$\Delta S_H \leq S_{\mathrm{FL}} \times F \tag{18}$$

where

ΔS_{H} is ΔS_{Hr}, in psi or kPa, for railroads, and

is ΔS_{Hh}, in psi or kPa, for highways.

S_{FL} is the fatigue endurance limit of longitudinal weld obtained from Table 3, in psi or kPa.

F is the design factor.

4.8.2.2.2 Railroad Crossing

Equation 18 is the general form of the longitudinal weld fatigue check. As described in 4.8.2.1.1 dealing with girth weld fatigue at railroad crossings, it is overly conservative to use double track cyclic stresses for fatigue purposes. Therefore, the cyclic circumferential stress used in the longitudinal weld fatigue check at railroad crossings is the live load stress from a single track loading situation. The resulting equation is as follows:

$$\Delta S_{\mathrm{Hr}} / N_{\mathrm{H}} \leq S_{\mathrm{FL}} \times F \tag{19}$$

where

ΔS_{Hr} is the cyclic circumferential stress determined from Equation 3, in psi or kPa.

N_{H} is the single or double track factor used in Equation 3 (see note).

S_{FL} is the fatigue endurance limit of longitudinal weld obtained from Table 3, in psi or kPa.

F is the design factor.

NOTE N_{H} = 1.00 for single track crossings.

4.8.2.2.3 Highway Crossing

The cyclic circumferential stress for highway crossings is determined using Equation 5. The longitudinal weld fatigue check is as follows:

$$\Delta S_{\mathrm{Hh}} \leq S_{\mathrm{FL}} \times F \tag{20}$$

Double lane factors are not used in the highway fatigue check since the design curves take adjacent truck loadings into account. The longitudinal weld fatigue endurance limits are given in Table 3.

4.9 Orientation of Longitudinal Welds at Railroad and Highway Crossings

The design checks against longitudinal weld fatigue in this recommended practice are based on the maximum value of the cyclic circumferential stress, ΔS_H. Thus, if the design check against longitudinal weld fatigue is satisfactory, locating the weld at any location is acceptable. However, it may be advantageous to consider the circumferential orientation of the pipeline welds during construction. The optimal location of all longitudinal welds is at the 45, 135, 225, or 315 degree position with the crown at the zero degree position. For any of these orientations, Equations 3 and 5 will predict conservative values of cyclic circumferential stress. Accordingly, these optimal weld locations listed provide an additional margin of safety against longitudinal weld fatigue.

4.10 Location of Girth Welds at Railroad Crossings

The optimal location of a girth weld at railroad crossings is at a distance, L_G, of at least 10 ft (3 m) from the centerline of the track for a single track crossing. As indicated in 4.8.2.1.1, substantial reductions in the value of applied cyclic longitudinal stress may be obtained in this case. No reduction factor should be taken for the fatigue check when evaluating pipeline crossings beneath two or more adjacent tracks. No reduction factor should be taken for the fatigue check associated with highway crossings. The variable positioning of highway traffic makes it impractical to locate girth welds for minimum cyclic loading effects.

5 Cased Crossings

5.1 Carrier Pipe Installed within a Casing

Design procedures for casings beneath railroad and highway crossings have been established and used in practice for many years. The relevant specifications for selecting minimal wall thickness in casings under railroads are given by the American Railway Engineering Association [11], and design practices suitable for casings beneath railroads and highways are provided by the American Society of Civil Engineers [13] and the American Society of Mechanical Engineers [8, 9, 12]. Carrier pipe for cased crossings should conform to the material and design requirements of the latest edition of ASME B31.4 or B3.1.8. Casings may be coated or bare.

5.2 Casings for Crossings

Suitable materials for casings are new or used line pipe, mill reject pipe, or other available steel tubular goods, including longitudinally split casings.

5.3 Minimum Internal Diameter of Casing

The inside diameter of the casing pipe should be large enough to facilitate installation of the carrier pipe, to provide proper insulation for maintenance of cathodic protection, and to prevent transmission of external loads from the casing to the carrier pipe. The casing pipe should be at least two nominal pipe sizes larger than the carrier pipe.

5.4 Wall Thickness

5.4.1 Bored Crossings

The minimum nominal wall thickness for steel casing pipe in bored crossings should equal or exceed the values shown in Annex C.

5.4.2 Open Trenched Crossings

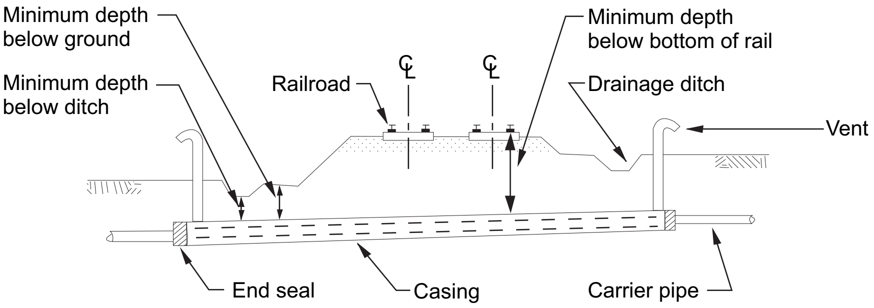
If the requirements of 5.7 are fulfilled at open cut or trenched installations, the minimum nominal wall thickness for steel casing for bored crossings in Annex C may be used. If the requirements of 5.7 cannot be met, installation of casing at greater depths, the use of heavier wall casing pipe, stabilized backfill, or other accepted methods should be utilized.

5.5 General

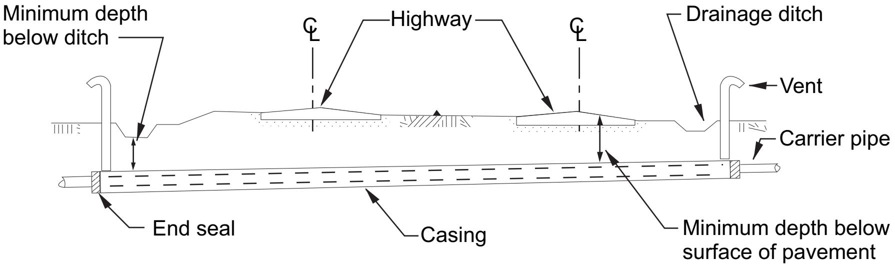
5.5.1 The casing pipe should be free of internal obstructions, should be as straight as practicable, and should have a uniform bedding for the entire length of the crossing. In addition to being properly compactable, padding and backfill must be of appropriate quality to prevent damage to pipeline and/or casing coatings.

