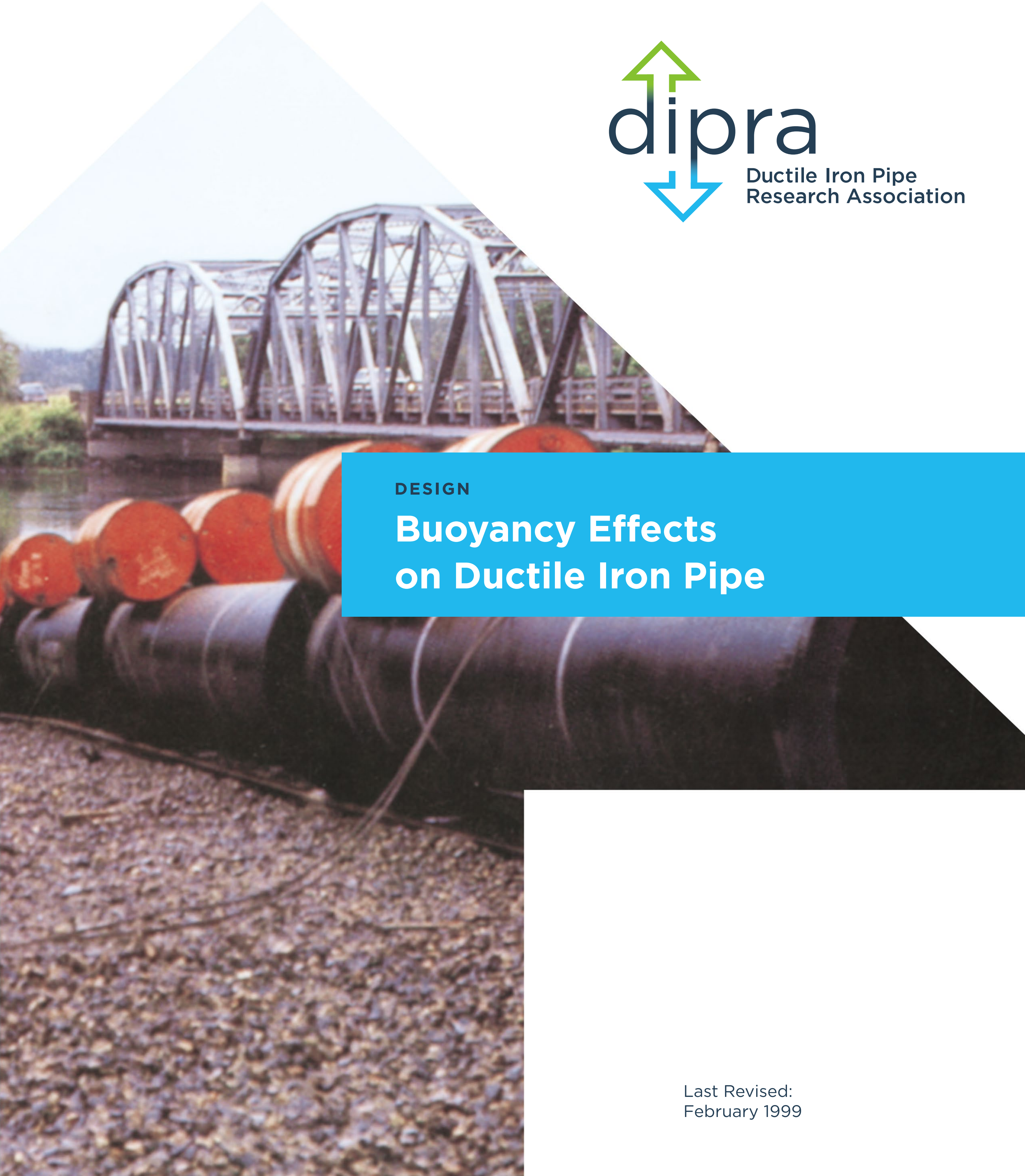
Strength and **Durability** for **LiFe**®

dipra
Ductile Iron Pipe
Research Association



DESIGN

Buoyancy Effects on Ductile Iron Pipe

Last Revised:
February 1999

BUOYANCY EFFECTS ON DUCTILE IRON PIPE

by Richard W. Bonds, P.E.
DIPRA Research/Technical Director

INTRODUCTION

Buoyancy is the tendency for a fluid to exert a supporting force on a body placed in the fluid. This force is called a "buoyant force" and is defined by Archimedes' principle as stated below.

