Coating Requirements for Pipelines Installed by Horizontal Directional Drilling

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Abstract

This paper describes a research project sponsored by the Pipeline Research Council International (PRCI). The objective of the research was to provide designers with hard data for use in specifying steel pipe coating systems for horizontally directionally drilled (HDD) pipeline crossings. This was accomplished by determining the performance characteristics of various coating systems when subjected to simulated HDD installation loads in rock. A testing device utilizing rock core samples from actual HDD river crossing projects was designed to replicate, as close as practical, HDD installation loading conditions. Testing resulted in determination of coating wear rates for various coatings.

Introduction

This paper describes the Pipeline Research Council International's (PRCI) research project performed under contract number PR 227-9812. The objective of this research was to determine the performance characteristics of selected coating systems when subjected to horizontal directional drilling (HDD) installation loads. Determination of coating system performance under controlled conditions will allow designers to specify coatings that are suitable for specific HDD crossing sites. The benefits of this are twofold. Pipeline integrity will be improved by providing coatings that will not be damaged during installation and eliminating conservatism in design will reduce costs.

Installation of natural gas pipelines by trenchless methods such as HDD has grown dramatically over the last twenty years. HDD is being utilized with greater frequency in soil conditions, such as hard rock, that can be detrimental to coating integrity. There is very little historical data on damage to coatings resulting from installation by HDD. In most cases, the pipe is not pulled very far out of the borehole. The extent of damage, or lack thereof, is unknown. Coating manufacturers are aware of a developing market for protective coatings and a number of new coating systems are being introduced.

Coating to Soil Loading

The bearing pressure between a pipe and the soil during HDD installation results from two characteristics of the pipe, its weight and its stiffness. A pipe being installed by HDD is typically submerged in drilling mud. Depending on its wall thickness and diameter, it will either float to the top of a rock hole or sink to the bottom.

An HDD installation will also have elastic bends. The pipe is forced to conform to these bends by bearing against the sides of the rock hole. Weight and bending bearing forces are illustrated in Figures 1 and 2.

