# UNCASED PIPELINE CROSSING TRANSPORTATION ARTERIES

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The U.S. Department of Transportation now requires all new pipelines to be 100 percent cathodically protected. However, the use of casing pipe around carrier pipe obstructs the successful application of cathodic protection. Although once necessary because of materials and methods of construction, casing can now be eliminated because of better materials and manufacturing methods, welding procedures, and quality control and inspection methods. In 1971, 3 state highway departments allowed uncased pipes to be used at highway crossings. The following features were incorporated in this new design: Nominal pipe wall thickness increased by a minimum of 20 percent, heavier wall pipe extended 40 to 80 ft on either side of the highway right-of-way, complete X-ray examination of girth welds within right-of-way, pipe coated and wrapped to provide adequate protection and electrical insulation, 1-in. thick reinforced concrete jacket installed on the pipe to be pulled, cathodic protection of pipeline at all times, 3-ft minimum cover provided between pipe and ground surface within right-of-way, and hydrostatic pressure test at 125 percent of maximum operating pressure level for a 24-hour period.

•THIS PAPER will acquaint those persons actively engaged in the design, construction, and maintenance of transportation arteries or in the legislation and writing of rules and regulations governing the installation of pipeline crossings under these arteries with the methods employed by Colonial Pipeline Company in crossing paved roads. This report presents reasons for our favoring the uncased pipeline construction over the encased construction.

## METHODS EMPLOYED IN 1971-1972

In 1971 the Colonial Pipeline Company requested and received permission from 3 state highway departments to use a new type of uncased pipeline in highway crossings constructed in those states. The new design incorporated the following features:

1. Increase the nominal pipe wall thickness by a minimum of 20 percent over that used in cross-country pipe,
2. Extend this heavier wall pipe 40 to 80 ft on either side of the right-of-way to provide for future widening of the highway,
3. Perform complete X-ray examination of all girth welds at time of construction,
4. Apply a coating of primer and enamel and wrap the pipe in glass and felt to provide adequate protection and electrical insulation (Fig. 1),
5. Install a 1-in. thick concrete jacket reinforced with wire mesh on the pipe to be pulled to protect the coating during installation (Fig. 1),
6. Maintain complete cathodic protection,
7. Provide a minimum of 3 ft cover between the top of pipe and the ground surface within the right-of-way, and
8. Conduct a 24-hour hydrostatic pressure test at 125 percent of maximum operating pressure level.

The crossings were bored in the usual manner by an auger machine on which was fastened a cutting head on the end of the auger. When the carrier pipe was bored into position, a section of mandrel pipe was welded to the front end of the carrier pipe in which the cutting head could work during the boring procedure (Figs. 2 and 3). When the bore was completed, the cutting head was taken off and the auger removed from the pipe. A specially built pulling head was then tacked to the end of the mandrel section of pipe (Fig. 4), and the concrete-coated pipe was pulled forward and positioned under the highway (Fig. 5). Once the pipe was positioned, the mandrel joint was removed and reused at another crossing. Additional heavy wall pipe then was welded to both ends of the concrete-coated pipe to extend beyond the right-of-way on both sides of the crossing (Fig. 6).

## CASING REQUIREMENTS OF THE PAST

In earlier days, casing was necessary for a variety of reasons, the most important of which was the use of mechanical methods for joining sections of pipe. The joints were a constant source of leaks because of corrosion at the joints, uneven settlement of the pipe, or strain that could cause the seal of mechanical pipe joints to break. The casing pipe acted as a conduit that allowed the carrier pipe to be shoved through the casing joint by joint, thus minimizing the danger of damaging the joints (Fig. 7).

Pipe used in the early days was inferior to that of today. The earlier pipe was manufactured from steel of low yield strength, and the longitudinal seam was joined by the butt-weld or lap-weld process. In most cases, the pipe had little or no protection against corrosion, and leaks were quite probable. Thus, the use of casing was necessary, for in the event of a leak the pipe could be withdrawn from the casing and repaired at minimum cost and with little or no inconvenience or hazard to the public.

