more applications of underground radar will be found, thus providing inexpensive, practical information about "what's down there" to a large group of scientists, engineers, and industrial users.

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Design Procedure for Uncased Natural-Gas Pipeline Crossings of Roads and Highways

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A method for designing uncased natural-gas pipeline crossings of roads and highways is presented. The procedures used are not new, but are adaptations of techniques that have been thoroughly tested and validated. The method involves a combined calculation of the internal hoop stress in the pipe that results from the operating pressure of the pipeline and the external stresses that result from dead load, live load, and impact loading. The internal stress is calculated by the Barlow formula, and the external stresses are calculated by the Spangler formula, which incorporates the Marston theory for the calculation of dead load and the Boussinesq point-load theory for live load. A brief resumé of the history of the use of cased pipeline at highway crossings is given to explain the reasons for using it in the past. Advances in the technology of steel making, pipe manufacture, pipeline construction, nondestructive inspection, pressure testing, cathodic protection, and maintenance inspection are listed to support the increased use of uncased pipeline. The improved cathodic protection of the carrier pipe that is available in uncased crossings is given as the primary justification for their use.

This paper presents a method for the design of uncased, natural-gas pipeline crossings of roads and highways. The design criteria used are equal to or exceed the specifications of the federal pipeline-safety standards (8).

BACKGROUND

History of Cased Pipeline at Highway Crossings

The practice of encasing pipeline crossings of highways dates back to the beginning of natural-gas pipeline construction and was undoubtedly used with other types of pipelines earlier. Early pipelines were constructed of cast iron or low-strength steel, and their sections were joined by screwed connections, mechanical couplings, or bell and spigot joints. The pipe was not coated or cathodically protected to prevent corrosion and, as a result of joint failure and corrosion, leaks that required repair or replacement of pipe sections developed (3, 4). The use of casings at road crossings provided a relatively simple and economical way to repair and replace pipes under roads without affecting the surface use of the roads.

Although welding has become a common method of joining pipe sections and coatings have been developed to protect the pipe from exposure to the factors that cause corrosion, the use of casings at highway crossings has continued for several reasons. Among these are the lack of integrity of the circumferential welds produced by using the oxyacetylene or bare-electrode, manual-arc processes, lack of sophisticated welding inspection techniques, and inadequate cathodic protection techniques.

Justification for Uncased Pipeline at Highway Crossings

Over the past 20 years, progress in all areas of pipeline technology has resulted in a pipeline network that has one of the best safety records of any form of transportation. Technological progress that has affected pipeline safety includes

1. The development of high-strength steels with improved ductility and notch toughness;
2. Improved processes for manufacturing steel plate for pipe, which results in fewer internal flaws in the pipe wall;
3. Advanced welding techniques for making the longitudinal seam in pipe joints;
4. Modern inspection techniques, including ultrasonic and radiographic procedures, for quality control of pipe in the manufacturing process;
5. Standardized shipping procedures that reduce shipping-related damage;
6. New coating materials and application techniques that result in better bonding and improved protection of the pipe surface from corrosive environments;
7. Improved welding techniques and materials for joining pipe;
8. The use of radiographic techniques for on-site inspection of pipe welding during construction;
9. Strength testing of pipeline segments following construction to at least 90 percent of yield;
10. Installation of cathodic protection systems that virtually eliminate pipe corrosion and the resulting leakage; and
11. Detailed inspection and monitoring procedures for the operation of pipelines.

Because of these and many other improvements in pipeline design, construction, and testing and operating procedures, the requirement for encasing pipeline crossings of highways is today greatly reduced. Most authorities on pipeline operations now recognize that encasing pipelines severely reduces the cathodic protection of the encased carrier pipe. Thus, encasing, which was once a simple and economical means for maintaining, repairing, and replacing pipeline sections under roadways, is now itself a major maintenance problem. More and more agencies and organizations concerned with pipeline safety, including the National Transportation Safety Board (NTSB) (10), the U.S. Department of Transportation Office of Pipeline Safety Operations, the National Association of Railroad and Utility Commissioners (NARUC), the American Petroleum Institute (API), and the American Society of Mechanical Engineers (ASME), are recommending that the use of cased pipeline at highway crossings be discontinued.