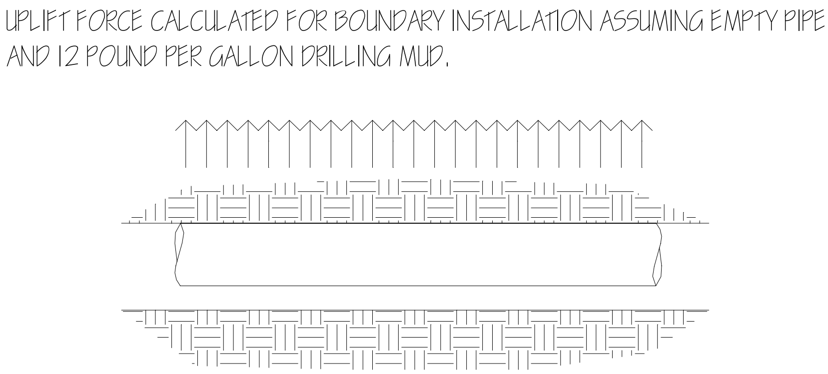

Figure 1, Bearing Force Resulting from Weight

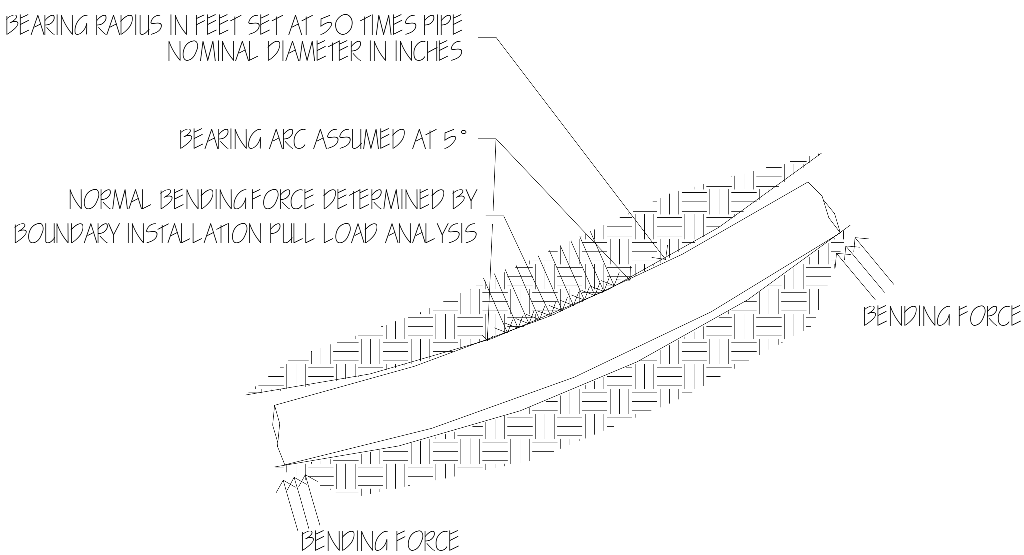

Figure 2, Bearing Force Resulting from Bending

Boundary Installation

The worst-case pipe to soil loading condition is defined by the boundary installation. Experience and analysis indicates that the boundary installation is a 36-inch pipeline with no buoyancy control. That is, the pipe is installed empty. Most knowledgeable HDD contractors will employ some type of buoyancy control for pipe 36 inches in diameter and larger. This usually involves filling the pipe with water as it is installed to ballast it down. Uplift force, and the resulting pulling force, are reduced. Diameter to wall thickness ratios for HDD segments are generally held to below 80. For the boundary installation, a wall thickness of 0.625 inches has been assumed. Elastic bends in HDD segments are generally designed with a radius of curvature (in feet) of 100 times the nominal diameter in inches. However, the actual radius of curvature (in feet) for bends in the drilled hole is often as low as 50 times the nominal diameter in inches. For the boundary condition, a radius of 1,800 feet has been assumed.

Pulling Load Analysis

Bending and uplift forces for the boundary installation have been calculated using the model developed under PRCI Contract PR 227-9424[1]. The lengths of the drilled path sections analyzed have been assumed for convenience. The total drilled length of this hypothetical installation is 3,428 feet. The total pulling force is 717,628 pounds. The uplift force is 398 pounds per foot. The total normal force required for an elastic sag bend near the completion of the pull back is 183,265 pounds.

Bearing Area

Assumptions have been made to determine the area over which weight and bending forces act. A pipe installed by HDD in rock will be pulled into in a reamed hole approximately 12 inches larger than its diameter. It has been assumed that it will bear against the hole wall over a circumferential arc of 10º (refer to Figure 3). For a 36-inch pipeline, this is an arc length of 3.1 inches.

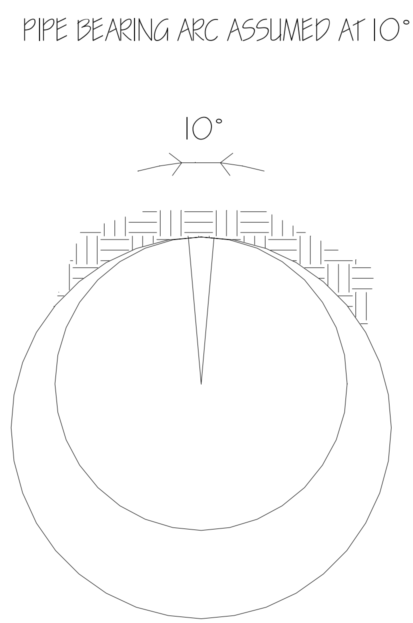

Figure 3, Assumed Bearing Arc

[1] *Installation of Pipelines by Horizontal Directional Drilling, An Engineering Design Guide*, Prepared under the sponsorship of the Pipeline Research Committee International of the American Gas Association, J. D. Hair & Associates, Inc., Louis J. Capozzoli & Associates, Inc., Stress Engineering Services, Inc., April 15, 1995.-

The normal force to produce an elastic bend is assumed to act over a longitudinal arc of 5º (refer to Figure 2). For a 1,800-foot radius, this is an arc length of 157.1 feet. It should be noted that this is a considerable approximation. Actual pilot holes are not drilled with the degree of precision that allows long smooth curves. The pipe will bear over shorter distances as the hole moves up and down. However, the normal force calculated is for an entire 12º sag bend. It is reasonable to distribute this force over a longer area with the understanding that the actual 12º bend may be made up of smaller deflections of varying radii.