## MORE RECENT DEVELOPMENTS

Many improvements have been made in construction methods, pipe quality, and means of pipe protection. In the early 1900s, joints were welded by the oxyacetylene method; in the 1920s they were electrically welded, and "bare" rods came into use. Although these joining procedures were great improvements over threaded ends and collars, the methods of welding left much to be desired.

In 1930, shielded or coated electrodes or both were used experimentally, and from that time electric welding gained rapid acceptance as strides were made in its development. Beginning in 1946, the use of X-ray offered a means for control of welding quality. This method of checking the deposited weld material locates defects of a significant nature that might affect the strength of the completed joint.

The installation of pipe has further been improved in recent years by close inspection of all phases of construction, improved welding techniques, availability of large and powerful construction equipment, and increased use of nondestructive testing of welds.

The manufacture of pipe also has greatly improved. In the 1920s, seamless pipe was introduced, and electric resistance welded pipe became available in the 1930s. Pipe manufacturers have continually improved the quality of the pipe by various means such as improved quality control, carefully controlled alloying elements, closely controlled rolling temperatures, oxygen injection in open-hearth steel furnaces, and improved weld and test equipment.

The increased use of centrifugal pumps and pressure control and safety equipment in recent years has further reduced the number of leaks occurring from equipment failure and operational causes. Centrifugal pumps develop a constant pressure at a given flow in contrast to reciprocating pumps that produce a variable flow and pressure with each stroke of the piston. Modern equipment accurately controls discharge pressure to a set maximum. If there is an upset in the system, such as power loss at a station or an unexpected valve closure, the control equipment will maintain a maximum discharge pressure by reducing flow, and the backup safety equipment will shut down the pump units on high pump case pressure or the complete station on high discharge pressure if the controller malfunctions.

Figure 1. Uncased pipe.

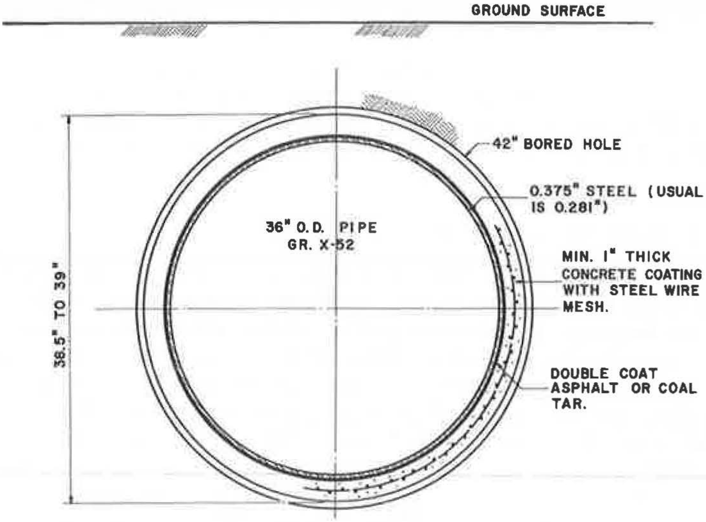



Figure 2. Road-boring equipment and procedure.

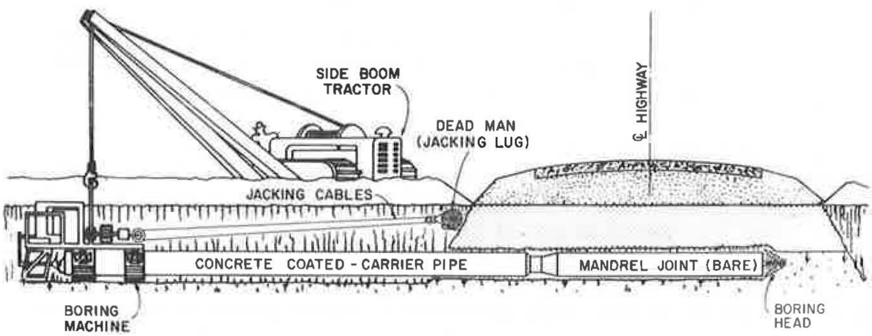
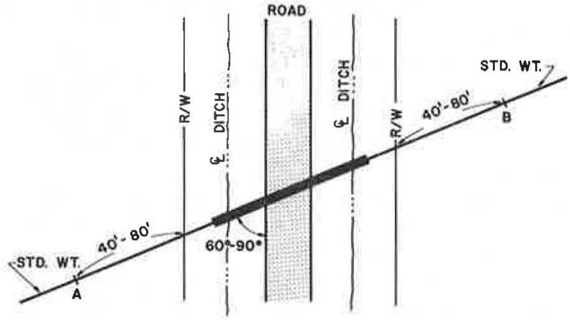



Figure 3. Road-boring equipment in operation.

