THE DESIGN DECISION MODEL™
FOR CORROSION CONTROL OF
DUCTILE IRON PIPELINES
Introduction

The iron pipe industry has a long tradition of innovation, consistently providing the preferred pipe material for utility engineers across the generations. While the success of iron pipe has been remarkable, manufacturers continue to seek new ways to make a proven product even more reliable.

One area of improved reliability is in the field of corrosion control. Since the first use of polyethylene encasement to protect iron pipe in an operating system in 1958, corrosion control has come increasingly to the forefront. As utilities become more aware of the need to protect their infrastructures, more are seeking the advice of corrosion engineers.

These experts bring considerable knowledge of corrosion-protection solutions for various piping materials to the water and wastewater industry. However, the experience of many corrosion engineers with Ductile Iron varies widely and is generally more limited than with steel or other materials. Therefore, corrosion-control recommendations for new Ductile Iron pipelines also vary widely. As a result, utility engineers face the unfortunate necessity of having to choose among corrosion-control design recommendations that contradict one another.

To better serve the water and wastewater industries, the Ductile Iron Pipe Research Association (“DIPRA”) and Corrpro Companies, Inc.* tapped their extensive knowledge and experiences to jointly develop a practical, cost-effective corrosion-control solution. The result is a Design Decision Model™ (DDM™) that both DIPRA and Corrpro use as an engineering tool to address corrosion on proposed Ductile Iron transmission and distribution pipeline projects.

The DDM™ represents a significant advancement in the area of corrosion control for Ductile Iron pipelines. In the three years of development of this practical design tool, DIPRA and Corrpro evaluated many factors, including:

- Shared corrosion experiences and know-how.
- Analysis of DIPRA’s and Corrpro’s extensive databases on corrosion.
- Laboratory and field testing of standard, as-manufactured Ductile Iron pipe.
- Field inspections of existing Ductile and Gray Iron pipe, including test site and in-service pipes.
- Joint field investigations of proposed Ductile Iron pipelines.
- A comparison of soil-testing protocols and results.

The advanced, two-dimensional DDM™ incorporates a comprehensive system of corrosion-control recommendations. The result is a highly effective, economical corrosion-control strategy that gives utility managers confidence that, throughout its intended life, the pipeline they install tomorrow will provide the reliable service they insist upon for their customers.

The Design Decision Model™

The DDM™ is a risk matrix concept that incorporates an evaluation of the likelihood of corrosion along a proposed Ductile Iron pipeline route and the consequences that may result from a corrosion-related problem. In this way, a utility is provided with a recommendation for corrosion control that is best suited for the particular installation under design. Recommendations range from simply installing the Ductile Iron pipe as-manufactured with its protective standard shop coating and annealing oxide layer, to encasing the pipe in polyethylene, to providing cathodic protection currents to control the rate of corrosion.

* Corrpro Companies, Inc. is the world’s largest provider of corrosion-engineering services. Additional information on Corrpro may be found at www.Corrpro.com.

† DDM™ (Design Decision Model™) is a trademark for the statistical corrosion decision model jointly owned by Corrpro Companies, Inc. and the Ductile Iron Pipe Research Association (DIPRA).
Figure 1 shows that the recommendations for corrosion control result from obtaining a point count for both Likelihood and Consequence Factors. Entering the graph at the appropriate points, a color-coded intersection is found that establishes the appropriate corrosion mitigation recommendation. As enumerated in Figure 1, the methods include:

1. Installing the pipe as-manufactured with its protective standard shop coating/annealing oxide system.
2. Encasing the pipe in polyethylene.
3. Encasing the pipe in polyethylene or encasing the pipe and providing bonded joints.
4. Encasing the pipe in polyethylene and providing bonded joints or providing life-extension cathodic protection currents, with or without encasement.
5. Cathodic protection.

**Likelihood Factors**

Using the 10-Point System as described in Appendix A of ANSI/AWWA C105/A21.5 as a basis, the DDM™ evaluates the following factors in determining the likelihood that corrosion could be a problem for a proposed Ductile Iron pipeline:

- Resistivity
- Moisture Content
- Ground Water Influence
- pH
- Chlorides
- Sulfides
- Redox Potential
- Bi-metallic Considerations
- Known Corrosive Environments

Of the above, resistivity, pH, redox, sulfides, and moisture content are criteria that carry over from the 10-Point Soil Evaluation System that the Ductile Iron pipe industry has used for decades. For a discussion of the importance of these factors in contribution to a corrosion cell, please refer to Appendix A of ANSI/AWWA C105/A21.5.