Bearing stresses calculated for the boundary installation using the foregoing models and assumptions are as follows.

Bearing Stress Resulting from Weight	=	11 psi
Bearing Stress Resulting from Bending	=	31 psi
Total Upper Boundary Bearing Stress	=	42 psi

Rotary Abrasion Tester

A specific testing method was developed to replicate, as close as practical, HDD installation loading conditions. The method utilizes rock core samples from actual HDD project geotechnical surveys. This allows the relationship between coating wear and rock properties to be explored. Testing is conducted on coated 8-inch pipe samples that can be submerged in drilling fluid in a similar manner to a pipeline being pulled beneath a river. Core samples are loaded to bear against the pipe at a stress level approximating the coating to soil load described previously. Rotating the coated pipe sample simulates pipe movement.

The rotary abrasion tester fabricated for this research is shown in Figures 4, 5 and 6. Weighted arms load rock cores that rotate over to bear on the top of the samples. The weight can be adjusted to provide the desired bearing stress. Sample rotation is by an electric motor with speed controlled to a level similar to the speed of a pipe being installed by HDD.

Coating thickness is measured with a digital mil gage (PosiTector 6000 Model FS from Defelsko). The gage has the ability to measure a wide range of coating thickness with a fixed accuracy tolerance of less than ±2 mils. In order to insure that measurements are taken at consistent locations, a template is used. The template consists of a non-ferrous material of known length with a perfect straight edge on one side. Holes are drilled incrementally along the straight edge to the diameter of the gage probe to create a profile of the coating thickness. The drilled holes are individually labeled so the measurement "points" can be recorded. An example of a template made from a yardstick is shown in Figure 7 with measurement points labeled "A, B, C, D, E, F, and G".

Soil Samples

In order to replicate subsurface conditions that would be the most abrasive, and therefore most damaging to a pipe coating, 2 inch diameter cylindrical cores of competent igneous and metamorphic bedrock were chosen for use in the rotary abrasion testing procedure. Individual rock core samples were taken from actual HDD river crossing projects. The cores were obtained using standard core barrel techniques. The leading edge of each sample was trimmed prior to the beginning of each test so that consistency between contact surfaces could be maintained.