Development of Design Criteria

Although the movement toward the use of uncased pipeline at highway crossings is relatively recent, the development of acceptable design criteria for uncased crossings is at least 15 years old. The design procedure presented in this paper is not new, but rather is adapted from several methods developed primarily under the sponsorship of the American Society of Civil Engineers (ASCE) Research Council on Pipeline Crossings of Railroads and Highways. In 1955, the first revision of the American Standards Association code for pressure piping (13) included design criteria for natural-gas pipelines that were based on the population density adjacent to the pipeline and for uncased pipeline crossings of roads, highways, and railroads. To provide consistency in the design criteria, the criteria established for uncased pipeline crossings in each population-density classification were equivalent to those for cased pipeline crossings for the next higher population-density classification. This resulted in a 10 to 12 percent decrease in the operating-stress level and a 20 to 25 percent increase in safety factor over the adjacent pipe sections. The validity of this design criteria has been thoroughly documented (6). The design criteria are included in the present federal pipeline safety standards.

On the basis of the ASCE studies and independent research, Spangler (2) developed the design procedure that is often referred to as the Iowa formula (3, 4, 5). This has become the most widely accepted procedure for the design of uncased pipeline highway crossings and is used by the API (7).

Unfortunately, the use of cased pipeline crossings has acquired the status of infallibility that accompanies age and experience. As a result, there is great reluctance among highway engineers, designers, and administrators to accept uncased pipeline crossings of highways in spite of the mass of test data that supports present design criteria. Very few states permit uncased pipeline crossings under any conditions, and those that do generally impose stringent restrictions in factors of pipe diameter and operating pressure or stress level or both. A summary of present state policies on casing is given in Policies for Accommodation of Utilities on Highway Rights-of-Way (11).

Approved Design Procedure

The design procedure for uncased crossings presented here uses the Barlow formula for the calculation of internal pipeline stress and the Spangler method for the calculation of external stresses, including dead load, live load, and impact loading. The Barlow formula for determining the pipe-hoop stress that results from internal loading is taken from the federal pipeline safety standards (8) and includes a design factor known as the class location that limits the level of internal stress on the basis of the population density adjacent to the pipeline. A complete description of the recognized class locations and the applicable design factors can be found in the federal pipeline safety standards (8).

The Spangler method (1, 2) for the calculation of external stress loading incorporates the Marston theory for the calculation of dead load and the Boussinesq point-load theory (1, 3) for the calculation of live load, including impact loading. The Spangler formula includes several design parameters that may be varied to satisfy the overall design concept of the approving authority. These parameters include the load coefficient, the wheel load, the impact factor, and the bending and deflection parameters.

A brief description of three of these factors, the load coefficient, the bending parameter, and the deflection parameter, and the range of variability of each is appropriate at this point. The load coefficient is a factor in Marston's calculation for loads on pipes in trenches. It is a function of the ratio of the height of backfill or earth above the pipe to the width of the ditch or the diameter of the bored hole. It is also a function of the internal friction of the soil backfill and the coefficient of friction between the backfill and the sides of the ditch. The original formula recognized five different classes of soil. The factor generally accepted today is the soil class that Marston labeled ordinary maximum for clay (thoroughly wet). However, higher and lower values of this factor are available and may be used where conditions warrant. Values of this factor are given in Table 1.

The bending and deflection parameters are derived from Spangler's work (1, 2) and are dependent on the distribution of load over the top half of the pipe and the resultant distribution of the bottom reaction. The load distribution over the top half of the pipe may be considered as uniform, but the bottom reaction depends largely on the extent to which the pipe settles into and is supported by the soil in the bottom of the trench. In bored installations, in which the bored hole normally exceeds the pipe diameter by 5.1 cm (2 in) or less, the bottom reaction is considered to occur over an arc of up to 120°. In open-trench installations, in which the width of the ditch may exceed the pipe diameter by 0.3 m (1 ft) or more, the bottom reaction is generally assumed to occur over an arc of 30 to 60°. Here again, the factors have a considerable range of variation that depends on the conditions at the particular installation. This latitude of design should readily satisfy the requirements of the approving authority. Values of deflection and bending parameters are shown below (12).