New Likelihood Factors include considerations related to the concentrations of chlorides in the soil and whether bi-metallic couplings such as corporation stops or connections to other pipe materials will be present. Also added to this system is an evaluation regarding the influence of the ground water that may be present and whether that ground water will fluctuate, such as would be found in tidal areas, on a multiple-times daily basis into and out of the pipe zone.

Also, as noted in Appendix A of ANSI/AWWA C105/A21.5, there is a need to recognize that there are soils and installations that are known to be corrosive regardless of the results of any testing that might be done. Examples include cinders, landfills, and peat bogs. These "known corrosive environments," when encountered, tell us that the likelihood of a corrosion problem would be significant if the pipe were to be installed as-manufactured.

**Consequence Factors**

Consequence Factors relate to operational reliability and the difficulties that may exist in effecting a repair to a Ductile Iron pipeline. The following core factors are used to establish those consequences:

- The Diameter of the Pipe.
- The Location of the Pipe.
- The Depth of Cover.
- Whether an Alternative Supply of Water Is Available.

These factors are used to evaluate access to the pipe at a particular location and the relative difficulty in effecting repairs. Access can be categorized as good, with minimal traffic considerations, typical excavation depths, the availability of an alternative supply of water, etc., or increasingly more difficult where depth of cover, right-of-way considerations, utility congestion, or unstable soil conditions may have an impact on repair efforts.

Taking the results of the Likelihood and Consequence assessments made at discrete locations along the proposed pipeline’s right of way, the two-dimensional Design Decision Model™ grid is used to find a recommended mitigation method at each location. In doing so, the corrosion decision-making process is simplified and yields a corrosion-control strategy that reflects a proven state-of-the-art solution. Using the DDM™ results in tailor-made corrosion control for the various conditions that may exist along the pipeline's
length, rather than using a broad brush solution that applies the worst case to the pipeline as a whole. In doing so, the DDM™ process provides a value-engineering approach that effectively, economically controls corrosion.

**The Basis of the DDM™**

The DDM™ began with an evaluation of the results of decades of corrosion-related research and field experience involving Gray and Ductile Iron pipes. Combining data from DIPRA and Corrpro resulted in a database comprising more than 60,000 individual data entries that included all of the compiled test site and field investigation results from the iron pipe industry and from Corrpro. In addition, Corrpro conducted laboratory and field studies to ascertain polarization characteristics, corrosion rates, and corrosion-protection current requirements for Ductile Iron pipe. These data helped formulate the recommendations in the DDM™.

**The Database: A Statistical Analysis**

Research into corrosion of iron pipe was initiated by what is now DIPRA in 1928. Through the years, DIPRA has conducted more than 115 corrosion-related research projects involving more than 2,000 individual production-run Gray and Ductile Iron specimens that were placed throughout the United States in test sites (see Figure 2) with varying soil environments, including some of the most corrosive found in nature.

**Figure 2: DIPRA Test Sites**

DIPRA’s test site locations represent a variety of soil conditions, from relatively non-aggressive soils to the most corrosive found in nature. Typical specimens are capped to prevent internal corrosion and removed incrementally to evaluate the effects of external corrosion over time. Weight loss and deepest pit measurements are taken and analyzed for each.

The database also included the results of some 300 inspections of in-service installations of Gray and Ductile Iron pipes in both aggressive and non-aggressive soils, with and without specifically applied corrosion control (see Figure 3).

**Figure 3: Typical Field Investigation Results**

Investigations such as these were conducted on in-service pipelines. Many were encased in polyethylene, such as the 4-inch Gray Iron pipe from Lafourche Parish, LA, shown on the left. This pipeline has been inspected many times, including, as shown above, after 45 years of service in an aggressive soil. Other investigations involved as-manufactured pipelines, as in the case of the 16-inch Ductile Iron pipe on the right from Princeton, KY, inspected some 40 years after installation in a non-aggressive environment.
From the database, a subset consisting of nearly 1,400 specimens and inspections in more than 300 different soil environments was developed. This subset was used to analyze the need for and effectiveness of encasement as a corrosion-control method for Ductile Iron pipe. Included in that database were 1,379 pipe specimens that were either sand blasted (annealing oxide removed), bare (the standard shop coating not provided, but the annealing oxide layer intact), as-manufactured (including the standard shop coating and annealing oxide layer), or polyethylene-encased Gray and Ductile Cast Iron pipes.