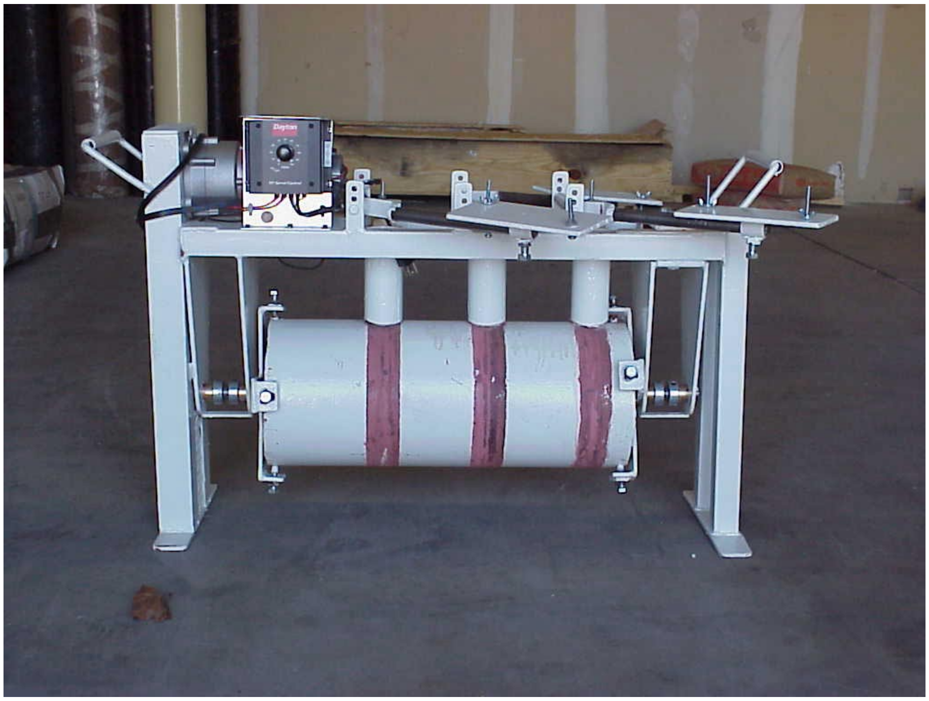

Figure 4, Rotary Abrasion Tester

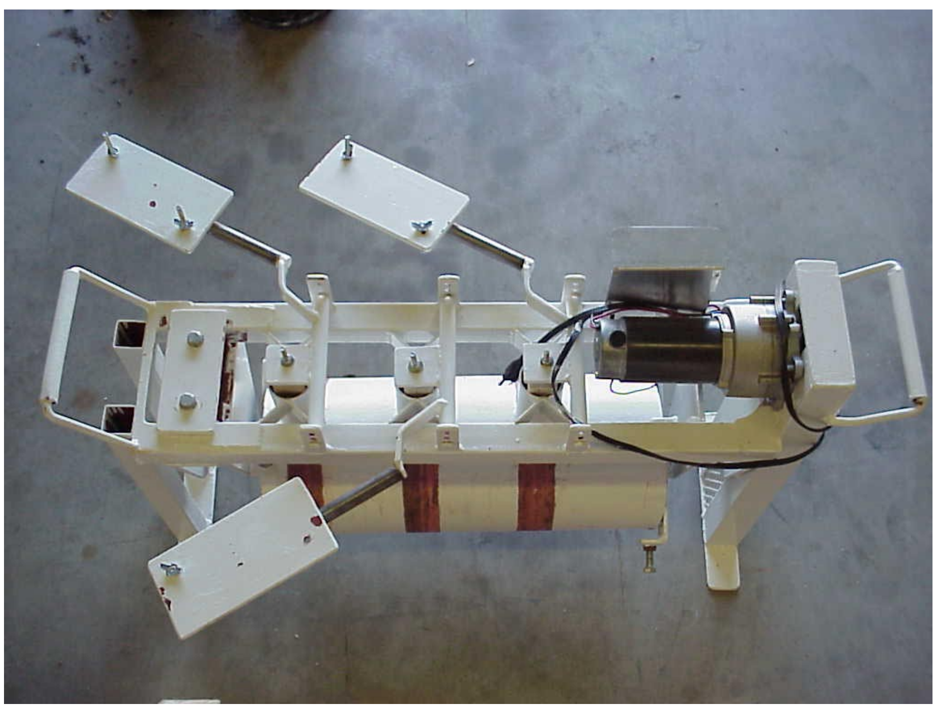

Figure 5, Rotary Abrasion Tester

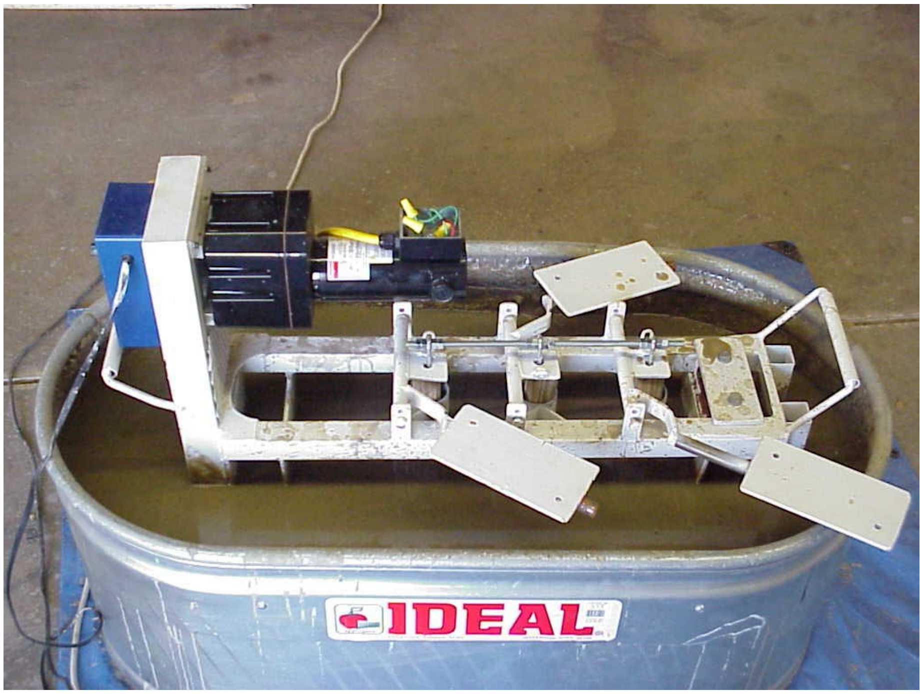

Figure 6, Rotary Abrasion Tester in Drilling Mud Bath

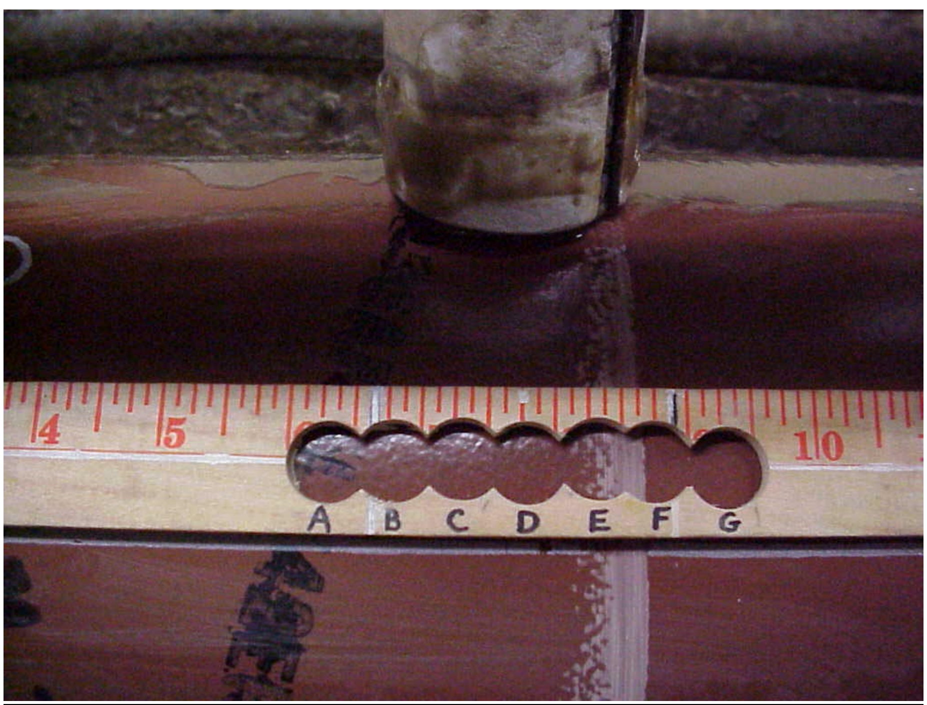

Figure 7, Template with measurement points

Summary of Test Results

Results of tests on coating systems are summarized in this section. Complete test data can be obtained from the PRCI. J. D. Hair & Associates conducted rotary abrasion testing at a project laboratory in Tulsa, Oklahoma. Ten coating systems were tested.