A body in a fluid, whether floating or submerged, is acted on by a buoyant force equal to the weight of the fluid displaced. The buoyant force acts vertically upward through the centroid of the displaced volume and can be defined mathematically by the equation:

$$F_b = \gamma_f V_d$$

where:

F_b = buoyant force, lb
γ_f = specific weight of the fluid, lb/ft^3
V_d = displaced volume of the fluid, ft^3

An object with an average specific weight less than that of the fluid will tend to float while a object with an average specific weight greater than that of the fluid will tend to sink. When a body is floating freely, it displaces a sufficient volume of fluid to just balance its own weight.

The analysis of problems dealing with pipe buoyancy requires the application of the equation of static equilibrium in the vertical direction, $\sum F_v = 0$, assuming the object is at rest in the fluid.

The following procedure can be used for all problems:

Step 1. Draw a free body diagram of the pipe in the fluid. Show all forces which act on the pipe in the vertical direction including the weight of the pipe, the buoyant force, and all external forces.

Step 2. Sum all forces in the vertical direction, $\sum F_v$, assuming the positive direction to be upward.

Step 3. Solve for the resultant force. A resulting positive force will indicate that the pipe will tend to float and a resulting negative force will indicate that the pipe will tend to sink.

Any pipe material, e.g., concrete, steel, plastic, iron, etc., can be affected by buoyancy. Because the specific weight of Ductile Iron is greater than that of water, a Ductile Iron pipe/pipeline which is full of water will not float in water.

PIPE SUBMERGED IN A FLUID

A submerged body is acted on over its entire exterior surface by a pressure exerted by the fluid perpendicular to the surface of the body. The buoyant force is then the net vertical force exerted by the fluid on its surface. Each force can be measured as the weight of a column of fluid projected up to the free surface, plus, in the case of pressure at the free surface, the additional equivalent height of fluid added to the column. The net effect must simply be the difference in the magnitudes of these forces, since it is clear that the forces on top of the body are in opposite directions to the forces on the bottom of the body. In summing the forces, everything cancels except for an upward force equal to the weight of the fluid displaced by the body. This is the recognized Archimedes principle.

Figure 1 shows an assumed 1-foot long piece of pipe with capped ends submerged in a liquid, and its resulting free body diagram.

