BRIDGE CROSSINGS WITH DUCTILE IRON PIPE

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Introduction

The Ductile Iron Pipe Research Association (DIPRA) periodically receives requests from engineers and contractors concerning recommendations on the design and/or installation of pipelines spanning waterways, highways, and railroads. Because the variables involved in such installations present numerous alternatives and challenges for designers and contractors, DIPRA does not provide recommendations and does not assume responsibility for design or installation practices on such projects. DIPRA does, however, recognize the engineering complexities inherent to bridge crossing pipelines and offers information to assist those involved with this type of installation and points out typical design criteria which should be considered for bridge crossings. Adaptation of the entire pipeline as a unit applied to a bridge structure involves close detail to many parameters in both structures. The following sections cover these parameters in detail.

General

Ductile Iron pipe is centrifugally cast in 18- and 20-foot nominal laying lengths. Nominal diameters range from 3 to 64 inches, with a variety of pressure and special thickness classes. Although Ductile Iron pipe is usually furnished with a cement-mortar lining, optional internal linings also are available for a wide range of special applications. Also, Ductile Iron pipe is normally furnished with an external asphaltic shop coat for a "finished" appearance, although shop-applied primers for special painting systems also are available for above ground use.

Joints

Ductile Iron pipe is furnished with several different types of joints: push-on, mechanical, restrained, ball and socket, flanged, and grooved and shouldered joints. Typically, bridge crossings involve push-on joints, restrained joints, or combinations thereof.

Push-on joints (see Figure 1) are excellent for bridges with properly designed and constructed supports. Ample deflections in these joints are possible when properly braced support structures are provided to carry the weight of the pipe and its contents and resist any forces acting against the pipe supports. Normally, expansion and contraction of the pipe due to temperature changes can be adequately provided for with such joints; if more adjustment is needed, expansion couplings (see section on Expansion/Contraction Couplings) should be considered.

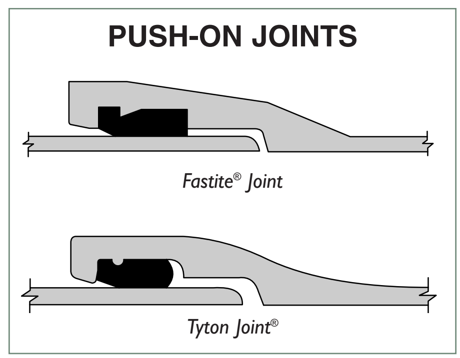

Figure 1

Mechanical joints (see Figure 2) are often used for fittings but are not generally used for straight runs of pipe. To accommodate possible pipe movement caused by thermal expansion and contraction, the push-on joint may be a better choice than the mechanical joint due to its deeper socket depth.

Figure 2

Since standard push-on and mechanical joints are not "restrained," due consideration should be given to proper design and construction of supports or anchorages to resist thrust forces, dead loads, impact and shock loads, and thermal changes.

The restrained joint complements the push-on and mechanical types by maintaining flexibility and also by providing both ease of assembly and a "locking feature" to resist pull-out. Numerous types are available employing modifications of the push-on and mechanical joint designs (consult with the pipe manufacturer regarding the use of standard push-on joints with gripping type gasket products on bridges). In a pressurized system, some flexible restrained joints are subject to significant joint extension. Therefore, when utilizing restrained joints, proper design and construction techniques normally should include provisions for extending each joint so as to engage its restraints. This may be accomplished by extending the joints fully during assembly and/or by hydrostatically testing the horizontal portion of the crossing separately (using restrained closures) before making connections to offset bends or riser pipes. Cumulative joint extension due to thrust pressure over a long crossing could result in over-deflection, excessive movements, and excessive beam loadings to fitting connections at the ends of a crossing.