**Figure 4. Pulling head being tack-welded to pipe for positioning of pipe.**

**Figure 5. Uncased pipe in place before foam is applied to annular space.**

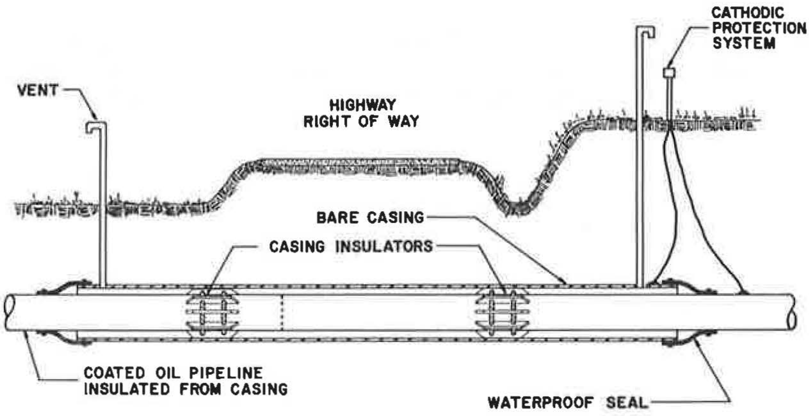
**Figure 6. Typical uncased pipe crossing road.**




NOTES:

1. HEAVY WALL THICKNESS PIPE A TO B
2. CONCRETE JACKET UNDER ROAD AND DITCHES
3. DOUBLE COATING A TO B
4. EXTRA DEPTH R/W TO R/W
5. CATHODIC TEST POINT AT R/W LINE

**Figure 7. Cased pipe under highway.**



## REASONS FOR CHANGE

In earlier days, pipelines had little or no protection against corrosion. Today, however, new pipelines have good protective coatings that are supplemented with cathodic protection. According to requirements of the U.S. Department of Transportation, they must be checked at least once a year.

The use of casing pipe around carrier pipe has long been recognized by pipeline corrosion engineers as being undesirable and an obstruction to the successful application of cathodic protection. The U.S. Department of Transportation now requires that a buried pipeline be electrically isolated from the casing pipe or that the casing be interconnected to the carrier pipe and cathodically protected as a single unit. The former is often impossible, and the latter more often is impractical.

A short in a casing results in a number of corrosion control problems (Fig. 8). It is supposed that a carrier pipe inside a casing pipe, which is short-circuited to it, receives no cathodic protection current because of the shielding effect of the casing. In addition, the shorted casing pipe absorbs a disproportionate amount of the cathodic protection current. Recently, on a 3-mile section of 12-in. pipeline, a 42-ft section of 18-in. casing shorted to the carrier pipe, resulting in an increase in current requirements of 1,500 times the normal.

Colonial Pipeline Company has been spending $60,000 to $70,000 per year repairing these shorted casings that impose electrical drainage on cathodic protection systems. The idea that repairs could be made easier and, in the event of a leak, the casing, acting as a conduit, would bring this leakage to the vents near the edge of the right-of-way was valid where diameters were small and lines had little protection against corrosion. Today, however, the casing and spacer blocks are more likely to cause trouble than prevent it in that they sometimes dent the carrier pipe, harm the pipe coating, and short the corrosion protection system. Any such damage increases the possibility of leaks. In most cases, the large-diameter pipe in use today makes it faster and more economical to bore a new crossing beside the old one and change the line over rather than remove the damaged pipe and repair or replace it.