5.5.2 The casing pipe should be installed with an overbore as small as possible so as to minimize the void between the pipe and the adjacent soil.

5.5.3 Steel casing pipe should be joined completely to ensure a continuous casing from end to end.



RAILROAD CROSSING



HIGHWAY CROSSING

NOTE For simplicity, drawing does not include insulators/spacers (5.8 and 5.11) or test stations (6.3.6)

Figure 19—Examples of Cased Crossing Installations

5.6 Location and Alignment

5.6.1 Where casing pipe is installed, it should extend a minimum of 2 ft (0.6 m) beyond the toe of slope or base grade, 3 ft (0.9 m) beyond the bottom of the drainage ditch, whichever is greater (see Figure 19). Additionally for railroad crossings, the casing pipe should extend a minimum distance of 25 ft (7.6 m) each side from centerline of outside track when casing is sealed at both ends, or a minimum distance of 45 ft (13.7 m) each side of the centerline of the outside track when casing is open at both ends.

5.6.2 The angle of intersection between pipeline crossings and the railroad or highway to be crossed should be as near to 90 degrees as practicable. In no case should it be less than 30 degrees.

5.6.3 Crossings in wet or rock terrain, and where deep cuts are required, should be avoided where practicable.

5.6.4 Vertical and horizontal clearances between the pipeline and a structure or facility in place must be sufficient to permit maintenance of the pipeline and the structure or facility.

5.7 Cover

5.7.1 Railroad Crossings

Casing pipe under railroads should be installed with a minimum cover, as measured from the top of the pipe to the base of the rail, as follows (see Figure 19):

Location	Minimum Cover
a) Under track structure proper, except secondary and industry tracks.	5.5 ft (1.7 m)
b) Under track structure proper for secondary and industry tracks.	4.5 ft (1.4 m)
c) Under all other surfaces within the right-of-way or from bottom of ditches.	3 ft (0.9 m)
d) For pipelines transporting HVL, from the bottom of ditches.	4 ft (1.2 m)

5.7.2 Highway Crossings

Casing pipe under highways should be installed with a minimum cover, as measured from the top of the pipe to the top of the surface as follows (see Figure 19):

Location	Minimum Cover
a) Under highway surface proper.	4 ft (1.2 m)
b) Under all other surfaces within the right-of-way.	3 ft (0.9 m)
c) For pipelines transporting HVL, from the bottom of ditches.	4 ft (1.2 m)

5.7.3 Mechanical Protection

If the minimum coverage set forth in 5.7.1 and 5.7.2 cannot be provided, mechanical protection shall be installed.

5.8 Installation

5.8.1 Carrier pipe installed in a casing should be held clear of the casing pipe by properly designed supports, insulators, or other devices, and installed so that no external load will be transmitted to the carrier pipe. This also may be accomplished by building up a ring of layers of coating and outer wrap, or by a concrete jacket. Where manufactured insulators are used, they should be uniformly spaced and securely fastened to the carrier pipe.

5.8.2 Multiple carrier pipes may be installed with one casing pipe where restricted working areas, structural difficulties, or special needs are encountered. The stipulations in the above paragraph should apply, and each carrier pipe should be insulated from other carrier pipes, as well as from the casing pipe.

5.9 Casing Seals

The casing should be fitted with end seals at both ends to reduce the intrusion of water and fines from the surrounding soil. It should be recognized that a water-tight seal may not always be possible under field conditions, and in some circumstances water infiltration should be anticipated. The seal should be formed with a flexible material that will inhibit the formation of a waterway through the casing,

5.10 Casing Vents

5.10.1 Vents are not required on casings.

5.10.2 One or two vent pipes may be installed, if used, vent pipe should be not less than 2 in. (51 mm) in diameter, should be welded to the casing, and should project through the ground surface at the right-of-way line or fence line (see Figure 19). A hole through the casing not less than one-half the vent pipe diameter must be made prior to welding the casing vent over it.

5.10.3 Vent pipe should extend not less than 4 ft (1.2 m) above the ground surface. The tops of vents should be fitted with suitable weather caps.

5.10.4 Two vent pipes maybe installed to facilitate filling the casing with a “casing filler” by connecting the vent pipe at the low end of the casing to the bottom of the casing and connecting the vent pipe at the high end of the casing to the top of the casing.

5.11 Insulators

Insulators electrically isolate the carrier pipe from the casing by providing a circular enclosure that prevents direct contact between the two. The insulator should be designed to promote minimal bearing pressure between the insulator and carrier coating.

5.12 Inspection and Testing

Supervision and inspection should be provided during construction of the crossing. Before installation, the section of carrier pipe used at the crossing should be inspected visually for defects. All girth welds should be inspected by radiographic or other nondestructive methods. After a cased crossing is installed, a test should be performed to determine that the carrier pipe is electrically isolated from the casing pipe.

6 Installation

6.1 Trenchless Installation

6.1.1 General

Pipe jacking with an auger borer is the predominant means in U.S. practice of pipeline installation beneath railroads and highways. Percussive molding also is used but is restricted to small pipelines, typically less than 6 in. (150 mm) in diameter. For trenchless construction techniques that excavate an oversized hole relative to the size of the pipe, the diameter of the bored hole, B_d, needs to be known or specified before construction. By means of Figure 5, the designer can account for the influence of the bored hole diameter, B_d, on the earth load transmitted to the pipe.

When the auger is adjusted to excavate a hole equal in size to the pipe, or when percussive molding or a similar insertion method is used, the designer should assume that the bored diameter is equal to the pipe diameter, $B_d = D$.