Pipe Cradle Supports

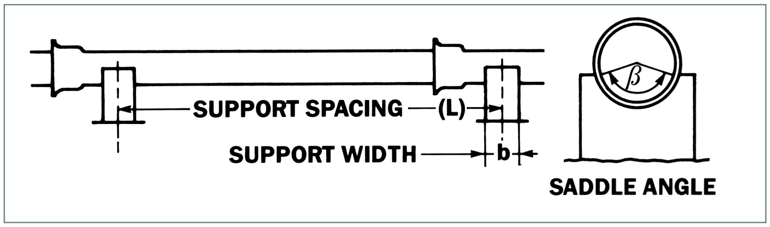

Figure 3

Typical installations of Ductile Iron pipe on bridges involve a basic "pipe-on-supports" approach, depending on local practice, regulatory requirements, the bridge structure, placement of the pipe on the bridge, the details of bridge/support systems, etc. When utilizing cradle supports which follow the contour of the pipe as referenced in the DIPRA publication, "Design of Ductile Iron Pipe on Supports" (see Figure 3), "the minimum pressure class in all sizes is more than adequate to support the weight of the pipe and water it contains" with one support per length of pipe (i.e., a span length of 18 or 20 feet). Proprietary assemblies are available for long span (multiple lengths per support) applications. Contact DIPRA member companies for details.

It is recommended that the saddle angle of the support be between 90 and 120 degrees. Little or no benefit is gained by increasing the saddle angle more than 120 degrees, while stresses tend to increase rapidly with angles less than 90 degrees. It is also recommended to use one support per length of pipe positioned immediately behind the bell. With these assumptions, each span can be conservatively treated as a simply supported beam.

It is of the utmost importance that sufficiently sturdy and properly located pipeline support structures be provided to prevent lateral and vertical movement of the pipe or joints and to also prevent any detrimental axial bending of the supports in response to axial pipeline movements. When a flexibly joined Ductile Iron pipeline is pressurized, some thrust forces develop — even at slightly deflected joints. If not adequately stabilized, these forces can cause the joints to deflect to their maximum, creating a "snaking" of the pipeline and possibly even separation of unrestrained joints.

Support structures must be designed to accomodate the weight of the pipe and its contents, and other applicable loadings and conditions, such as joint movement, seismic loadings, traffic vibrations, insulation, etc.

The location of the pipeline on the bridge will, in many cases, dictate the type of support to be used. Because of the many types of bridges and placements for these pipelines, specific design details for supports for all possibilities cannot be presented; however, three common locations for pipe placement are inside a concrete box utility corridor, underneath the deck between girders, and on the exterior side. Each location may require different types of support structures; here is a look at each.

- **Inside a concrete box utility corridor**

Support of the pipeline inside a box utility corridor is normally provided by the ceiling or the floor. One method of ceiling support is shown in Figure 4.

Lateral and axial movement is restricted by bracing the support structure against the side of the box corridor. Long rod lengths are not advisable due to the possibility of twisting or buckling and the lack of proper support resulting from critical movements.

Supporting the pipe from the "floor" of the box corridor may be accomplished in several ways. One way is shown in Figure 5. Straps should be used to secure the pipe to the support, with each length of pipe "strapped down" immediately behind the bell (the bell should not rest on the floor).

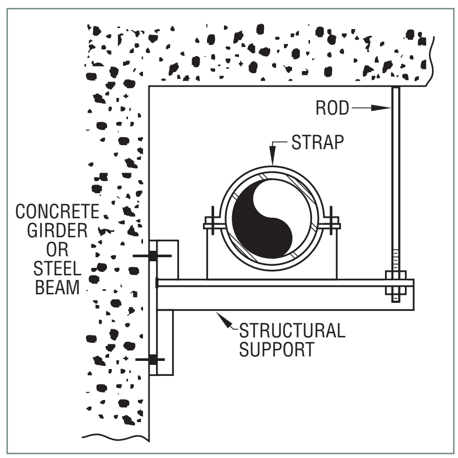

Figure 4

- **Underneath the deck between girders**

Because of the unlimited configurations in types of bridges and structural supports, it is impossible to address all the variations. In many cases, the pipe can be supported from the concrete deck as in Figure 4, with sufficient vertical and lateral support from the bridge under-structure. Where structural steel beams are used throughout the bridge, beam clamps present an easy solution to carrying the load. However, the support structure will require adequate lateral and axial bracing. Many bridges have steel beams running laterally under the bridge which may serve to anchor the support structure.