Width of Uniform Reaction (°)	Parameters	
	Deflection	Bending
0	0.110	0.294
30	0.108	0.235
60	0.103	0.189
90	0.096	0.157
120	0.089	0.138
150	0.085	0.128
180	0.083	0.125

The following parameters were used in the development of the design procedure presented here.

1. Class-location factor: By agreement, the class-location design factor was taken as 0.50, the design factor specified for class location 3, for all installations in class locations 1, 2, and 3. Since uncased crossings in class locations 2 and 3 are required to have a design factor of 0.50 under the federal pipeline safety standards, the cost impact of using this factor in class 1 locations also will be minimal. This design factor limits the maximum allowable operating pressure of the pipeline to a pressure that will produce a hoop stress of 50 percent of the specified minimum yield strength. A class-location design factor of 0.40 was used for instal-

Table 1. Safe working values of C_d for calculation of loads on pipes in trenches.

	C_d				
H/B[a]	Minimum Possible Without Cohesion[b]	Maximum for Ordinary Sand[c]	Completely Saturated Topsoil	Ordinary Maximum for Clay (thoroughly wet)[d]	Extreme Maximum for Clay (completely saturated)[e]
0.5	0.455	0.461	0.464	0.469	0.474
1.0	0.830	0.852	0.864	0.881	0.898
1.5	1.140	1.183	1.208	1.242	1.278
2.0	1.395	1.464	1.504	1.560	1.618
2.5	1.606	1.702	1.764	1.838	1.923
3.0	1.780	1.904	1.978	2.083	2.196
3.5	1.923	2.075	2.167	2.298	2.441
4.0	2.041	2.221	2.329	2.487	2.660
4.5	2.136	2.344	2.469	2.650	2.856
5.0	2.219	2.448	2.590	2.798	3.032
5.5	2.286	2.537	2.693	2.926	3.190
6.0	2.340	2.612	2.782	3.038	3.331
6.5	2.386	2.675	2.859	3.137	3.458
7.0	2.423	2.729	2.925	3.223	3.571
7.5	2.454	2.775	2.982	3.299	3.673
8.0	2.479	2.814	3.031	3.366	3.764
8.5	2.500	2.847	3.073	3.424	3.845
9.0	2.518	2.875	3.109	3.476	3.918
9.5	2.532	2.898	3.141	3.521	3.983
10.0	2.543	2.918	3.167	3.560	4.042
11.0	2.561	2.950	3.210	3.626	4.141
12.0	2.573	2.972	3.242	3.676	4.221
13.0	2.581	2.989	3.266	3.715	4.285
14.0	2.587	3.000	3.283	3.745	4.336
15.0	2.591	3.009	3.296	3.768	4.378
Very Great	2.599	3.030	3.333	3.846	4.545

[a] Height of fill above top of pipe to breadth of ditch a little below the top of the pipe.
[b] These values give the loads generally imposed by granular filling materials before tamping or settling.
[c] Use these values as safe for all ordinary cases of sand filling.
[d] Use these values as safe for all ordinary cases of clay filling.
[e] Use these values only for extremely unfavorable conditions.

lations in class location 4 (multistory buildings).

2. Load coefficient: The values for ordinary maximum for clay (thoroughly wet) were taken from Marston's tables.

3. Wheel load: A value of 9072 kg (20 000 lb) was assumed.

4. Impact factor: A value of 1.5 (i.e., a nonrigid pavement) was assumed.

5. Bending and deflection parameters: The bending and deflection parameters were taken as the values for 0° arc (point loading) and for 60° arc for bored and for open-trench installations respectively.

COMPARISON OF DESIGN PROCEDURE WITH OTHER DESIGN CRITERIA

The design for uncased pipeline crossings at highways that results from the use of this procedure will be quite conservative. For comparison, the API recommended practice (7) uses design parameters of a 6800-kg (15 000-lb) wheel load and a 120° bottom-reaction arc for the deflection and bending parameters for bored installations, and the federal pipeline safety standards (8) require the use of a class-location design factor for the next higher class location.