There are also initial costs to consider. A larger hole, which is bored under the road when casing pipe is used, creates a larger void that might possibly result in later settlement, although Colonial Pipeline Company has not experienced this problem. At any rate, the larger hole, the casing pipe itself, vents, seals, insulators, and the labor to install these are of considerable cost. For example, the cost of a typical 100-ft-long crossing for a 36-in. diameter pipeline would be approximately $2,000 to $3,000 less for Colonial's uncased pipe than for the typical cased pipe. A no-casing-required policy when existing roads are widened would result in savings to the highway departments, for the work required by the existing pipelines is reimbursable. In 1968, 1969, and 1970, various state highway departments reimbursed Colonial Pipeline Company more than $200,000 per year to adjust cased crossings for highway widening and alterations.

## TECHNICAL SUPPORT DATA AND CALCULATIONS

The stated 20 percent minimum increase in pipe wall thickness for uncased pipelines crossing highways translates into the data given in Table 1.

API Bulletin RP 1102 entitled "Recommended Practice for Liquid Petroleum Pipeline Crossing Railroads and Highways" sets out the design criteria used by the pipeline industry. The formula used for calculating the circumferential stress resulting from external loads is the Spangler Iowa formula.

$$S = \frac{6K_b WERT}{ET^3 + 24K_z PR^3}$$

where

P = internal pressure, psi,
R = outside radius, in.,
T = wall thickness, in.,

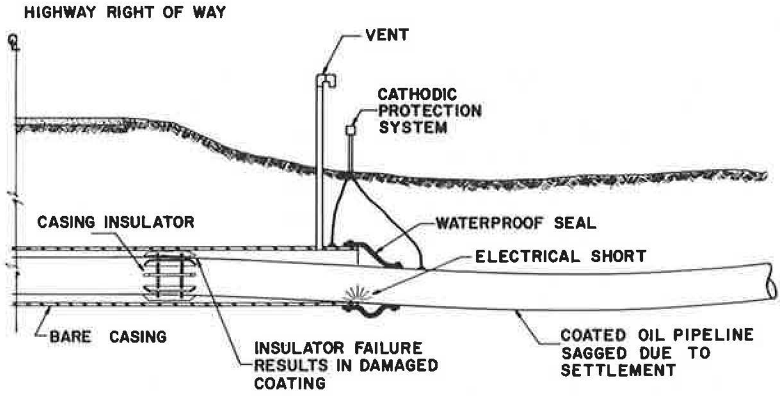



**Figure 8. Possible failures in cased pipes.**

**Table 1. Comparison of pipe normally used cross country to that proposed to be installed at road crossings.**

| Cross Country | | | | Road Crossings | | |
|---|---|---|---|---|---|---|
| Outer Diameter (in.) | Wall Thickness (in.) | Grade Pipe 5LX | Max Pressure[a] (psi) | Wall Thickness (in.) | Percent of Specified Min Yield Strength[b] | Percent of Ultimate Strength[b] |
| $6^5/_8$ | 0.188 | X-42 | 1 716 | 0.250 | 69 | 48 |
| $8^5/_8$ | 0.188 | X-42 | 1 318 | 0.250 | 71 | 50 |
| $10^3/_4$ | 0.219 | X-46 | 1 349 | 0.279 | 70 | 51 |
| $12^3/_4$ | 0.219 | X-52 | 1 286 | 0.281 | 67 | 53 |
| 16 | 0.250 | X-52 | 1 170 | 0.312 | 68 | 53 |
| 20 | 0.250 | X-52 | 936 | 0.312 | 67 | 48 |
| 24 | 0.250 | X-52 | 780 | 0.312 | 66 | 48 |
| 30 | 0.281 | X-52 | 702 | 0.344 | 66 | 48 |
| 32 | 0.281 | X-52 | 658 | 0.344 | 66 | 47 |
| 36 | 0.281 | X-52 | 585 | 0.344 | 65 | 47 |
| 40 | 0.312 | X-52 | 585 | 0.375 | 66 | 47 |

[a]72 percent of specified minimum yield strength.
[b]Combined maximum internal and external loading.