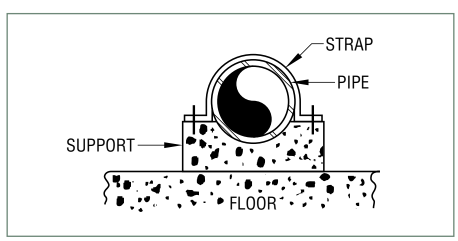

Figure 5

- **On the exterior side**

The structural material of the bridge exterior and its design configuration will generally dictate the arrangement for installing the Ductile Iron pipe. Examples of bridges with concrete or steel exteriors are shown in Figure 6. For bridges with wooden exteriors, drilling and tapping the supports are done easily in the field and generally, the spacing of supports will accommodate the 18- to 20-foot lengths of Ductile Iron pipe. The basic design of the supports and attachments should be directed or approved by the engineer, with due consideration for the structure to which the pipeline is to be attached.

The design choices for any placement location are many; however, these specific points need to be observed:

- At least one support per length of pipe is required (unless "long span" pipe is utilized).
- The minimum pressure class of Ductile Iron pipe is sufficient in all sizes to support the weight of the pipe and its contents.
- Proper lateral and vertical support is needed to prevent "snaking."

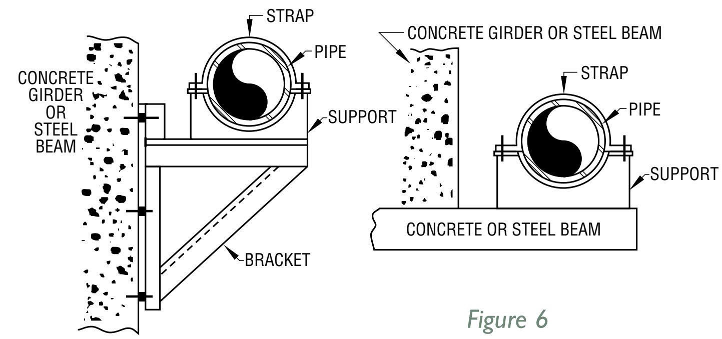

Figure 6

Pipe Supported on Rollers

Unlike cradle or saddle supports which follow the contour of the pipe and have a support/pipe contact area dependent on the diameter of the pipe, saddle angle and width of the support (see Figure 3), pipe supported on rollers normally has only two point contact locations at each roller support (see Figure 7). Due to smaller contact areas, this point loading results in much higher localized stress concentrations that are dependent on pipe size, pipe wall thickness, distance between rollers, location of rollers along the pipe length, radius of rollers, loading, etc. Formulas addressing these high stress concentrations for cylindrical shells and pipes have been published in technical literature. However, the stress analysis is difficult and the results are rendered uncertain by doubtful boundary conditions; therefore, the ultimate responsibility of such a design rests with the design engineer.

Even so, there have been thousands of successful Ductile Iron pipe bridge crossing installations utilizing roller supports. While one flat or roller support per length of pipe (normally located fairly close behind bells) has been shown in practice to be adequate for small diameter ductile iron pipelines (capitalizing on the innate strength and toughness of this pipe), multiple rollers per length may be appropriate for larger sizes. However, rollers should generally not be placed under spigots closely adjacent to bells, due to higher developed stresses and possible undesirable effects on joints.

As with cradled supports, it is of utmost importance that sufficient vertical and lateral stability be provided at roller supports behind bells, for both restrained and unrestrained joint pipe systems. A double roller "guide" or bracketed design (roller below and above the pipe) with lateral bracing is one method of accomplishing this (see Figure 8).