IMPLEMENTATION OF DESIGN PROCEDURE

The installation of uncased pipeline at highway crossings is not a common procedure, and the design and installation practices have not yet been standardized. At present, API is considering updating their recommended practice (7), revising it to include hydrocarbon-gas pipelines, and developing a standard procedure that would be acceptable to all of the states and to the railroads. It is unlikely that any company will adopt a standardized design procedure until it is determined whether the results of this activity are generally accepted and approved.

Because one of the major reasons for using uncased pipeline at crossings is improved cathodic protection for the carrier pipe, the protection of the pipe-coating material during installation is an important concern. There are various procedures available for this protection. The most effective procedure presently available for use in long bored installations is cement coating. This is a field-applied coating and is quite costly. Thus, for long bored installations, particularly those using large diameter pipe, the economics at present favor the use of casing with a heavy petroleum or wax filler in the void space.

Cost Comparison of Cased Versus Uncased Pipeline

A significant factor in the use of uncased pipeline for highway crossings is the reduced installation cost. Uncased pipeline eliminates the need for the additional casing pipe, casing seals, casing insulators between the casing and the carrier pipe, casing vents, and, in some instances, casing filler. The installation of an uncased crossing should cost about 25 percent less than that of a cased crossing (or 40 percent less if casing filler is required).

The saving in operating cost is equally significant. The federal pipeline safety standards require that all pipelines be patrolled and that their cathodic protection be monitored on a periodic basis. Cased crossings must be checked as a part of this monitoring procedure to determine whether a short has occurred in the cathodic-protection system between the carrier pipe and the casing. Shorts may result from physical contact between the carrier pipe and the casing because of movement or settling of the carrier pipe or as a result of the failure of the casing end seals, which permits groundwater to enter the casing and provides a contact path between the carrier pipe and the casing. The long-term performance of the available seals has been poor. If a short occurs, the pipe must be excavated to clear the short or to install casing filler to protect the carrier pipe from environmental factors that would cause, or accelerate, corrosion. The cost of clearing casing shorts may vary from several thousand dollars to several hundred thousand dollars, depending on the depth of cover and the conditions encountered in the excavation. Such expenditures could be eliminated by the use of uncased pipeline.

PIPELINE DESIGN PROCEDURE FOR UNCASED HIGHWAY CROSSINGS

Basic Design Formula

This procedure provides a means for determining the combined stress exerted on an uncased pipeline at a road crossing. The combined stress (for the purposes of this procedure) is considered to be the sum of the stress due to internal pressure and the stress created by external loading (soil and vehicular). The combined stress is determined as follows:

$$S_T = S_I + S_E = (PD/2t) + (0.024\,92 K_b WEDt)/(Et^3 + 3K_z PD^3) \quad (1)$$

$$W = C_d \delta B_D^2 + (3LDI/2\pi H^2) \quad (2)$$

where

- S_T = total combined stress (kilopascals),
- S_I = hoop stress due to internal pressure (kilopascals),
- S_E = hoop stress due to external loading (kilopascals),
- P = internal pipeline pressure (kilopascals) (which may not exceed the pressure determined by Barlow's formula using design factors of 0.50 in class 1, 2, and 3 locations and 0.40 in class 4 locations),
- D = outside pipe diameter (meters),
- t = nominal wall thickness (meters),
- K_b = bending parameter [for bored installations at 0° = 0.294, and for open-trench installations at 60° = 0.189 (see text table)],
- W = total external load (kilograms per linear meter) of pipe (includes soil dead load and vehicular live load),
- E = modulus of elasticity of steel [206.8 GPa (30 000 000 lb/in²)],
- K_z = deflection parameter [for bored installations at 0° = 0.110, and for open-trench installations at 60° = 0.103 (See text table)],
- C_d = load coefficient (Table 1),
- δ = unit weight of soil [use 1922 kg/m³ (120 lb/ft³) unless the unit weight of the highway subsoil material is known],
- B_D = width of pipe trench or diameter of bored hole (meters),
- L = wheel load = 9072 kg (20 000 lb),
- I = impact factor (use 1.5 for nonrigid pavement and 1.0 for rigid pavement), and
- H = height of soil over pipe (meters).