6.1.2 Boring, Jacking, or Tunneling

6.1.2.1 Auger boring for a pipeline crossing often is performed with an auger that is a fraction of an inch to as much as 2 in. (51 mm) larger in diameter than the pipe, under circumstances in which the auger is advanced in front of the casing. Modifications of the method, such as reducing the auger size and fitting the pipe or casing with stops to prevent the auger from leading the pipe, can substantially reduce overexcavation. Reduction in the amount of overexcavation will decrease the chances of disturbing the surrounding soil and overlying facility and can diminish the amount of earth load imposed on the pipe. It should be recognized, however, that reductions in overcutting generally will increase frictional and adhesive resistance to the advance of the pipe. It may be necessary, therefore, to require trackmounted equipment in the launching pit with a suitable end bearing wall so that adequate jacking forces can be mobilized. For long or sensitive crossings, the use of bentonite slurry to lubricate the jacked pipe may be helpful.

6.1.2.2 The following provisions apply to bored, jacked, or tunneled crossings:

a) The diameter of the hole for bored or jacked installations should not exceed by more than 2 in. (51 mm) the outside diameter of the carrier pipe (including coating). In tunneled installations, the annular space between the outside of the pipe and the tunnel should be held to a minimum.

b) Where unstable soil conditions exist, boring, jacking, or tunneling operations should be conducted in a manner that will not be detrimental to the facility to be crossed.

c) If too large a hole results or if it is necessary to abandon a bored, jacked, or tunneled hole, prompt remedial measures should be taken to provide adequate support for the facility to be crossed.

6.1.3 Excavation

The pipe is jacked from an excavation, referred to as a launching pit, into an excavation, referred to as a receiving pit. Both the launching and receiving pits should be excavated and supported in accordance with applicable regulations to ensure the safety of construction personnel and to protect the adjacent railroad or highway.

6.1.4 Backfilling

Carefully placing and compacting the backfill under the carrier pipe in the launching and receiving pits helps reduce the settlement of the carrier pipe adjacent to the crossing. This, in turn, decreases the bending stress in the carrier pipe where it enters the backfilled launching and receiving pits. Good backfilling practice includes, but is not limited to, removing remolded and disturbed soil from the bedding of the carrier pipe and placing fill compacted in sufficiently small lifts to achieve a dense bedding for the carrier. Earth- or sand-filled bags or other suitable means should be used to firmly support the carrier pipe adjacent to the crossing prior to backfill. Support materials subject to biological attack, such as wooden blocking, may decompose and increase the chance of local corrosion.

6.2 Open Cut or Trenched Installation

6.2.1 General Conditions

6.2.1.1 Work on all trenched crossings from ditching to restoration of road surface should be scheduled to minimize interruption of traffic.

6.2.1.2 Where an open cut is used, the trench shall be sloped or shored in accordance with Occupational Safety and Health Administration (OSHA) requirements. The pipe as laid should be centered in the ditch so as to provide equal clearance on both sides between the pipe and the sides of the ditch.

6.2.1.3 The bottom of the trench should be prepared to provide the pipe with uniform bedding throughout the length of the crossing. In addition to being properly compactable, padding and backfill must be of appropriate quality to prevent damage to pipeline and/or casing coatings.

6.2.2 Backfill

Backfill should be compacted sufficiently to prevent settlement detrimental to the facility to be crossed. Backfill should be placed in layers of 12 in. (305 mm) or less (uncompacted thickness) and compacted thoroughly around the sides and over the pipe to densities consistent with that of the surrounding soil. Trench soil used for backfill (or a substituted backfill material) must be capable of producing the required compaction. In addition to being properly compactable, padding and backfill must be of appropriate quality to prevent damage to pipeline and/or casing coatings.

6.2.3 Surface Restoration

The surface of pavement that has been cut should be restored promptly in accordance with the appropriate highway or railroad authority's specifications.

6.3 General

The considerations listed in 6.3.1 through 6.3.7 apply to trenchless and open cut pipeline installation, irrespective of uncased or cased crossings.

6.3.1 Construction Supervision

Construction should be supervised by personnel qualified to oversee the welding of line pipe and the types of pipeline installation referred to in 6.1 and 6.2. The work should be coordinated, and close communication should be maintained between construction supervisors in the field and authorized agents of the railroad or highway to be crossed. Precautionary measures should be taken when transporting construction equipment across railroads and highways. Railroad and highway facilities should be protected at all times, and drainage ditches should be maintained to avoid flooding or erosion of the roadbed and adjacent properties.

6.3.2 Inspection and Testing

Inspection should be provided during the construction of the crossing. Before installation, the section of carrier pipe used at the crossing should be inspected visually for defects.

6.3.3 Welding

Carrier pipe at railroad or highway crossings should be welded with welding procedures developed in accordance with the latest approved edition of API Standard 1104, *Welding, of Pipelines and Related Facilities* [7]. Nondestructive testing in accordance with the aforementioned specification is required for all girth welds beneath or adjacent to the crossing. At uncased crossings, nondestructive testing normally will be required for girth welds within a horizontal distance of 50 ft (15 m) from either the outside or inside rail and from either the outside or inside highway pavement line. For cased crossings, the same applies for welds within 50 ft (15 m) of the end seals of the casing.

6.3.4 Pressure Testing

The carrier pipe section should be pressure tested before startup in accordance with 49 *CFR*, Part 192 or Part 195 requirements.

6.3.5 Pipeline Markers and Signs

Pipeline markers and signs should be installed as set forth in the latest approved edition of API Recommended Practice 1109, *Marking, Liquid Petroleum Pipeline Facilities* [17].

6.3.6 Cathodic Protection

6.3.6.1 Cathodic protection systems at cased crossings should be reviewed carefully. Casings may reduce or eliminate the effectiveness of cathodic protection. The introduction of a casing creates a more complicated electrical system than would prevail for uncased crossings, so there may be difficulties in securing and interpreting cathodic protection measurements at cased crossings. Test stations with test leads attached to the carrier pipe and casing pipe should be provided at each cased crossing.

6.3.6.2 A cased carrier pipe can be exposed to atmospheric corrosion as a result of air circulation through vents attached to the casing and moisture condensation in the casing annulus. A proper coating, jeep testing, proper spacing and end seals reduce the potential for atmospheric corrosion or electrical shorts. This problem may be minimized by filling the casing with a high dielectric casing filler, corrosion inhibitor, or inert gas. This is most easily accomplished immediately after construction.

