

Steel Pipelines Crossing Railroads and Highways

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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.

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Suggested revisions are invited and should be submitted to the Standards Department, API, 200 Massachusetts Avenue, NW, Washington, DC 20001, 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:	
$S_{He} = K_{He} B_e E_c \gamma D$	(1)
Live Load:	
$w = P/A_p$	(2)
$\Delta S_{Hr} = K_{Hr} G_{Hr} N_H F_i w$	(3)
$\Delta S_{Lr} = K_{Lr} G_{Lr} N_L F_i w$	(4)
$\Delta S_{Hh} = K_{Hh} G_{Hh} R L F_i w$	(5)
$\Delta S_{Lh} = K_{Lh} G_{Lh} R L F_i w$	(6)
Internal Load:	
$S_{Hi} = p(D - t_w)/2t_w$	(7)
Natural gas:	
$[S_{Hi}(\text{Barlow}) = pD/2t_w] \leq F \times E \times T \times SMYS$	(8a)
Liquids:	
$[S_{Hi}(\text{Barlow}) = pD/2t_w] \leq F \times E \times T \times SMYS$	(8b)
Limits of Calculated Stresses:	
Circumferential:	
$S_1 = S_{He} + \Delta S_H + S_{Hi}$	(9)
Longitudinal:	
$S_2 = \Delta S_L - E_s \alpha_T (T_2 - T_1) + v_s (S_{He} + S_{Hi})$	(10)
Radial:	
$S_3 = -p = -MAOP \text{ or } -MOP$	(11)
$S_{eff} = \sqrt{\frac{1}{2}[(S_1 - S_2)^2 + (S_2 - S_3)^2 + (S_3 - S_1)^2]}$	(12)
$S_{eff} \leq SMYS \times F$	(13)
$\Delta S_L \leq S_{FG} \times F$	(14)

$$\Delta S_{Lr}/N_L \leq S_{FG} \times F \quad (15)$$

$$R_F \Delta S_{Lr}/N_L \leq S_{FG} \times F \quad (16)$$

$$\Delta S_{Lh} \leq S_{FG} \times F \quad (17)$$

$$\Delta S_H \leq S_{FL} \times F \quad (18)$$

$$\Delta S_{Hr}/N_H \leq S_{FL} \times F \quad (19)$$

$$\Delta S_{Hh} \leq S_{FL} \times F \quad (20)$$

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 auger 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 drilling, 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):

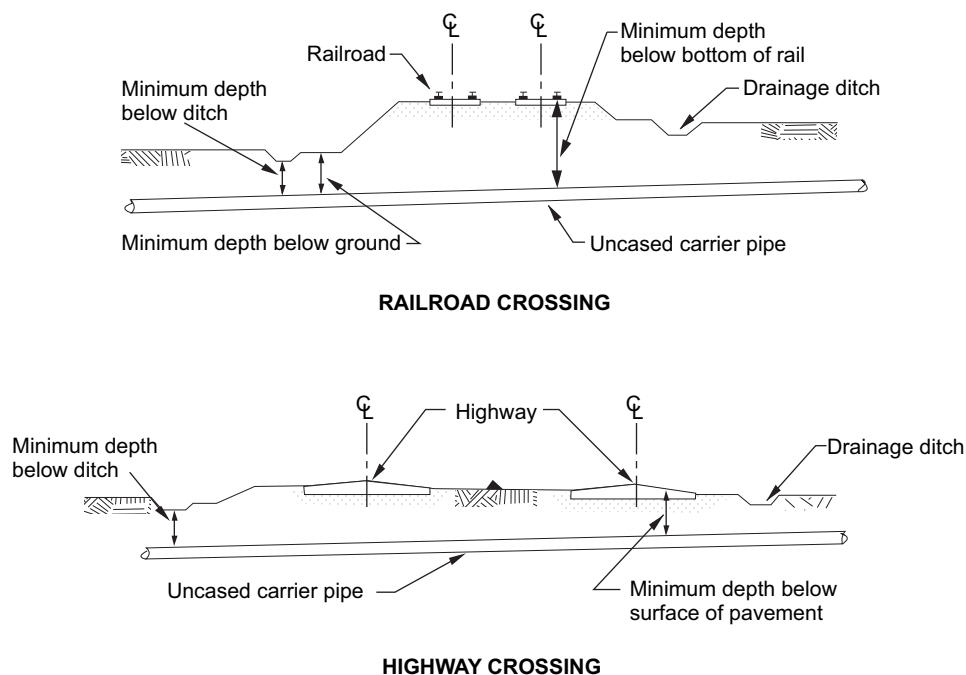


Figure 1—Examples of Uncased Crossing Installations

<u>Location</u>	<u>Minimum Cover</u>
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).