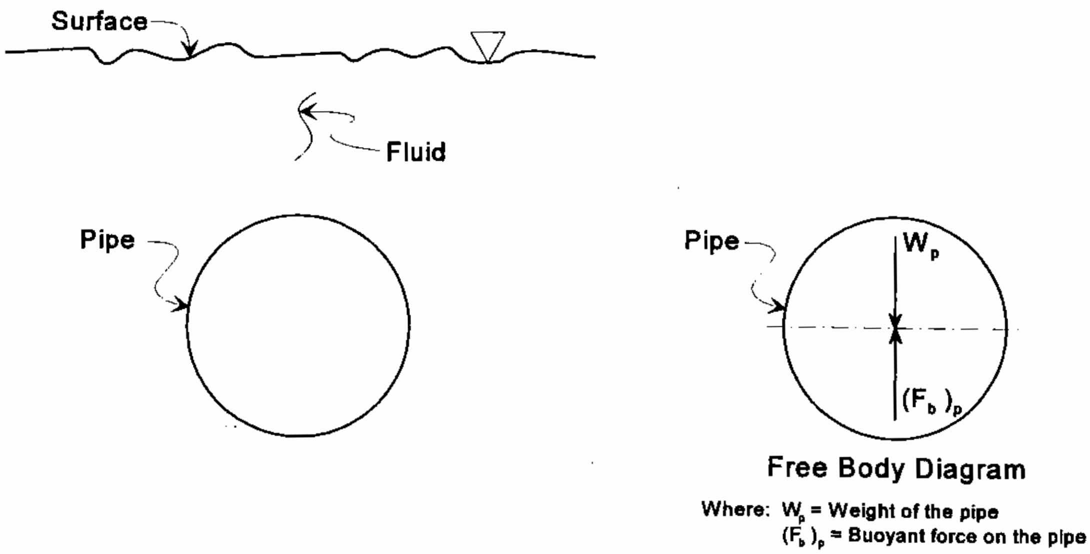


FIGURE 1

As an example, consider the 1-foot long pipe in Figure 1 as an unlined, totally empty (worst case) 6-inch diameter (outside diameter = 6.9-inch) Pressure Class 350 Ductile Iron pipe with a unit weight of 16.5 lb/ft. Assume the fluid is water which has a specific weight of 62.4 lb/ft^3. The analysis of this example would be as follows:

Step 1. Draw the free body diagram (see Figure 1).

Step 2. Sum all forces in the vertical direction.

$$\sum F_v = (F_b)_p - W_p$$

Step 3. Solve for the resultant force.

$$(F_b)_p = \gamma_f V_d$$

$$V_d = \frac{\pi D^2 L}{4} = \frac{\pi \left(\frac{6.9}{12} \text{ ft} \right)^2 1 \text{ ft}}{4} = 0.26 \text{ ft}^3$$

$$(F_b)_p = (62.4 \text{ lb/ft}^3)(0.26 \text{ ft}^3) = 16.22 \text{ lb}$$

$$W_p = (16.5 \text{ lb/ft})(1 \text{ ft}) = 16.5 \text{ lb}$$

Therefore:

$$\sum F_v = 16.22 \text{ lb} - 16.5 \text{ lb} = -0.28 \text{ lb}$$

The resulting negative force indicates that the 6-inch Pressure Class 350 Ductile Iron pipe, even full of air, would tend to sink in water.

As a second example, consider the 1-foot long pipe in Figure 1 as an unlined, totally empty (worst case) 48-inch diameter (outside diameter = 50.8-inch) Pressure Class 150 Ductile Iron pipe with a unit weight of 240.3 lb/ft. Again, assume the fluid is water which has a specific weight of 62.4 lb/ft^3. The analysis of this example would be as follows:

Step 1. Draw the free body diagram (see Figure 1).

Step 2. Sum all forces in the vertical direction.

$$\sum F_v = (F_b)_p - W_p$$

Step 3. Solve for the resultant force.

$$(F_b)_p = \gamma_f V_d$$

$$V_d = \frac{\pi D^2 L}{4} = \frac{\pi \left(\frac{50.8}{12} \text{ ft} \right)^2 1 \text{ ft}}{4} = 14.08 \text{ ft}^3$$

$$(F_b)_p = (62.4 \text{ lb/ft}^3)(14.08 \text{ ft}^3) = 878.59 \text{ lb}$$

$$W_p = (240.3 \text{ lb/ft})(1 \text{ ft}) = 240.3 \text{ lb}$$

Therefore:

$$\sum F_v = 878.59 \text{ lb} - 240.3 \text{ lb} = 638.29 \text{ lb}$$

The resulting positive force indicates that the 48-inch Pressure Class 150 Ductile Iron pipe, full of air, would float in water.

As long as a pipe has an average specific weight greater than that of the fluid it displaces, it will tend to sink. Eighteen and twenty foot laying lengths of push-on joint Ductile Iron pipe in the following sizes and classes will not float in water (62.4 lb/ft^3) even when they are unlined and fully empty: 3, 4, and 6-inch diameter in all pressure and thickness classes; 8-inch diameter Special Thickness Class 52 and greater; 10-inch diameter Special Thickness Class 54 and greater; and 12-inch diameter Special Thickness Class 56. Also, Ductile Iron ball joint pipe in small sizes, generally 4-inch through 16-inch, will not float in water when they are empty. Buoyancy data for each type of ball joint pipe can be obtained from the manufacturer.