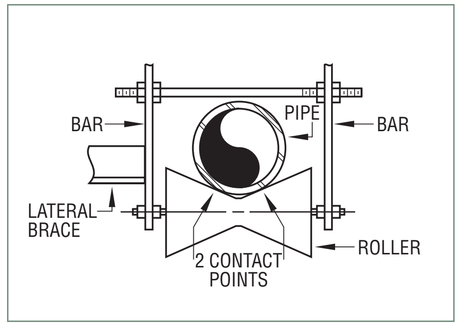

Figure 7

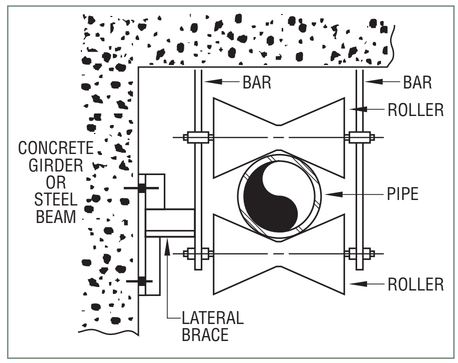

Figure 8

Expansion/Contraction Couplings

Conditions of fluid flow inside a Ductile Iron pipeline — as well as ambient temperature changes throughout the year — will affect expansion and contraction of the pipeline with respect to the bridge. Attention should be drawn to the fact that bridge expansion could differ from that of the pipe because of (1) differences between bridge and pipe temperature, with pipe temperature being affected by the temperature of its contents, (2) differences in coefficients of thermal expansion,* and (3) locations of bridge expansion joints which may concentrate movement relative to the pipe. Also, the engineer needs to consider the interaction of expansion/contraction couplings with thrust restraint systems, especially when restrained joints are used.

Expansion and contraction in conjunction with thrust movement could introduce excessive stresses in the Ductile Iron pipe, its joints, or its structural supports.

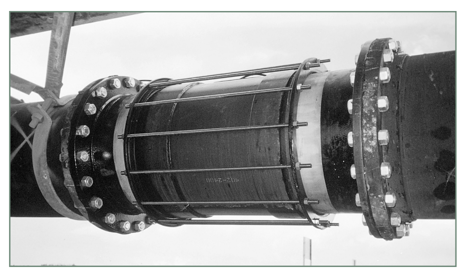
Figure 9

The number and location of expansion/contraction couplings, if required, are determined by the length and design of the bridge in consideration of the maximum anticipated temperature differential. These couplings are normally utilized for longer crossings and bridges with multiple spans. Typically, expansion/contraction couplings in the pipeline will be located adjacent to bridge expansion joints. These expansion/contraction couplings should be anchored to the bridge so they are isolated and will "work" with the bridge expansion joint and not cause lengthening of the pipeline that may cause unwanted stress to supports and over deflected bends at the ends of the bridge. Since these devices occasionally require maintenance, they should be located in an area that is easily accessible.

Basically, there are two types of couplings: single-end and double-end (see Figure 9). Manufacturers' recommendations for installation and proper use should be followed. The type of joints used for the Ductile Iron pipe will dictate the possible need for an expansion/contraction coupling.

*Coefficients of expansion:
Ductile Iron 0.0000062 inch/inch °F; structural steel 0.0000065 inch/inch °F; reinforced concrete 0.0000070 inch/inch °F

Generally speaking, push-on joints, strapped down behind the bell, are adequate for most short crossings without special expansion/contraction devices, assuming care is exercised in the installation procedure of these joints. Specifically, push-on joints should not be assembled completely "home" if installed in the winter, due to the expansion caused as the weather becomes warmer. This temperature change could cause a reaction to occur at each joint, "kicking" it out of alignment and creating a "snaking" action.