6.3.7 Pipe Coatings

Pipeline coatings should be selected with due consideration of the construction technique and the abrasion and contact forces associated with pipeline installation. There are a variety of coatings that are tough and exhibit good resistance to surface stress, moisture adsorption, and cathodic disbondment. In areas where damage to the protective coating is likely, consideration should be given to applying an additional protective coating, such as concrete, over the carrier pipe coating prior to installation.

7 Railroads and Highways Crossing Existing Pipelines

7.1 Adjustment of Pipelines at Crossings

If an existing pipeline at a proposed railroad or highway crossing complies with the requirements of this practice, no adjustment of the pipeline is necessary. However, other considerations outside the scope of this recommended practice may necessitate an adjustment to an existing pipeline. If adjustments are required, the pipeline crossing should be lowered, repaired, reconditioned, replaced, or relocated in accordance with this practice.

7.2 Adjustment of In-service Pipelines

7.2.1 Lowering Operations

If lowering of the pipeline at a crossing in place is required, care should be exercised during the design phase and the lowering operation to prevent undue stress on the pipeline, in accordance with the latest approved edition of API Recommended Practice 1117, *Lowering In-Service Pipelines* [18]. The pipeline should be uncovered for a sufficient distance on either side of the crossing so that the carrier pipe may be uniformly lowered to fit the ditch at the required depth by natural sag. All movements of liquid petroleum pipelines should comply with the U.S. Department of Transportation’s required maximum operating pressures, as contained in 49 *Code of Federal Regulations* Part 195 [6].

7.2.2 Split Casings

Where stress due to external loads of the railroad or highway necessitates casing of a pipeline, the casing may be installed by using the split casing method. This method provides for cutting the casing into two longitudinal segments and welding the segments together over the carrier pipe after the coating is repaired and casing insulators are installed. Precautions should be taken to prevent weld splatter from the welding operation from causing damage to the carrier pipe coating or the insulating spacers.

7.2.3 Temporary Bypasses

A temporary bypass utilizing suitable mechanical means to isolate the section to be adjusted may be installed to avoid interruption of service.

7.3 Adjustments of Pipelines Requiring Interruption of Service

When a pipeline cannot be taken out of service for more than a few hours for a required adjustment, a new separate crossing generally is constructed. In such cases, the only shutdown required is the time necessary for making the tie in connections of the new pipeline to the existing line.

7.4 Protection of Pipelines During Highway or Railroad Construction

An agreement between the pipeline company and the party constructing the crossing should be made to protect the pipeline from excessive loads or damage from grading (cut or fill) by work equipment during the construction of the railroad or highway. The pipeline alignment should be clearly marked with suitable flags, stakes, or other markers at the crossing. This recommended practice should be used to determine expected stresses on the pipeline. As necessary, suitable bridging, reinforced concrete slabs, or other measures should be employed to protect the pipeline.

Annex A

Supplemental Material Properties and Uncased Crossing Design Values

This annex contains tables and figures on material properties and design values that give supplemental information to that contained in the body of this recommended practice.

A.1 Tables of Typical Values

Table A-1—Typical Values for Modulus of Soil Reaction, E'

Soil Description	E', ksi (MPa)
Soft to medium clays and silts with high plasticities	0.2 (1.4)
Soft to medium clays and silts with low to medium plasticities; loose sands and gravels	0.5 (3.4)
Stiff to very stiff clays and silts; medium dense sands and gravels	1.0 (6.9)
Dense to very dense sands and gravels	2.0 (13.8)

Table A-2—Typical Values for Resilient Modulus, E_r

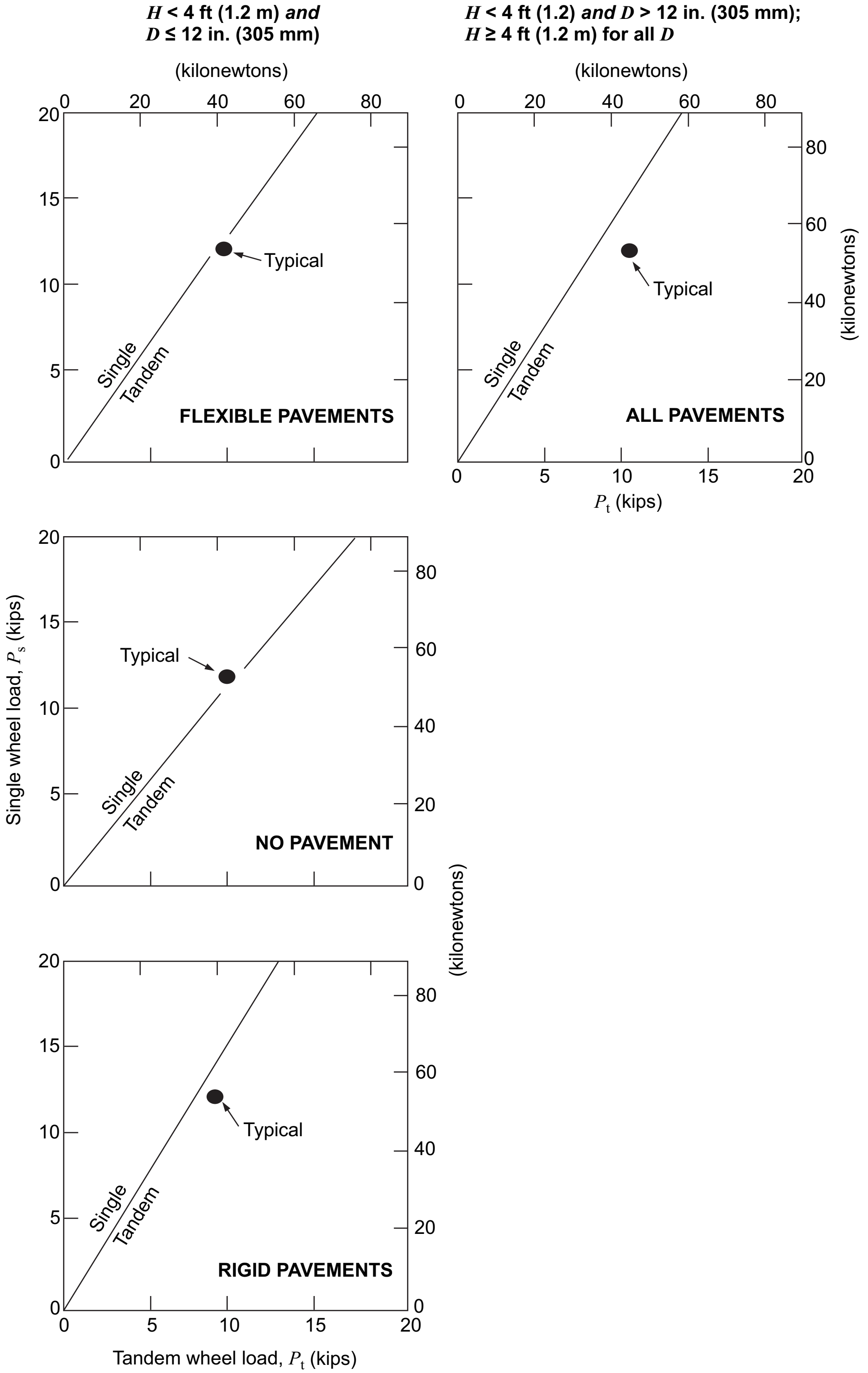
Soil Description	E_r, ksi (MPa)
Soft to medium clays and silts	5 (34)
Stiff to very stiff clays and silts; loose to medium dense sands and gravels	10 (69)
Dense to very dense sands and gravels	20 (138)