Sample Calculations

Bored Installation

Assume the following conditions: (a) pipe diameter = 0.508 m (20 in), (b) thickness of pipe wall = 0.0103 m (0.406 in), (c) pipe grade = 5LX-42 [specified minimum yield = 289.590 MPa (42 000 lbf/in²)], (d) maximum operating pressure = 5.516 MPa (800 lbf/in²), (e) class 1 location, (f) minimum cover depth = 1.52 m (5 ft), (g) acceptable wheel load = 9072 kg (20 000 lb), (h) unit weight of soil = 1922 kg/m³ (120 lb/ft³), and (i) impact factor = 1.5. Determine the total combined stress at maximum internal pressure and at zero internal pressure.

1. Calculate the internal stress at maximum internal pressure :

$$S_I = PD/2t = 5516 \times 0.508 \times 10^2/2 \times 1.03 = 136.025 \text{ MPa} \quad (19\,704 \text{ lbf/in}^2) \quad (1a)$$

2. Calculate the stress due to external load:

$$S_E = 29.42 \times 10^{-3} K_b WEDt/(Et^3 + 3K_z PD^3) \quad (1b)$$

where

K_b = 0.294,
K_z = 0.110,
B_D = 0.56 m (1.82 ft) [bore 0.051 m (2 in) larger than D],
H = 1.52 m (5 ft),
H/B_D = 2.72, and
$W = 1.951 \times 1922 \times 0.56^2 + (3 \times 9072 \times 0.508 \times 1.5)/(2 \times 3.142 \times 1.52^2)$
$= 1176.19 + 1428.68$
$= 2604.87$ kg/m (144.76 lb/in),

which gives $S_E = 29.42 \times 10^{-3} \times 0.294 \times 2604.87 \times 206.8 \times 10^6 \times 0.506 \times 1.03 \times 10^{-2}/\{[206.8 \times 10^6 \times (1.03 \times 10^{-2})^3] + (3 \times 0.110 \times 5516 \times 0.508)^3\} = 52.475$ MPa (7550 lbf/in²).

3. $S_T = 136.025 + 52.475 = 188.500$ MPa (27 254 lbf/in²) and the specified minimum yield = 188.500/289.590 = 65 percent.

Open Trench Installation

Assume the following conditions: (a) pipe diameter = 0.61 m (24 in), (b) pipe wall thickness = 0.0127 m (0.500 in), (c) pipe grade = 5LX-60 [specified minimum yield = 413.700 MPa (60 000 lbf/in²)], (d) maximum operating pressure = 8.274 MPa (1200 lbf/in²), (e) class 1 location, (f) minimum cover depth = 1.22 m (4 ft), (g) acceptable wheel load = 9072 kg (20 000 lb), (h) unit weight of soil = 1922 kg/m³ (120 lb/ft³), and (i) impact factor = 1.5. Determine the total combined stress at maximum internal pressure and at zero internal pressure.

1. Calculate the internal stress at maximum internal pressure:

$$S_I = PD/2t = 8274 \times 0.61/2 \times 1.27 \times 10^{-2} = 198.706 \text{ MPa} \quad (28\,800 \text{ lbf/in}^2) \quad (1a)$$

2. Calculate the stress due to external load:

$$S_E = 29.42 \times 10^{-3} K_b WEDt/(Et^3 + 3K_z PD^3) \quad (1b)$$

where

K_b = 0.189,
K_z = 0.103,
B_D = 0.91 m (3 ft) (based on standard bucket width),
H = 1.22 m (4 ft),
H/B_D = 1.33,
C_d = 1.12 (from Table 1), and
$W = 1.12 \times 1922 \times 0.91^2 + (3 \times 9072 \times 0.61 \times 1.5)/(2 \times 3.142 \times 1.22^2)$
$= 1782.6 + 2662.8$
$= 4445.4$ kg/m (249.7 lb/in),

which gives $S_E = 29.42 \times 10^{-3} \times 0.189 \times 4445.4 \times 206.8 \times$

$10^6 \times 0.61 \times 1.27 \times 10^{-2}/[(206.8 \times 10^6 \times 0.500^3) + (3 \times 0.103 \times 8274 \times 0.61^3)] = 39.446$ MPa (5742 lbf/in^2).