The soil data that was collected allowed DIPRA to analyze the behavior of these pipes according to whether the soil was considered corrosive. Table 1 shows the results of the investigations that were conducted on pipe in soils that were not considered to be aggressive according to the 10-Point Soil Evaluation System found in Appendix A of ANSI/AWWA C105/A21.5.

The data indicate that as-manufactured Ductile Iron pipe placed in soils that are not considered to be aggressive will not suffer from meaningful corrosion attack.

### Table 1: Investigations of Gray and Ductile Iron Pipes in Non-Aggressive Soils

<table>
<thead>
<tr>
<th>Pipe Condition</th>
<th>Number of Specimens</th>
<th>Mean Deepest Pitting Rate (in./yr.)</th>
<th>Years to Penetration*</th>
</tr>
</thead>
<tbody>
<tr>
<td>As-manufactured (Standard Shop Coating)</td>
<td>43</td>
<td>0.00067</td>
<td>373</td>
</tr>
<tr>
<td>Polyethylene Encased</td>
<td>12</td>
<td>0.0000</td>
<td>∞</td>
</tr>
</tbody>
</table>

*Years to Penetration* is calculated using the single deepest pit in each specimen and the assumptions that a linear pitting rate would exist and the pipe had a wall thickness of 0.25 inches (the minimum nominal Ductile Iron pipe wall that is manufactured). These assumptions result in a conservative evaluation.

The Effectiveness of Polyethylene Encasement

As shown in Table 2, another analysis of the database considered pipe specimens and investigations that were taken from corrosive soils as evaluated by the 10-Point System in Appendix A of ANSI/AWWA C105/A21.5†.

### Table 2: Investigations of Gray and Ductile Iron Pipes in Corrosive Soils

<table>
<thead>
<tr>
<th>Pipe Condition</th>
<th>Number of Specimens</th>
<th>Mean Deepest Pitting Rate (in./yr.)</th>
<th>Years to Penetration*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand Blasted (annealing oxide layer removed)</td>
<td>102</td>
<td>0.025</td>
<td>10</td>
</tr>
<tr>
<td>Bare (uncoated)</td>
<td>22</td>
<td>0.0151</td>
<td>17</td>
</tr>
<tr>
<td>As-manufactured (Standard Shop Coating)</td>
<td>103</td>
<td>0.0105</td>
<td>24</td>
</tr>
<tr>
<td>Polyethylene Encased</td>
<td>151</td>
<td>0.00045</td>
<td>556</td>
</tr>
</tbody>
</table>

Comparing the pitting rates for the unprotected versus polyethylene-encased iron pipes, the results show that polyethylene encasement is a very effective way to control corrosion on Ductile Iron pipelines in most corrosive soils. These results have been confirmed through more than 45 years of successful usage of polyethylene encasement on tens of millions of feet of water and wastewater lines throughout North America.

### Summary: The Performance of Iron Pipe

In addition to the results shown previously, the statistical work conducted in analyzing the DIPRA/Corrpro databases also addressed related questions regarding comparisons of Gray and Ductile Iron corrosion rates and the corrosion rate at damaged areas in polyethylene encasement compared to as-manufactured specimens.

* “Years to Penetration” is calculated using the single deepest pit in each specimen and the assumptions that a linear pitting rate would exist and the pipe had a wall thickness of 0.25 inches (the minimum nominal Ductile Iron pipe wall that is manufactured). These assumptions result in a conservative evaluation.
† This analysis does not include specimens that were placed in what are defined as “Uniquely Severe Environments” in Appendix A of that standard.
In summary, the results of the statistical analyses of the database showed:

- Ductile Iron pipe’s mean deepest pitting rate was less than that of Gray Iron. This allowed the corrosion data for Gray Iron to be conservatively analyzed in combination with the data for Ductile Iron pipe.
- Polyethylene encasement provides effective corrosion control for Ductile Iron pipe in most corrosive environments.
- As-manufactured, shop coated Ductile Iron pipe does not require additional corrosion protection in non-aggressive environments.
- The corrosion rate of iron pipe at damaged areas in polyethylene encasement is not greater than that of non-encased iron pipe.
- The 10-Point Soil Evaluation System in Appendix A of ANSI/AWWA C105/A21.5 is a reliable tool for evaluating the corrosivity of soils to Ductile Iron pipe.