Table A-3—Typical Steel Properties

Property	Typical Range
Young's modulus, E_s, psi (kPa)	$28 – 30 \times 10^6$ $(1.9 – 2.1 \times 10^8)$
Poisson's ratio, v_s	0.25 – 0.30
Coefficient of thermal expansion, α_T, per °F (per °C)	$6 – 7 \times 10^{-6}$ $(1.6 – 1.9 \times 10^{-5})$

A.2 Critical Highway Axle Configurations

For design wheel loads different from the recommended maximums of P_s = 12 kips (53.4 kN) and P_t = 10 kips (44.5 kN), the critical axle configuration may be different than given in Table 1. Figure A-1 is used to determine whether single or tandem axle configurations produce greater carrier pipe live load stresses. If the design P_s and P_t coordinate ties above the line in Figure A-1 for a particular design pavement type, burial depth, H, and carrier pipe diameter, D, then single axle configurations are more critical. If the design P_s and P_t coordinate lies below the line in Figure A-1 for a particular design pavement type, then tandem axle configurations are more critical. In Figure A-1, the plotted points represent the recommended design loads of P_s = 12 kips (53.4 kN) and P_t = 10 kips (44.5 kN), with the resulting critical axle configurations as given in Table 1 in the main body of this recommended practice.



$H < 4$ ft (1.2 m) *and* $D \leq 12$ in. (305 mm)

$H < 4$ ft (1.2) *and* $D > 12$ in. (305 mm); $H \geq 4$ ft (1.2 m) for all D

Figure A-1—Critical Case Decision Basis for Whether Single or Tandem Axle Configuration Will Govern Design

Annex B

Uncased Design Example Problems

B.1 Highway Crossing Design

A 12.75-in. (324-mm) diameter liquid product pipeline with a wall thickness of 0.250 in. (6.4 mm) is intended to cross a major highway that is paved with asphaltic concrete. The pipe is constructed of Grade X42 steel with ERW welds and will operate at a maximum pressure of 1000 psi (6.9 MPa). The pipeline will be installed without a casing at a design depth of 6 ft (1.8 m), using auger boring construction with a 2-in. (51-mm) overbore. The soil at the site was determined to be a loose sand with a resilient modulus of 10 kips/in.^{2} (69 MPa).

Using API Recommended Practice 1102, check whether the proposed design is adequate to withstand the applied earth load highway live load, and internal pressure. Ignore any change in pipe temperature.

Step a—initial Design Information

Pipe and operational characteristics:
Outside diameter, D = 12.75 in.
Operating pressure, p = 1,000 psi
Steel grade = X42
Specified minimum yield strength, $SMYS$ = 42,000 psi
Design factor, F = 0.72
Longitudinal joint factor, E = 1.00
Installation temperature, T_1 = N/A
Maximum or minimum operating temperature, T_2 = N/A
Temperature derating factor, T = N/A
Wall thickness, t_w = 0.250 in.

Installation and site characteristics:
Depth, H = 6.0 ft
Bored diameter, B_d = 14.8 in.
Soil type = Loose sand
Modulus of soil reaction, E' = 0.5 ksi
Resilient modulus, E_r = 10 ksi
Unit weight, γ = 120 lb/ft^3 = 0.069 lb/in.^{3}
Type of longitudinal weld = ERW
Design wheel load from single axle, P_s = 12 kips
Design wheel load from tandem axles, P_t = 10 kips
Pavement type = Flexible

Other pipe steel properties:
Young's modulus, E_s = 30,000 ksi
Poisson's ratio, v_s = 0.30
Coefficient of thermal expansion, α_T = 6.5×10^{-6} per °F

Step b—Check Allowable Barlow Stress

Equation 8b with:
p = 1,000 psi
D = 12.75 in.
t_w = 0.250 in.
F = 0.72
E' = 1.00

S_{Hi} (Barlow) = 25,500 psi

$F \times E \times T \times SMYS$ = N/A
$F \times E \times SMYS$ = 30,240 psi

		T = N/A $SMYS$ = 42,000 psi	
			S_{Hi} (Barlow) ≤ Allowable? Yes

Step c—Circumferential Stress Due to Earth Load

c.1	Figure 3 with:	t_w/D = 0.020 E' = 0.5 ksi	K_{He} = 3,024
c.2	Figure 4 with:	H/B_d = 4.9 Soil type = Loose sand = A	B_c = 1.09
c.3	Figure 5 with:	B_d/D = 1.16	E_e = 1.11
c.4	Equation 1 with:	D = 12.75 in. γ = 120 lb/ft^3 = 0.069 lb/in.^{3}	S_{He} = 3,219 psi