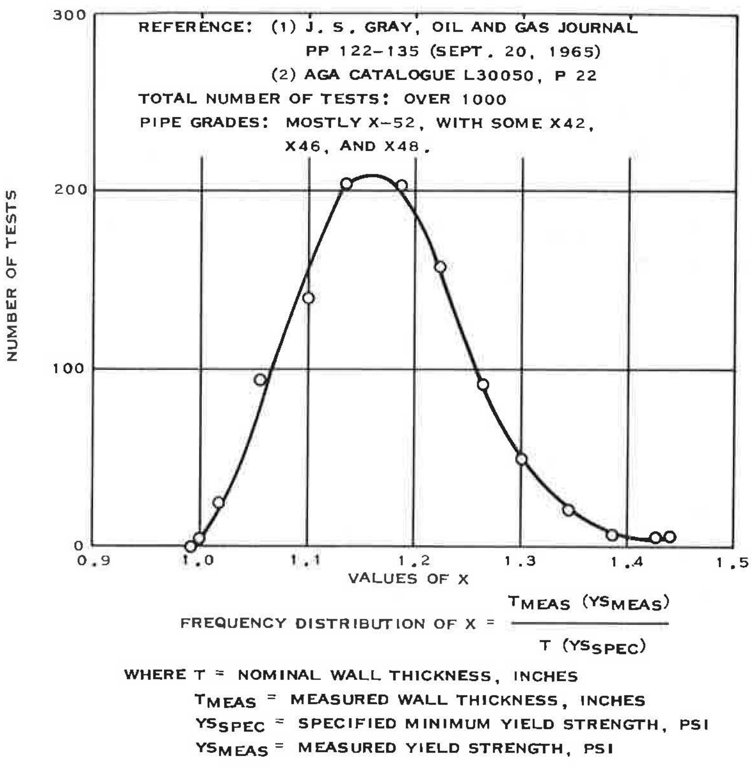



**Figure 9. Composite distribution of yield strength and thickness.**

$K_b$ = bending parameter (0.138 for bored hole),
$K_z$ = deflection parameter (0.089 for bored hole),
S = stress due to external loads, psi,
E = modulus of elasticity of metal ($30 \times 10^6$), and
W = total vertical load (dead, live, and impact), lb/lin in. using Coopers E-72 loading for railroads and 15,000-lb single-wheel loading for highways. Impacts of 1.75 for railroad and 1.50 for highways were used, each decreasing 0.03/ft below 5 ft of cover.

An excerpt from the foreword of API Bulletin RP 1102 follows:

> The performance of casings and uncased carrier pipe installed since 1934 and operated in accordance with API code 26 and API code 1102 has been excellent in that there is no known record in the history of the petroleum industry of a structural failure due to imposed earth and live loads of either a casing or carrier pipe under a railroad or highway. API RP 1102 has been expanded to include highway crossings and has been improved by utilizing more recent research experience measuring actual performance of externally loaded pipelines under various environmental conditions, including the use of new materials and construction techniques developed since API 1102 was last revised.
>
> This edition of API RP 1102 incorporated the knowledge gained from the consideration of known applicable data on carrier pipe and casing design and the performance under dead and live loads as well as internal pressures. Extensive computer analysis was performed using M. G. Spangler's Iowa Formula to determine the stress in uncased carrier pipe and wall thickness of casing pipe. The stresses were determined covering a range of pipe sizes from 2 inches to 60 inches in various soil conditions and under fill heights from 1 foot to 30 feet.

API Bulletin RP 1102 contains graphs and nomographs for determining the stresses due to external loading by using the Iowa formula. The total circumferential stress is the sum of the stresses created by internal and external loading. The formula used for calculating stress due to internal loading is Barlow's formula.

$$P = \frac{2St}{D} \quad \text{or} \quad S = \frac{PD}{2t}$$

where

P = internal pressure, psi;
D = outside diameter of pipe, in.; and
t = nominal wall thickness of pipe, in.

An example calculation for determining the circumferential stresses and percentage of specified minimum yield (SMY) is as follows:

P = 702 psi (72 percent of SMY of $30 \times 0.281$-in. X-52 line pipe),
D = 30 in.,
T = 0.344 in. (wall thickness of pipe used for road crossings),
H = 6 ft (minimum cover as specified by Colonial Pipeline Company), and
W = 180 lb (from graph 1 of API RP 1102).