**Corrpro’s Research: Controlling the Rate of Corrosion**

As part of the cooperative effort between DIPRA and Corrpro in the development of the DDM™, Corrpro undertook research in its laboratories and at DIPRA test sites. The research included laboratory studies that evaluated the protective value of Ductile Iron pipe’s standard shop coating and annealing oxide layer on corrosion rates, as well as laboratory and field studies to evaluate polarization characteristics, corrosion rates, and corrosion-protection current requirements for production Ductile Iron pipe. The laboratory work involved some 100 specimens in five aqueous solutions of known resistivity and 40 samples in five different soils, including soils from DIPRA test sites. The field work was conducted on 32 as-manufactured pipes installed at four DIPRA test sites having a range of soil corrosivities.

Corrpro’s ultimate goal in this research was to document the benefits of established corrosion-mitigation techniques that ensure an acceptable minimum pipeline service life for Ductile Iron pipelines to be installed in more aggressive, higher-consequence locations.

**The Value of the Standard Shop Coating/Annealing Oxide Layer — a Unique Combination**

Corrpro used specimens taken from production pipe of varying shop coating conditions, placed them in various aqueous solutions of known resistivity, and measured the resulting corrosion rates. These specimens included pipe that was uncoated as well as shop coated pipes of varied coating thickness and age. The results indicated that the corrosion rates were lower on coated samples and that the standard asphaltic shop coating/annealing oxide layer does provide a good degree of corrosion protection.

**Soil Testing — Coating Resistance, Polarization Levels, and Corrosion Rates**

Corrpro tested production pipes in soils, both in the laboratory and in the field. The soils used in the laboratory work were selected to obtain a range of conditions and included soils from four DIPRA test sites where field tests were also conducted. The soils were largely selected because they were aggressive to Ductile Iron.

![Figure 4: Polarization versus Corrosion Rate](image)

Field and laboratory testing demonstrated the feasibility of controlling corrosion rates on as-manufactured Ductile Iron pipes in a variety of soils. For example, referring to the above graph, the service life of Ductile Iron pipe could be quadrupled (corrosion rate reduced to 25 percent) by the application of a cathodic current that would polarize the pipe approximately 0.070 volts.

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5 Test sites included Spanish Fork, UT, Everglades, FL, Hughes, AR, and Raceland, LA.
**Bonded Coatings and Ductile Iron Pipe**

In the DDM™, the use of bonded coatings on Ductile Iron pipe is excluded. Reasons for this relate to the nature of the external surface of Ductile Iron pipe, which results from the manufacturing process, and the incompatibility of Ductile Iron pipe and bonded coatings. More practical and equally effective methods are included in the model, offering lower-cost options for corrosion control to the owner.

**The Manufacture of Ductile Iron Pipe**

Ductile Iron pipe is a cast product. The manufacturing process involves centrifugal casting to form the pipe and subsequent annealing of the pipe to set its physical properties (see Figure 5).

![Figure 5: The Manufacturing of Ductile Iron Pipe](image)

Manufacturing Ductile Iron pipe is a dynamic process that includes the centrifugal casting of molten iron into pipe and subsequent annealing of the pipe after removal from the casting machine. The resulting product includes a pronounced peen pattern and annealing oxide layer in the outer surface of the pipe.

![Figure 6: Annealing Oxide Layer](image)

The manufacturing of Ductile Iron pipe includes an annealing process that results in a protective iron oxide layer on the outside surface of the pipe, as shown above on the left. Blasting of the pipe often results in the blistering or slivering of the pipe surface that is evident on the right, making the pipe unusable.

The casting process results in a pronounced peen pattern on the outside surface of the pipe. This peening is transferred from the casting mold and is used to improve the quality of the casting in many ways, including helping to anchor the molten iron and distribute it circumferentially against the mold. Annealing the pipe relieves residual stresses within the pipe wall and establishes the desired ferritic character of the final product. Without this annealing process, the pipe would be brittle and subject to mechanical failures — not what the water and wastewater industries have come to expect from Ductile Iron pipe.

Annealing the pipe also results in the formation of a corrosion-resistant oxide layer on the outside surface of Ductile Iron pipe (see Figure 6). The oxide layer in conjunction with the shop coating plays a part in providing the inherent resistance of Ductile Iron pipe to corrosion in most soil environments.
In order to apply a bonded coating used in underground pipeline corrosion control, Ductile Iron pipe, like any metallic pipe, would require a surface preparation that includes a sand or shot blasting to help the coating adhere. Unfortunately, this blasting often results in a “blistering” or “slivering” of the annealing oxide (see Figure 6) and, in effect, ruins the pipe.

Further, while bonded coatings require a “blast profile” for their application, these profiles are generally on the order of 1 to 4 mils thick. However, the peen pattern in Ductile Iron pipe is on the order of 20 to 30 mils, exceeding these typical blast profiles many times over. Such a deep profile raises concerns as to whether the coating can properly cover the peened surface without numerous thin spots and holidays. This, added to concerns over the damage that may occur to the pipe surface during blasting, makes the prospect of good coating performance over the long term questionable.