Step d—impact Factor, F_i,and Applied Design Surface Pressure, w

d.l	Figure 7 for highways with:	H = 6 ft	F_i = 1.47
d.2	Applied design surface pressure, w		
	Section 4.7.2.2.1:	Flexible pavement	P_t = 10 kips
	Critical case: tandem axles		w = 69.4 psi

Step e—Cyclic Stresses, ΔS_{Hh} and ΔS_{Lh}

e.1	Cyclic circumferential stress. ΔS_{Hh}			
	e.1.1	Figure 14 with:	t_w/D = 0.020 E_r = 10 ksi	K_{Hh} = 14.3
	e.1.2	Figure 15 with:	D = 12.75 in. H = 6 ft	G_{Hh} = 0.99
	c.1.3	Table 2 with:		R = 1.00
		Flexible pavement	H = 6 ft	L = 1.00
		Tandem axles	D = 12.75 in.	
	e.1.4	Equation 5:		ΔS_{Hh} = 1,444 psi
e.2	Cyclic longitudinal stress, ΔS_{Lh}			
	e.2.1	Figure 16 with:	t_w/D = 0.020 E_r = 10 ksi	K_{Lh} = 9.9
	e.2.2	Figure 17 with:	D = 12.75 in. H = 6 ft	G_{Lh} = 1.01
	e.2.3	Table 2 with:		R = 1.00
		Flexible pavement	H = 6 ft	L = 1.00
		Tandem axles	D = 12.75 in.	
	e. 2.4	Equation 6:		ΔS_{Lh} = 1,020 psi

Step f—Circumferential Stress Due to Internal Pressurization, S_{Hi}

Equation 7 with:	$p = 1{,}000$ psi $D = 12.75$ in. $t_w = 0.250$ in.	$S_{Hi} = 25{,}000$ psi

Step g—Principal Stresses, S_1, S_2, S_3

	$E_s = 30 \times 10^6$ psi $\alpha_T = 6.5 \times 10^{-6}$ per °F T_1 = N/A T_2 = N/A $v_s = 0.30$	
g.1 Equation 9 with:	$S_{He} = 3{,}219$ psi $\Delta S_{Hh} = 1{,}444$ psi $S_{Hi} = 25{,}000$ psi	$S_1 = 29{,}663$ psi
g.2 Equation 10 with:	$\Delta S_{Lh} = 1{,}020$ psi $S_{He} = 3{,}219$ psi $S_{Hi} = 25{,}000$ psi	$S_2 = 9{,}486$ psi
g.3 Equation 11 with:	$p = 1{,}000$ psi	$S_3 = -1{,}000$ psi
g.4 Effective stress, S_{eff}		
Equation 12 with:	$S_1 = 29{,}663$ psi $S_2 = 9{,}486$ psi $S_3 = -1{,}000$ psi	$S_{eff} = 26{,}994$ psi
g.5 Check allowable effective stress		
	$F = 0.72$ $SMYS = 42{,}000$ psi	
Equation 13 with:	$S_{eff} = 26{,}994$ psi $SMYS \times F = 30{,}240$ psi	
		$S_{eff} < SMYS \times F$? Yes

Step h—Check Fatigue

h.1 Girth welds		
	$F = 0.72$	
Table 3		$S_{FG} = 12{,}000$ psi
Equation 17 with:	$\Delta S_{Lh} = 1{,}020$ psi $S_{FG} \times F = 8{,}640$ psi	$\Delta S_{Lh} \leq S_{FG} \times F$? Yes
h.2 Longitudinal welds		
	$F = 0.72$	
Table 3		$S_{FL} = 21{,}000$ psi (ERW)
Equation 20 with:	$\Delta S_{Hh} = 1{,}444$ psi $S_{FL} \times F = 15{,}120$ psi	$\Delta S_{Hh} \leq S_{FL} \times F$? Yes

B.2 Railroad Crossing Design

The same 12.75-in. (324-mm) diameter, 0.250-in. (6.4-mm) wall thickness liquid product pipeline described in the highway example problem now will cross underneath two adjacent railroad tracks. The depth of the uncased carrier is 6 ft (1.8 m). All other design parameters are the same as those used for the highway crossing.

Using API Recommended Practice 1102, check whether the proposed design is adequate to withstand the applied earth load, railroad live load, and internal pressure. Ignore any changes in pipe temperature. Assume that there will be a girth weld within 5 ft (1.5 m) of either track centerline.

B.2.1 Railroad Example Problem

Step a—Initial Design Information

Pipe and operational characteristics:

Outside diameter, D = 12.75 in.
Operating pressure, p = 1,000 psi
Steel grade = X42
Specified minimum yield strength, $SMYS$ = 42,000 psi
Design factor, F = 0.72
Longitudinal joint factor, E = 1.00
Installation temperature, T_1 = N/A
Maximum or minimum operating temperature, T_2 = N/A
Temperature derating factor, T = N/A
Wall thickness, t_w = 0.250 in.

Installation and site characteristics:

Depth, H = 6.0 ft
Bored diameter, B_d = 14.8 in.
Soil type = Loose sand
Modulus of soil reaction, E' = 0.5 ksi
Resilient modulus, E_r = 10 ksi
Unit weight, γ = 120 lb/ft^3 = 0.069 lb/in.^{3}
Type of longitudinal weld = ERW
Distance of girth weld from track centerline, L_G = 0 ft
Number of tracks (1 or 2) = 2
Rail loading = E-80

Other pipe steel properties:

Young's modulus, E_s = 30,000 ksi
Poisson's ratio, v_s = 0.30
Coefficient of thermal expansion, α_T = 6.5×10^{-6} per °F

Step b—Check Allowable Barlow Stress

Equation 8b with:

p = 1,000 psi
D = 12.75 in.
t_w = 0.250 in.
F = 0.72
E = 1.00
T = N/A
$SMYS$ = 42,000 psi