$$S = \frac{6K_bWERT}{ET^3 + 24K_zPR^3}$$

$$S = \frac{6(0.138)(180)(30 \times 10^6)(15)(0.344)}{(30 \times 10^6)(0.344^3) + 24\,(0.089)(702)(15)^3} = 3{,}673 \text{ psi (stress due to external load)}$$

$$P = \frac{2st}{D} \quad \text{or} \quad S = \frac{PD}{2t} = \frac{702 \times 30}{0.688} = 30{,}600 \text{ psi (stress due to internal pressure)}$$

Total stress = stress due to external loads and stress due to internal pressure
= 3,673 + 30,600 = 34,273 psi

Percentage of SMY = 34,273/52,000 = 66 percent

Percentage of ultimate bursting pressure = 34,273/72,000 = 48 percent

Calculations were made of all sizes of pipe given in Table 1, and the percentage of specified minimum yield strength of the pipe is shown in the next to last column.

The specified minimum yield strength (52,000 psi in the previous example) is the minimum strength for the pipe specified. Yield strength is probably the property most difficult to control within narrow limits, and the manufacturers are forced to aim for an average considerably higher than the minimum to avoid rejections. The result is an increase, on the average, of the actual safety factor above that specified.

There is usually a misconception regarding pipe thickness tolerance. The API Standards permit an undertolerance of 8 to 12.5 percent on thickness of individual length depending on type and diameter of pipe. However, the standards also have a weight tolerance requiring that each length of pipe be weighed and not be more than 3.5 to 5.0 percent (depending on nominal thickness category) under the tabulated weight. In addition, each carload lot is weighed and must not be underweight by more than 1.75 percent of the nominal weight. This weight specification, when combined with the uniformity of thickness of plate used for welded pipe, results in a preponderance of pipe wall thicknesses significantly above those permitted by the tolerance on thickness of individual lengths (3, p. 47).

The combined distributions of yield strength and thickness almost never result in a figure below the equivalent of nominal wall at specified minimum yield strength (Fig. 9). The average strength is about 15 percent above specifications (3, p. 47).

It should also be remembered that the aforementioned calculations are made on the maximum steady-state operating pressure allowed, which occurs only at the discharge side of a pump station. Any other point on the line would be subjected to less pressure.

The effect of the road crossing being at any other point on the line is shown in Figure 10. The percentage of maximum design working pressure for various points based on percentage of distance between pump stations is shown. Figure 10 also shows the factor of safety that is based on both yield strength and tensile strength as the distance increases from the discharge of one pump station to the suction of the next station.

All these things combine to make the resulting stress calculations given in Table 1 ultraconservative.

## CONCLUSIONS

Some of the states have recently been more lenient concerning casing requirements. In Georgia, Tennessee, and Mississippi, Colonial Pipeline Company has recently installed pipes without casings under county roads or state and federal highways: 30 installations of 36-in. diameter pipe, 21 of 12-in. pipe, and 70 of 10-in. pipe in Georgia; more than 50 of 36-in. pipe in Mississippi; more than 60 of 10-in. pipe in Tennessee. In these installations, the bored hole was kept to a minimum size and the annular space between the pipe and hole was filled with urethane foam near the ends of the bored hole to block any possible water channelization (Fig. 11).

Colonial Pipeline Company proposes, where practical, the design and construction of uncased pipelines in lieu of casings in the crossing of all transportation arteries. We believe these uncased crossings will offer the following advantages:

1. The increased thickness of the pipe over normal pipe will result in lower stress levels and higher strength.
2. There is no problem of shorting the cathodic protection system.
3. The concrete jacket protects the pipe coating during installation.
4. There are no insulating spacers that could cause dents in the carrier pipe or damage the protective coating.
5. Vent pipes are eliminated; therefore, vandalizing of the pipeline by dropping explosives or pouring acid down the vent pipe is eliminated.
6. There is no annular space in which moisture can collect because of the breathing action through the vents or leakage at the casing-to-pipe seals.
7. Initial cost is reduced.
8. Because of the heavy pipe extending on both sides of the right-of-way, there would be no need to rework the crossing should a highway be widened. This would save the highway department from having to pay nonbetterment expense to the pipeline company as is done when cased pipes have to be extended.