BURIED INSTALLATIONS

When a pipe with a buoyant force that would tend to make it float in water is buried below the water table, the question as to the security from pipe "flotation" could be important to the designer. For such installations, the force on the pipe due to backfill should be included in the calculations.

Buoyant forces affect earth as well as objects such as pipe; therefore, if some or all of the backfill above the pipe is below the water table, it is also subject to buoyant forces. These buoyant forces in theory reduce the load on the pipe from the backfill by the weight of the fluid displaced; however, the resultant force can obviously not be less than zero.

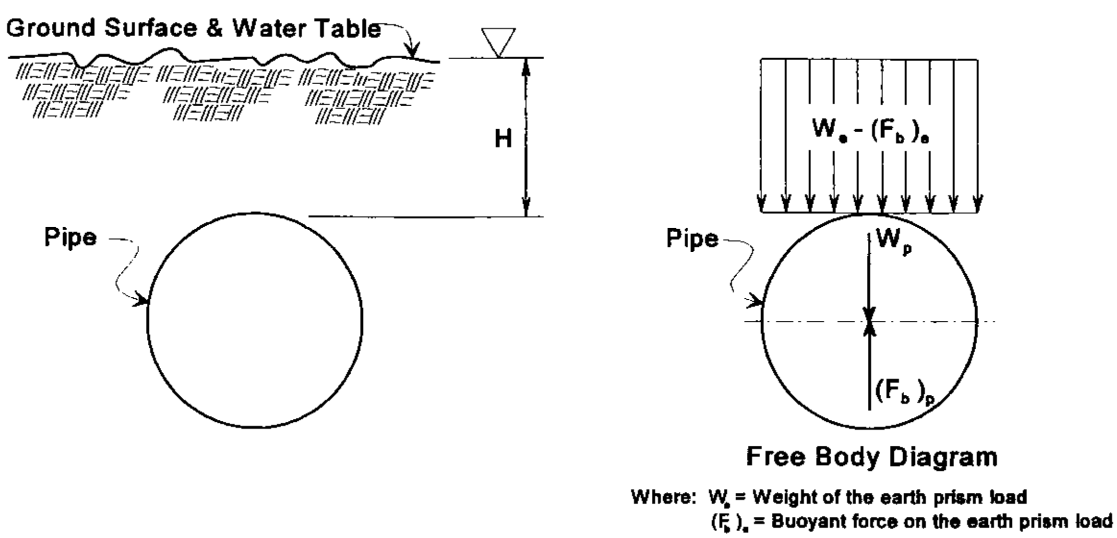


FIGURE 2

If the 48-inch Pressure Class 150 Ductile Iron pipe in the above example is to be buried with 4-feet of cover (H) in an environment where the water table will be at the ground surface or above, the pipe may tend to float. The analysis of this example would be as follows:

Step 1. Draw the free body diagram (see Figure 2).

Step 2. Sum all forces in the vertical direction.

$$\sum F_v = (F_b)_p - W_p - [W_e - (F_b)_e]$$

Step 3. Solve for the resultant force.

The buoyant force of the pipe and the weight of the pipe are as was previously determined:

$$(F_b)_p = 878.59 \text{ lb}$$

$$W_p = 240.3 \text{ lb}$$

The weight of the earth (W_e) is the weight of the prism of soil above the pipe:

$$W_e = \gamma_e H D L$$

$$W_e = (120 \text{ lb/ft}^3)\ (4 \text{ ft}) \left(\frac{50.8}{12} \text{ ft} \right) 1 \text{ ft} = 2{,}032 \text{ lb}$$

The buoyant force on the prism of earth [$(F_b)_e$] is the weight of the fluid displaced by the earth:

$$(F_b)_e = \gamma_f H D L$$

$$(F_b)_e = (62.4 \text{ lb/ft}^3)\ (4 \text{ ft}) \left(\frac{50.8}{12} \text{ ft} \right) 1 \text{ ft} = 1{,}056.64 \text{ lb}$$

Therefore:

$$\sum F_v = 878.59 \text{ lb} - 240.3 \text{ lb} - [2{,}032 \text{ lb} - 1{,}056.64 \text{ lb}] = -337.07 \text{ lb}$$

The resulting negative force indicates that the 48-inch Pressure Class 150 Ductile Iron pipe, even full of air, would not tend to float for this application.