S_{Hi} (Barlow) = 25,500 psi

$F \times E \times T \times SMYS$ = N/A
$F \times E \times SMYS$ = 30,240 psi

S_{Hi} (Barlow) $\leq$ Allowable? Yes

Step c—Circumferential Stress Due to Earth Load

c.1	Figure 3 with:	$t_w/D = 0.020$ $E' = 0.5$ ksi	$K_{He} = 3{,}024$
c.2	Figure 4 with:	$H/B_d = 4.9$ Soil type = Loose sand = A	$B_e = 1.09$
c.3	Figure 5 with:	$B_d/D = 1.16$	$E_e = 1.11$
c.4	Equation 1 with:	$D = 12.75$ in. $\gamma = 120\ \text{lb/ft}^3 = 0.069\ \text{lb/in.}^3$	$S_{He} = 3{,}219$ psi

Step d—Impact Factor, F_i, and Applied Design Surface Pressure, w

d.1	Figure 7 for railroads with:	$H = 6$ ft	$F_i = 1.72$
d.2	Applied design surface pressure, w Section 4.7.2.2.1:	Rail loading = E-80	$w = 13.9$ psi

Step e—Cyclic Stresses, ΔS_{Hr} and ΔS_{Lr}

e.1 Cyclic circumferential stress. ΔS_{Hr}

e.1.1	Figure 8 with:	$t_w/D = 0.020$ $E_r = 10$ ksi	$K_{Hr} = 332$
e.1.2	Figure 9 with:	$D = 12.75$ in. $H = 6$ ft	$G_{Hr} = 0.98$
e.1.3	Section 4.7.2.2.3 and Figure 10 with:	$N_t = 2$	$N_H=1.11$
e.1.4	Equation 3:		$\Delta S_{Hr} = 8{,}634$ psi

e.2 Cyclic longitudinal stress, ΔS_{Lr}

e.2.1	Figure 11 with:	$t_w/D = 0.020$ $E_r = 10$ ksi	$K_{Lr} = 317$
e.2.2	Figure 12 with:	$D = 12.75$ in. $H = 6$ ft	$G_{Lr} = 0.98$
e.1.3	Section 4.7.2.2.3 and Figure 13 with:	$N_t = 2$	$N_L = 1.00$
e.2.4	Equation 4:		$\Delta S_{Lr} = 7{,}427$ psi

Step f—Circumferential Stress Due to Internal Pressurization, S_{Hi}

Equation 7 with:	$p = 1{,}000$ psi $D = 12.75$ in. $t_w = 0.250$ in.	$S_{Hi} = 25{,}000$ psi

Step g—Principal Stresses, S_1, S_2, S_3

$E_s = 30 \times 10^6$ psi
$\alpha_T = 6.5 \times 10^{-6}$ per °F
T_1 = N/A
T_2 = N/A
$v_s = 0.30$

g.1 Equation 9 with: $S_{He} = 3{,}219$ psi — $S_1 = 36{,}853$ psi
$\Delta S_{Hr} = 8{,}634$ psi
$S_{Hi} = 25{,}000$ psi

g.2 Equation 10 with: $\Delta S_{Lr} = 7{,}427$ psi — $S_2 = 15{,}893$ psi
$S_{He} = 3{,}219$ psi
$S_{Hi} = 25{,}000$ psi

g.3 Equation 11 with: $p = 1{,}000$ psi — $S_3 = -1{,}000$ psi

g.4 Effective stress, S_{eff}
Equation 12 with: $S_1 = 36{,}853$ psi — $S_{eff} = 32{,}845$ psi
$S_2 = 15{,}893$ psi
$S_3 = -1{,}000$ psi

g,5 Check allowable effective stress
$F = 0.72$
$SMYS = 42{,}000$ psi
Equation 13 with: $S_{eff} = 32{,}845$ psi
$SMYS \times F = 30{,}240$ psi
$S_{eff} \leq SMYS \times F$? No

B.2.2 Railroad Example Problem (Revised Wall Thickness)

Step a—Revised Design Information

Pipe and operational characteristics:
Outside diameter, D = 12.75 in.
Operating pressure, p = 1,000 psi
Steel grade = X42
Specified minimum yield strength, $SMYS$ = 42,000 psi
Design factor, F = 0.72
Longitudinal joint factor, E = 1.00
Installation temperature, T_1 = N/A
Maximum or minimum operating temperature, T_2 = N/A
Temperature degrating factor, T = N/A
Wall thickness, t_w = 0.281 in.

Installation and site characteristics:
Depth, H = 6.0 ft
Bored diameter, B_d = 14.8 in.
Soil type = Loose sand
Modulus of soil reaction, E' = 0.5 ksi
Resilient modulus, E_r = 10 ksi
Unit weight, γ = 120 lb/ft^3 = 0.069 lb/in.^{3}
Type of longitudinal weld = ERW

Distance of girth weld from track centerline, L_G = 0 ft
Number of tracks (1 or 2) = 2
Rail loading = E-80

Other pipe steel properties:
Young's modulus, E_s = 30,000 ksi
Poisson's ratio, v_s = 0.30
Coefficient of thermal expansion, α_T = 6.5×10^{-6} per °F

Step b—Check Allowable Barlow Stress

Equation 8a with:	p = 1.000 psi D = 12.75 in. t_w = 0.281 in.	S_{Hi} (Barlow) = 22,687 psi
	F = 0.72 E = 1.00 T= N/A $SMYS$ = 42,000 psi	$F \times E \times T \times SMYS$ = N/A $F \times E \times SMYS$ = 30,240 psi
		S_{Hi} *(Barlow)* ≤ Allowable? Yes

Step c—Circumferential Stress Due to Earth Load

c.1	Figure 3 with:	t_w/D = 0.022 E' = 0.5 ksi	K_{He} = 2,500
c.2	Figure 4 with:	H/B_d = 4.9 Soil type = Loose sand = A	B_e = 1.09
c.3	Figure 5 with:	B_d/D = 1.16	E_e = 1.11
c.4	Equation 1 with:	D = 12.75 in γ = 120 lb/ft^3 = 0.069 lb/in.^{3}	S_{He} = 2,661 psi

Step d—Impact Factor, F_i, and Applied Design Surface Pressure, w

d.1	Figure 7 for railroads with:	H = 6 ft	F_i = 1.72
d.2	Applied design surface pressure, w Section 4.7.2.2.1:	Rail loading = E-80	w = 13.9 psi