**Figure 10. Effect of road crossing on points on the pipeline.**

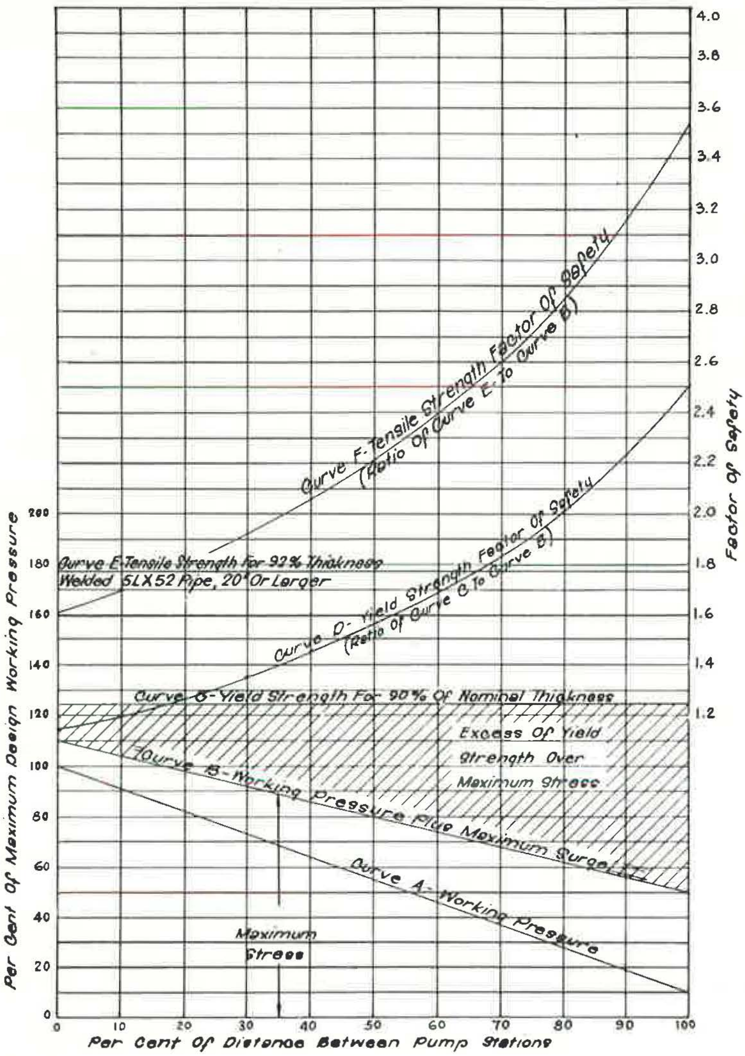
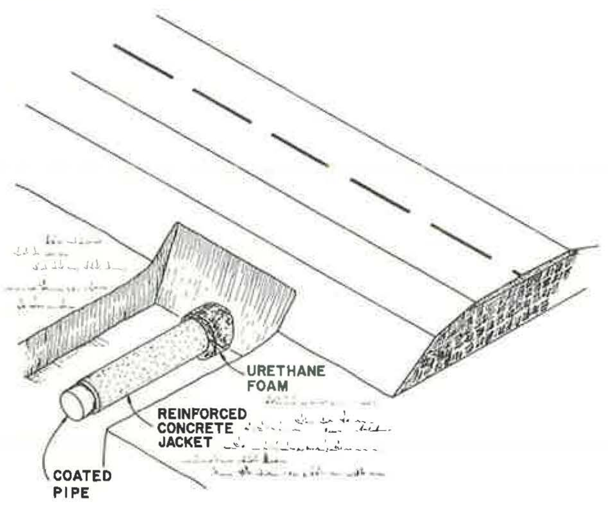



**Figure 11. Use of urethane foam to fill annular space.**



When the advantages of uncased pipelines crossing highways are weighed against the disadvantages of cased pipelines, it is readily apparent that the uncased pipelines are more advantageous both to the pipeline company and to the governing agency of the transportation artery being crossed.

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2. Bagwell, M. U. Georgia Permits Better, Less Costly Pipeline Crossing of Highways. Civil Engineering, Feb. 1973.
3. Statements on behalf of American Petroleum Institute and Association of Oil Pipe Lines. In Transportation of Liquids by Pipeline, Hearings before the Hazardous Materials Regulation Board, U.S. Department of Transportation, Docket HM-6, Notice 69-27, Jan. 20, 1970.