If only a portion of the backfill is below the water table, then only that portion is effected by buoyancy. Figure 3 shows such an example. The only change in the analysis of this example from the previous example would be the reduction in the buoyant force of the prism of earth due to only the H_2 depth being under the water table instead of the entire depth of cover.

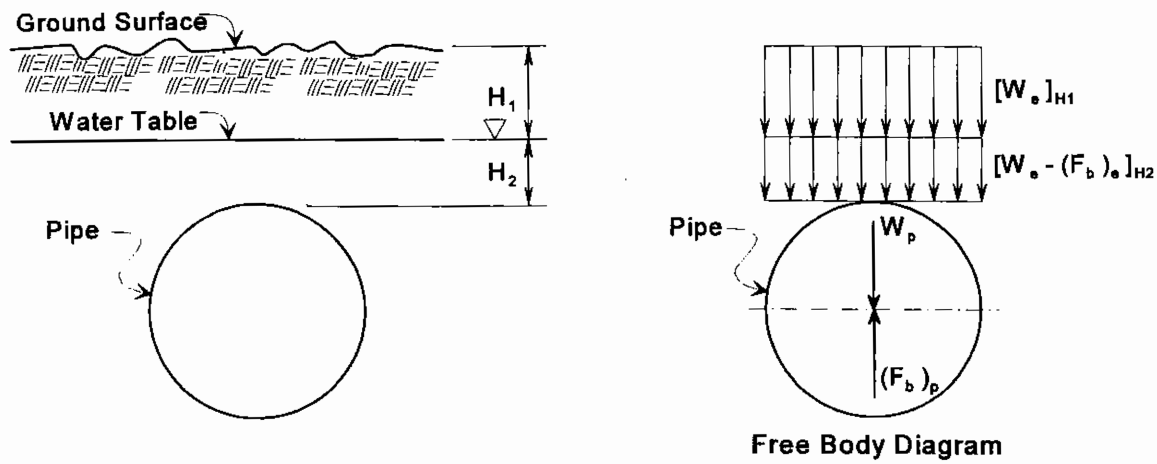


FIGURE 3

The examples in this paper have neglected the friction and adhesion between the pipe and soil and the cohesion of the soil which would have to be overcome in order for the pipe to rise. Also, the minimum weight of pipe per linear foot is used by assuming continuous 20-foot laying lengths, push-on joints, and unlined pipe. Normally this is not the case and the designer should include any additional weight in his calculations.

Buried pipe might not experience buoyant forces in all soils. For example, tight clays may not readily absorb water. One would expect that only disturbed or loose silts, granular soils, etc., would be candidates for buoyancy forces on buried pipe.

LIQUIDS OTHER THAN WATER

As stated before, a body in a fluid is acted on by a buoyant force equal to the weight of the fluid it displaces. Therefore, the higher the specific weight of the fluid, the greater the buoyant force.

Concrete and grout exist as fluids before hydration and have a specific weight of approximately 130 to 150 pounds per cubic foot. This creates a buoyant force more than twice that of water. For this reason, when liquid concrete is poured entirely around any pipe, the pipe tends to rise. This problem can be eliminated by either pouring the concrete in lifts and allowing the concrete to hydrate and become solid before the next lift is poured, or using tie downs on the pipe.

CONCLUSION

In areas where buoyant conditions might exist, it is advisable to design large diameter ductile iron pipe with "normal" (not extremely shallow) depths of cover and with reasonable backfill quality. In any conditions where calculations reveal less than adequate safety factors for pipe flotation, precautions such as burying the pipe deeper should be employed.