Abutments/Approach Piping

Design and installation of a pipeline on a bridge can be challenged by the pipeline's transition from underground to the bridge itself. When the pipeline can be run directly across the bridge and straight into the soil, even when this requires some purposeful deflection of pipe joints, this can often simplify many aspects of the design as opposed to using multiple offsetting bends in the approach/abutment areas. This may be particularly true in the case of long, pressure pipeline bridge crossings. In the event that bends must be used and external anchorage (by tie- down gravity blocks or batter piles, etc.) is provided to strictly control thrusts and thermal movements at these down bend locations, it may be advantageous to use as small an angle change as feasible to accomplish the needed elevation offset, as opposed to very large angle bends with large resultant thrust forces.

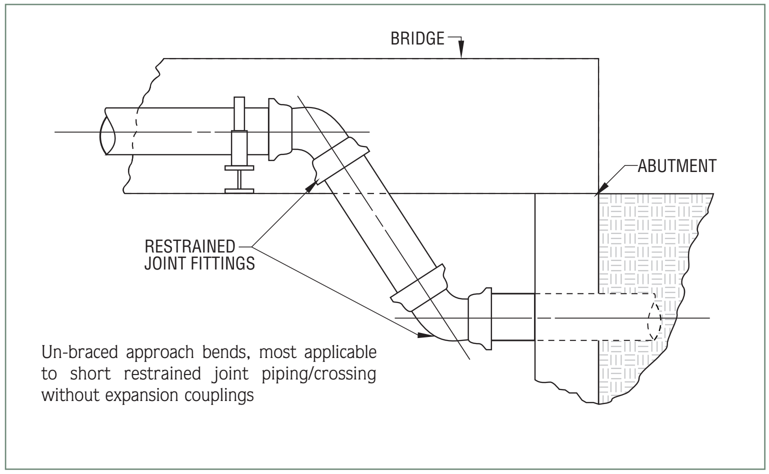

Figure 10

Thrust restraint is of primary importance particularly at this transition section if there is a change in direction, valve, or other thrust focus in the area (see Figure 10). If restrained joints are utilized on the bridge structure, the thrust can be carried through this transition section back to the underground piping on each side of the bridge. The equations for calculating the thrust forces are covered in the DIPRA manual "Thrust Restraint Design for Ductile Iron Pipe." If desired, a concrete block can be poured to anchor the elbow or bend at the end of the bridge. Sometimes the abutment of the bridge or separate piles, piers, batter piles, rock or soil anchors, etc. can safely be used to "tie down" the pipeline and/or bends and restrain the thrust forces. In particularly long exposed and pressurized crossings these types of anchors can prevent any rebating or "wagging" (outward and inward movement) of the bends in response to daily/seasonal temperature/length changes of the horizontal piping section on the bridge.

It is normally best practice to externally brace or tie down any vertical (down) bends in exposed pressure pipelines (e.g. strapped to adequate abutments or batter piles), particularly when long crossings are involved. This prevents any substantial horizontal and/or up and down "rebating" movements of these bends in response to pressure thrust and also thermal fluctuations in the horizontal span, that might over a period of time unnecessarily wear on the pipeline or seals. However, if these bends are not tied down, it should be understood that there will normally be some movement of these bends (e.g. outward and/or upward), and this movement can be particularly substantial if installers do not "extend" restrained joints and/or if crossings are long. For this reason, if bends are not externally anchored, it may be advisable to not place a strap or top roller firmly down on the spigot pipe barrel connecting to such bends, lest these straps or roller barrel locations be highly stressed by unblocked bend movements.

In the event that any approach bends are not buttressed or tied down, it may be necessary to fix/anchor the horizontal piping section (normally near the middle of the bridge) to the supporting structure. This is to minimize any tendency (caused by thermal movements or traffic vibration, etc.) of the piping to "walk" or edge (essentially as a unit) in one direction or the other, that could unreasonably over-deflect or load bend joints on one end and/or the other of the bridge.

When a Ductile Iron pipeline is to be installed on a new bridge, coordination with the contractor can facilitate this transition section by leaving an opening in the abutment wall for the pipeline.