Coating Abrasion Wear Index

Evaluation of coating performance under the rotary abrasion test is accomplished by calculating a *Coating Abrasion Wear Index*. The index is calculated by taking the maximum coating loss and dividing it by the duration of the test. This yields a figure in mils per hour. Selected test results are presented below.

	Index
1. Fusion Bonded Epoxy A	0.14
2. Polyurethane/Polyurea	0.58
3. Epoxy Polymer	0.81
4. Fusion Bonded Epoxy B	0.33
5. Epoxy Urethane	0.10
6. Urethane	0.27
7. Fusion Bonded Epoxy C	0.13

Care should be exercised in using the indices presented above to determine relative performance of coating systems. Although every effort was made to perform the tests under a consistent set of conditions, some variation is inevitable since the rotary abrasion tester uses natural rock samples. The abrasiveness of the rock can change in the same sample. Rock samples fracture and wear during testing. Bearing areas change with a resulting change in bearing stress.

Coating Abrasion Wear Rate

Differences in the hole wall to pipe contact mechanism during installation and the sample to pipe contact during testing need to be considered when relating the coating abrasion wear index to reduction of coating thickness. An appropriate contact factor should be applied.

A point on the surface of a pipeline could conceivably be in constant contact with the hole wall during pull back whereas the rock sample in the rotary abrasion tester comes into contact with a point on the surface of the pipe once every revolution. However, it is unlikely that any point on the surface of the pipe is in constant contact with the hole wall during pull back. A 10° arc out of the total circumference of the pipe has been assumed to bear against the wall. Pull sections have been observed to slowly roll during installation. Reamed holes are not perfectly cylindrical nor do steel pipes conform to a directionally drilled hole. Any given point on the surface of the pipe will only be in intermittent contact with the hole wall and it is not possible to determine the duration of contact for any given pipeline pull back scenario.

On the other hand, the abrasion mechanism in the rotary tester is fairly aggressive. The same point on the sample is in contact with the same circumferential band. The coating material can be broken down and wear can accumulate over the entire duration of the test. At a rotation speed of approximately ten rpm, any given point on the pipe contacts the rock sample once every six seconds.

Taking the preceding discussion into account, a contact factor of four is recommended for determining a coating abrasion wear rate from the coating abrasion wear index. This can be visualized as having the same effect as adding three additional rock samples to the tester at equally spaced intervals around the circumference of the pipe sample. Any given point on the pipe would contact a sample every one and one half seconds.

For example, using a contact factor of four, the coating abrasion wear rate for Fusion Bonded Epoxy A is 0.56 (4 x 0.14) mils per hour. An HDD crossing in rock coated with Fusion Bonded Epoxy A and with an anticipated pull back duration of 10 hours would have an anticipated coating thickness loss of 5.6 mils at random locations. The same crossing coated with Epoxy Polymer would have an anticipated coating thickness loss of 32.4 mils (4 x 0.81 x 10) at random locations.

Conclusions and Recommendations

Conclusions and recommendations stemming from this research project are as follows.

- Coating loss due to abrasion from soil and very soft rock is not a critical problem in HDD installations. Initial tests were run in the rotary tester using soft rock samples (i.e. shale, mudstone). No coating wear resulted and the rock samples broke down during testing indicating that testing with very soft rock should be discontinued.

- Coating loss will occur during HDD installations through hard abrasive rock (i.e. granite, quartzite, hard sandstone). This loss has been conservatively quantified and can be mitigated by specifying the appropriate thickness of one of several available protective coating systems.

- The length and type of rock to be penetrated should be taken into consideration when specifying protective coating thickness. In general, bedrock with high unconfined compressive strength and Mohs hardness can be expected to be abrasive and cause coating wear.

- Point loads from sharp rock fragments and gravel will gouge coating. The depth of these gouges appears to be limited and coating integrity can be preserved by specifying the appropriate thickness of one of several available protective coating systems.