Buoyancy can also affect some pipelines during installation due to heavy rains before backfilling or high water tables. For installations where the pipe is buoyant, complete backfilling at an early stage (and prior to testing as recommended in ANSI/AWWA C600) is particularly effective in preventing empty pipes from floating. It is further advisable to fill the pipes with water as soon as possible after installation for maximum security.

(Revision Date: February 9, 1999)

For more information contact DIPRA or any of its member companies.

Ductile Iron Pipe Research Association

An association of quality producers dedicated to the highest pipe standards through a program of continuing research and service to water and wastewater professionals.

P.O. Box 19306
Birmingham, AL 35219
205.402.8700 Tel
www.dipra.org

Member Companies

AMERICAN Ductile Iron Pipe
P.O. Box 2727
Birmingham, Alabama 35202-2727
www.american-usa.com

Canada Pipe Company, Ltd.
55 Frid St. Unit #1
Hamilton, Ontario L8P 4M3 Canada
www.canadapipe.com

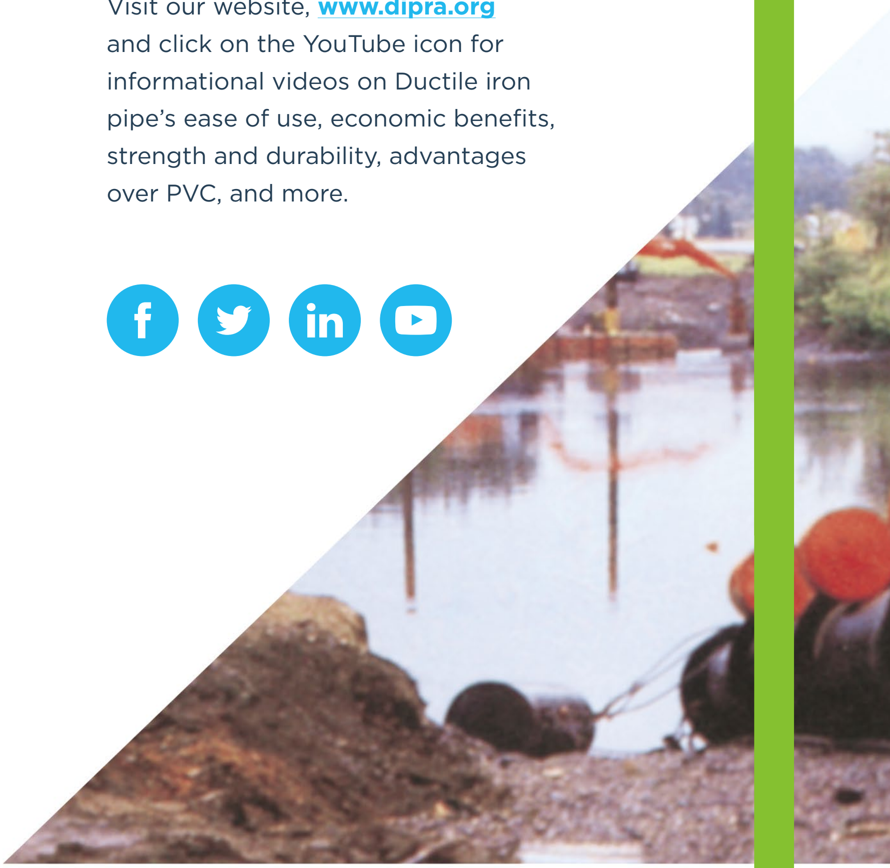
McWane Ductile
P.O. Box 6001
Coshocton, Ohio 43812-6001
www.mcwaneductile.com

U.S. Pipe
Two Chase Corporate Drive
Suite 200
Birmingham, Alabama 35244
www.uspipe.com

Social Media

Get in the flow with Ductile iron pipe by connecting with us on **Facebook**, **Twitter**, and **LinkedIn**.

Visit our website, **www.dipra.org** and click on the YouTube icon for informational videos on Ductile iron pipe's ease of use, economic benefits, strength and durability, advantages over PVC, and more.



dipra
Ductile Iron Pipe
Research Association