Air Release

Ductile Iron pipe installed on a bridge may need an air release valve assembly to purge the pipeline of any accumulated air (see Figure 11). The size of the valve and assembly is governed by the pipe size and expected accumulations of air. Some restrictions may apply from the governing authority, such as the State Highway Department. However, an air release valve assembly generally is required at a high point in the pipeline, such as could occur on a bridge due to the change in elevation from the underground piping up to the supports on the bridge, or on a long vertically arched bridge.

Figure 11

Seismic Conditions

Special design considerations and provisions are warranted when seismic conditions might be encountered. In particular, various state or other authorities may require special flexibility and/or settlement capabilities in the approach area to allow for potential significant movement of the bridge relative to the buried approach piping/soil mass in an earthquake event. The approach piping can be subject to great joint deflections during earthquakes as well as elongation and contraction as the earth moves. Likewise, the piping on the bridge needs adequate supports to maintain integrity during shaking.

Some examples of seismic provisions include specifications of very strong and flexible restrained push-on joint ductile iron pipes, strengthening of supports and anchorages to withstand (along with any other normal loadings) "acceleration" in an earthquake event that produces additional force equal to a certain percentage (e.g. 20%) of the weight of the pipeline and contents in any direction, and/or providing special flexibility and/or extension capability in the approach areas. The latter can sometimes be accomplished with proprietary ball and socket joints, telescoping sleeves, multiple very short lengths of pipe, flexible restrained pipes, etc., or combinations of such concepts.

External Protection

It has been found that standard Ductile Iron pipe per ANSI/AWWA C151/A21.51 exposed to the atmosphere does not require special corrosion protection measures in most cases. In areas subject to corrosive atmospheric conditions, appropriate protection should be provided for the pipe as well as the steel hangers, clevises, threaded rods, etc.

In underground installations where Ductile Iron pipe is subjected to corrosive soil conditions, polyethylene encasement is generally recommended in accordance with ANSI/AWWA C105/A21.5 Standard. For these installations at bridge crossings, the polyethylene sleeve should extend a minimum of 12 inches beyond the soil at the soil/atmosphere transition and be taped in place to the pipe. For a comprehensive system of corrosion-control recommendations, see DIPRA's brochure "The Design Decision Model™ For Corrosion Control of Ductile Iron Pipelines."

Freezing Conditions

In the northern part of the country as well as in mountainous areas, freezing of fluids in a Ductile Iron pipeline is a possibility. Freezing can occur whenever the flow of water is interrupted or reduced drastically, especially with small-diameter pipe. During periods of interrupted flow, raised bridge pipelines should be drained by means of blow-off valves at each end. The pipeline can also be insulated to retard freezing, and heat tape can be installed between the pipe and insulation if a source of electricity is available. It should be noted that insulation alone will not prevent freezing if the flow of water is interrupted for any extended length of time.

Insulated Pipe

The amount, type, and application of insulation depends upon job-site conditions. Information on insulating systems and their installation can be obtained from the insulation manufacturer. Insulated Ductile Iron pipe-on-supports is a special case, and due to the fact that insulation and jackets for same are generally of lesser strength than Ductile Iron pipe, the designer and/or manufacturer of the chosen insulation systems should be consulted as to the need for support requirements for such systems. Normally, the best solution is to remove the insulation at supports so the pipe is in direct contact with the support.

Basic Design Approaches

From a basic design standpoint, there are some generally accepted principles for the overall design of a Ductile Iron pipe installation on a bridge. Generally, they are dependent on the bridge structure, the type of pipe joint being utilized, and on the method of pipe support.

The use of restrained joints and fittings allows the following:

- Axial thrust forces can be resisted.
- Movement of the pipe due to thermal expansion/contraction may be transmitted to expansion/contraction couplings without joint separation.
- Thermal expansion/contraction may be accommodated without joint separation and without pipe expansion/contraction couplings.
- Extra security is provided in the event of failure or damage of a support.
- The pipeline is effectively "separated" from the bridge structure (in conjunction with rollers or other pipe supports.)
- Consideration of anchoring one pipe to its support structure near the center of any long span so that total movement is divided between the two halves of the crossing.
- An easy means is provided for testing the bridge pipeline separate from the main pipeline without external thrust restraint (using restrained joint test closures).