3. $S_T = 198.706 + 39.446 = 238.152$ MPa (34 542 lbf/in^2) and the specified minimum yield = 238.152/413.700 = 57.6 percent.

CONCLUSIONS

It appears obvious to many pipeline operators that the use of uncased pipeline at highway crossings is preferable to the use of cased pipeline in the present conditions of pipeline design, construction, testing, and operating technology. There are proven design procedures and criteria that will assure the operating safety of uncased crossings. Cathodic protection of uncased carrier pipe is much greater than that of cased pipe, which significantly reduces a major cause of pipeline leaks. Uncased crossings have definite economic advantages to both highway departments in terms of initial costs and pipeline operators in terms of initial and operating costs. The use of uncased crossings has been recommended by the NTSB and is being favorably considered for recommendation by NARUC. Technologically outmoded objections against the use of uncased pipeline at highway crossings should be put aside, and procedures for the approval of the use of uncased pipeline should be inplemented.

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REFERENCES

1. M. G. Spangler. Soil Engineering. International Textbook Co., Scranton, Penn., 2nd Ed., 1960.
2. M. G. Spangler. Pipeline Crossings Under Railroads and Highways. Paper presented at the Annual Conference of the American Waterworks Association, June 3, 1964.
3. K. E. Britain. A Report on the Redundancy of Casing in Today's Pipeline Design. Tennessee Gas Transmission Co., May 1966.
4. J. E. White and W. F. Saylors. Uncased Pipeline Crossing Transportation Arteries. TRB, Transportation Research Record 483, 1974, pp. 14-23.
5. Line Pipe. National Tube Division, Pittsburgh, 1954.
6. E. C. Rodabaugh, T. J. Atterbury, and G. L. Hinueber. Experimental Evaluation of Simulated Uncased Pipeline Crossings of Railroads and Highways. Association of American Railroads Research Center and Research Council on Pipeline Crossings of Railroads and Highways of ASCE, July 1971.
7. Recommended Practice for Liquid Petroleum Pipelines Crossing Railroads and Highways. American Petroleum Institute, RP 1102, 4th Ed., Sept. 1968.
8. U.S. Department of Transportation Minimum Federal Safety Standards for Gas Lines. Code of Federal Regulations, Pt. 192, Title 49.
9. Guide for Gas Transmission and Distribution Systems. ASME, 1976.
10. Pipeline Accident Report Michigan-Wisconsin Pipeline Company. National Transportation Safety Board Rept. NTSB-PAR-75-1, Monroe, La., March 2, 1974.
11. Policies for Accommodation of Utilities on Highway Rights-of-Way. NCHRP, Synthesis of Highway Practice 34, 1976.
12. M. G. Spangler. Pipeline Crossings Under Railroads and Highways. Journal of the American Waterworks Association, Aug. 1964.
13. Code for Pressure Piping, Section 8, Gas Transmission and Distribution Systems. American Standards Association, B 31, 1955.

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Coordinating Utility Relocations as a Function of State Highway Agencies

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Coordinating the relocation of utility facilities from the construction area for new highways and accommodating them on existing rights-of-way is an important consideration of state highway agencies. Data on the various divisions, bureaus, departments, sections, and units of the highway agencies that have the responsibility for this particular area of work were obtained from a questionnaire submitted to all 50 states and the District of Columbia. The results were tabulated and analyzed on the basis of 45 replies. It was concluded that all utility-related functions, such as preliminary engineering, estimates, liaison, coordination, plan development, and review and approval, for both highway projects and new utility installations should be referred to one central office or one individual in each district office for those agencies that are so structured.

The utility-relocation function has various concepts, levels of responsibility, and locations in different state highway agencies. Some agencies have a central office that is responsible for the required liaison with utility companies throughout the entire state. Others have divided the function on a geographical or political basis.