These concerns, in addition to those that relate to the difficulties in the coating of Ductile Iron pipe’s irregular-shaped joints and fittings in the field, the need to repair coating damage that results from in-transit handling, the inability to make ready field adjustments when installing the pipe, and the unfamiliarity of Ductile Iron pipe contractors with bonded coatings lead DIPRA, Corpro, and the manufacturers of Ductile Iron pipe to recommend that they not be specified. The ability of bonded coatings to provide the level of service desired is problematic at best, and there are alternative mitigation methods described in the DDM™ that are more cost effective.

### Polyethylene Encasement and Cathodic Protection

One aspect of the DDM™ includes the application of cathodic protection currents to Ductile Iron pipe either with or without polyethylene encasement. According to Kroon, “The use of corrosion-protection currents improves the effectiveness of polyethylene encasement by protecting the pipe where the film was damaged or not properly applied resulting in uncovered surfaces. The methods are not exclusive and there is synergy when used in combination.”

The use of polyethylene encasement and cathodic protection has seen an increase in recent years, with some of the more significant installations on large pipeline projects in the Dakotas and elsewhere. These projects, involving nearly 2 million feet of polyethylene-encased, cathodically protected iron pipe, have provided excellent opportunities to evaluate the effectiveness of cathodic protection in conjunction with unbonded films, and investigations into such installations have indicated successful corrosion control. The successes of these pipelines point to the efficacy of this system.

One example, a pipeline in North Dakota, involves some 42 miles of 12- through 30-inch polyethylene-encased Ductile Iron raw water main. Installed in 1989, the pipeline was provided cathodic protection in 1991. In April 2004, the pipeline was investigated at several locations to evaluate the effectiveness of the cathodic protection/polyethylene-encasement system. The results, as indicated in Figure 7, showed the pipe to be in excellent condition, with no evident corrosion pitting.

**Figure 7: Ductile Iron Pipe: Polyethylene Encasement and Cathodic Protection Investigation**

The above 30-inch Ductile Iron pipe was installed in 1989 with polyethylene encasement and supplemented with cathodic protection two years later. The investigation was conducted on April 21, 2004, at two locations where the native soils exhibited resistivities of 520 and 480 ohm-cm, respectively. The results showed that the pipe was in excellent shape, with no evidence of pitting.

Other inspections on cathodically protected, polyethylene-encased Ductile Iron pipelines have involved corrosion probe readings that indicate the relative corrosion rates. One such example from the Mid-Dakota project provided readings taken in 2003 which indicated the average rate of corrosion to be on the order of 0.7 mils/year, a rate that would translate into a service life in excess of 350 years, based on linear corrosion and a 0.25-inch wall thickness.

The synergistic compatibility of polyethylene-encased Ductile Iron pipe under cathodic protection is gaining an impressive track record, further justifying inclusion in the mitigation recommendations found in the DDM™.
The Design Decision Model™ — a Cooperative Effort

The work performed by DIPRA and Corrpro in the development of the DDM™ provides utility owners with improved mitigation techniques in combating the effects of corrosion on Ductile Iron pipe. The effort consisted of an analysis of combined data into the performance of iron pipe in soils, laboratory and field tests, comparing soil-testing protocols, and an overall sharing of corrosion experiences and knowledge to help establish that corrosion rates can be economically controlled. The results of these efforts led to conclusions that:

- The standard shop coating and annealing oxide layer of Ductile Iron pipe provide a good measure of corrosion protection.
- Ductile Iron pipe can be expected to provide a long service life when placed as-manufactured in non-aggressive environments.
- Polyethylene encasement is an effective and economical method of corrosion control.
- Corrosion rates can be effectively and economically controlled through life-extension cathodic protection currents, when necessary.
- Bonded coatings are not a cost-effective solution to potential corrosion problems on Ductile Iron pipe.

The Design Decision Model™ Provides Effective, Economical Corrosion Control

With the DDM™, water and wastewater pipeline engineers and utilities are provided an effective, economical corrosion-control system for their proposed installations. They are also afforded a recommendation upon which both corrosion engineering and Ductile Iron pipe experts agree. In this way, utilities and consultants can make design decisions for Ductile Iron pipelines that are based on agreement, rather than on varying recommendations that are difficult to resolve.

For more information on the use and development of the DDM™, please contact your local DIPRA Regional Engineer.

References