When using unrestrained push-on or mechanical joint pipe and fittings, some general guidelines are appropriate:

- Unrestrained pressure pipelines should not be installed on hangers with little or no lateral support. This also applies to flexible restrained joints.
- Unrestrained Ductile Iron pipe should be clamped securely to the supports or structure with at least one support per length of pipe.
- Expansion/contraction is accommodated by the rubber gasketed joints.
- Expansion/contraction couplings are normally installed at all expansion joints in the bridge structure.
- Fittings must be externally thrust anchored and/or blocked.
- If crossings are to be tested independently of and without attaching to the main pipeline, test closure pieces must be externally restrained and/or anchored.

Each individual unrestrained joint should be brought fully home and then, dependent on the ambient temperature conditions at the time of installation, backed out slightly to provide for anticipated or possible thermal expansion of the pipe lengths. If counted on for thrust restraint, restrained joints normally should be fully extended to remove slack, engage the restraint, and minimize movements under pressure.

If the pipeline is attached to the structure, particularly on long crossings, pipe expansion/contraction couplings may be required at the bridge expansion joint locations. If such couplings are required, the adjacent pipe generally must be firmly attached or anchored to the bridge to prevent joint separations as the bridge and pipeline expansion mechanisms do their jobs.

Governmental regulations and/or construction codes may affect the pipeline bridge crossing design/construction and should be adhered to where applicable.

Construction

This document is not intended to give step-by-step, detailed instructions for the design or installation of any particular Ductile Iron pipeline on a bridge; however, there are certain principles and application techniques of which the installer and the designer/engineer need to be aware:

1. The design location for placement of the pipeline on the bridge will dictate, in many cases, the choices available for handling and installing the pipe. For example, if the pipe is to be installed in a box utility corridor, the option of installing the pipe from below the bridge is eliminated.
2. From a performance standpoint, one support per length of pipe is sufficient. However, two supports per length may facilitate the actual construction of the pipeline and/or also provide some redundancy or increased security.
3. To eliminate over-deflected joints and misalignment, vertical as well as horizontal bracing must be properly designed and installed.
4. For any joint that needs to function as an expansion joint, a suitable water-insoluble pipe lubricant (such as an underwater lubricant or the like) may be preferable over regular water soluble joint lubricant or soap for exposed pipe on the bridge.
5. The designer/engineer needs to consider the ambient temperature conditions with regard to assembly and service of the joints and expansion/contraction devices.
6. Where necessary, appurtenant items such as air-release valves, drain blow-offs, insulation, etc., should be designed and constructed to facilitate any future maintenance.
7. Support and hanger installations are critical to the integrity of the pipeline and as such should be properly designed, installed and maintained.
8. In the design of a new bridge, consideration should be given to provision of support locations and insertions of anchors, openings in the abutment and/or beams, etc., to facilitate pipeline installation.
9. Thrust restraint for a pipeline on a bridge is critical and needs to be properly considered. All thrust restraint mechanisms designed for the pipeline on the bridge should be installed with proper care and attention to detail. The use of restrained joints should be coordinated with the manufacturer to ensure proper assembly and installation practices.

Summary

The design and construction of a Ductile Iron pipeline on a bridge structure is unique from the standpoint of its placement outside the confines of a typical underground installation, its transition from underground to the bridge structure, and its susceptibility to the various prevalent loadings and conditions. Even so, with proper design approaches and construction techniques, bridge crossing installations can be easily accomplished. Further design and installation information is available through DIPRA and/or its member companies.

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Thrust Restraint Design for Ductile Iron Pipe, Sixth Edition. Birmingham, Alabama: DIPRA, 2006.

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