Step e—Cyclic Stresses, ΔS_{Hr} and ΔS_{Lr}

e.1 Cyclic circumferential stress, ΔS_{Hr}

e.1.1	Figure 8 with:	t_w/D = 0.022 E_r = 10 ksi	K_{Hr} = 320
e.1.2	Figure 9 with:	D = 12.75 in. H = 6 ft	G_{Hr} = 0.98
e.1.3	Section 4.7.2.2.3 and Figure 10 with:	N_t = 2	N_H = 1.11
e.1.4	Equation 3:		ΔS_{Hr} = 8,322 psi

e.2 Cyclic longitudinal stress, ΔS_{Lr}

e.2.1 Figure 11 with:
$t_w/D = 0.022$
$E_r = 10$ ksi
$K_{Lr} = 305$

e.2.2 Figure 12 with:
$D = 12.75$ in.
$H = 6$ ft
$G_{Lr} = 0.98$

e.2.3 Section 4.7.2.2.3 and Figure 13 with:
$N_t = 2$
$N_L = 1.00$

e.2.4 Equation 4:
$\Delta S_{Lr} = 7{,}146$ psi

Step f—Circumferential Stress Due to Internal Pressurization, S_{Hi}

Equation 7 with:
$p = 1{,}000$ psi
$D = 12.75$ in.
$t_w = 0.281$ in.
$S_{Hi} = 22{,}187$ psi

Step g—Principal Stresses, S_1, S_2, S_3

$E_s = 30 \times 10^6$ psi
$\alpha_T = 6.5 \times 10^{-6}$ per °F
T_1 = N/A
T_2 = N/A
$v_s = 0.30$

g.1 Equation 9 with:
$S_{He} = 2{,}661$ psi
$\Delta S_{Hr} = 8{,}322$ psi
$S_{Hi} = 22{,}187$ psi
$S_1 = 33{,}170$ psi

g.2 Equation 10 with:
$\Delta S_{Lr} = 7{,}146$ psi
$S_{He} = 2{,}661$ psi
$S_{Hi} = 22{,}187$ psi
$S_2 = 14{,}600$ psi

g.3 Equation 11 with:
$p = 1{,}000$ psi
$S_3 = -1{,}000$ psi

g.4 Effective stress, S_{eff}

Equation 12 with:
$S_1 = 33{,}170$ psi
$S_2 = 14{,}600$ psi
$S_3 = -1{,}000$ psi
$S_{eff} = 29{,}629$ psi

g.5 Check allowable effective stress

$F = 0.72$
$SMYS = 42{,}000$ psi

Equation 13 with:
$S_{eff} = 29{,}629$ psi
$SMYS \times F = 30{,}240$ psi

$S_{eff} \leq SMYS \times F$? Yes

Step h—Check Fatigue

h.1 Girth welds

$F = 0.72$

Table 3
$S_{FG} = 12{,}000$ psi

h.1.1	If $L_G < 5$ ft (1.5 m) use:		
	Equation 15 with:	$\Delta S_{Lr} = 7{,}146$ psi $N_L = 1.00$ $\Delta S_{Lr}/N_L = 7{,}146$ psi $S_{FG} \times F = 8{,}640$ psi	$\Delta S_L/N_L \le S_{FG} \times F$? Yes
h.1.2	If $L_G > 5$ ft (1.5 m) use:		
	Figure 18 with:	$L_G =$	$R_F =$
	Equation 16 with:	$\Delta S_{Lr} =$ $N_L =$ $R_F\ \Delta S_{Lr}/N_L =$ $S_{FG} \times F =$	$R_F\ \Delta S_{Lr}/N_L \le S_{FG} \times F$?
h.2	Longitudinal welds		
		$F = 0.72$	
	Table 3		$S_{FL} = 21{,}000$ psi (ERW)
	Equation 19 with:	$\Delta S_{Hr} = 8{,}322$ psi $N_H = 1.11$ $\Delta S_{Hr}/N_H = 7{,}498$ psi $S_{FL} \times F = 15{,}120$ psi	$\Delta S_{Hr}/N_H \le S_{FL} \times F$? Yes

Annex C

Casing Wall Thicknesses

Table C-1—Minimum Nominal Wall Thickness for Flexible Casing in Bored Crossings

Nominal Pipe Diameter (in.)	Minimum Nominal Wall Thickness (in.)		
	Railroads		Highways
	When Coated or Cathodically Protected	When Not Coated or Cathodically Protected	
12.75 and under	0.188	0.188	0.134
14	0.188	0.250	0.134
16	0.219	0.281	0.134
18	0.250	0.312	0.134
20	0.281	0.344	0.134
22	0.281	0.344	0.164
24	0.312	0.375	0.164
26	0.344	0.406	0.164
28	0.375	0.438	0.164
30	0.406	0.469	0.164
32	0.438	0.500	0.164
34	0.469	0.531	0.164
36	0.469	0.531	0.164
38	0.500	0.562	0.188
40	0.531	0.594	0.188
42	0.562	0.625	0.188
44	0.594	0.656	0.188
46	0.594	0.656	0.219
48	0.625	0.688	0.219
50	0.656	0.719	0.250
52	0.688	0.750	0.250
54	0.719	0.781	0.250
56	0.750	0.812	0.250
58	0.750	0.812	0.250
60	0.781	0.844	0.250

Annex D

Unit Conversions

Table D-1—Unit Conversions

To Convert From	To	Multiply By
feet (ft)	meters (m)	0.3048
inches (in.)	millimeters (mm)	25.4
pounds (lb)	kilograms (kg)	0.4536
kips (k)	pounds (lb)	1000
	kilonewtons (kN)	4.448
pounds per square inch (psi)	kilopascals (kPa)	6.895
	kilonewtons per square meter (kN/m^2)	6.895
kips per square inch (ksi)	pounds per square inch (psi)	1000
	megapascals (MPa)	6.895
	meganewtons per square meter (MN/m^2)	6.895
degrees Fahrenheit, °F	degrees Celsius, °C = (°F – 32)/1.8	
pounds per cubic foot (pcf)	pounds per cubic inch (pci)	0.000579
(actually pounds-force)	kilonewtons per cubic meter (kN/m^3)	0.157

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