<u>Location</u>	<u>Minimum Cover</u>
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.

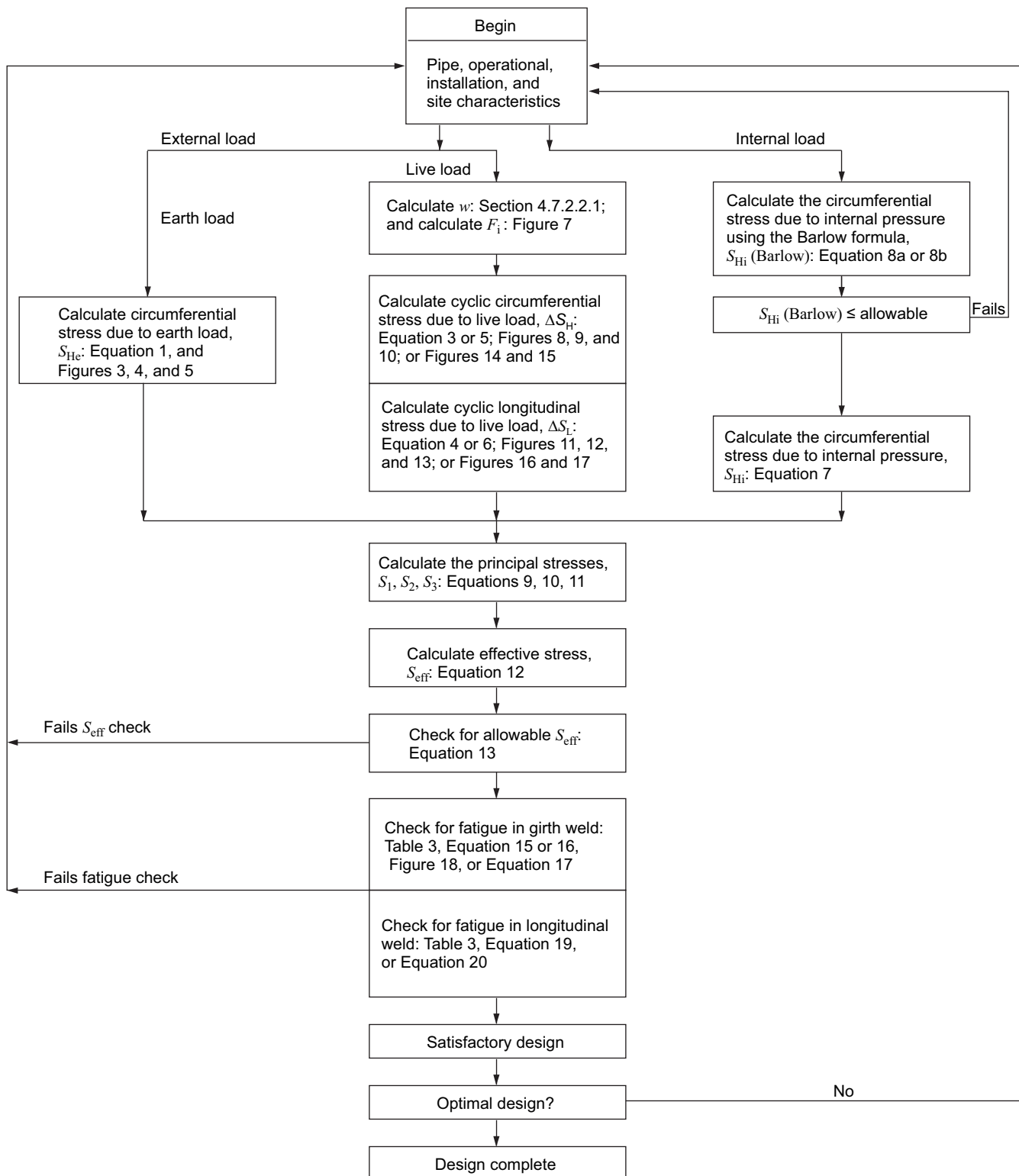


Figure 2—Flow Diagram of Design Procedure for Uncased Crossings of Railroads and Highways

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:

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

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/m³.

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

It is recommended that γ be taken as 120 lb/ft³ (18.9 kN/m³) (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