Inspecting Pipeline Installation

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No. 117

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Inspecting Pipeline Installation

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MANUALS AND REPORTS ON ENGINEERING PRACTICE

(As developed by the ASCE Technical Procedures Committee, July 1930, and revised March 1935, February 1962, and April 1982)

A manual or report in this series consists of an orderly presentation of facts on a particular subject, supplemented by an analysis of limitations and applications of these facts. It contains information useful to the average engineer in his or her everyday work, rather than findings that may be useful only occasionally or rarely. It is not in any sense a "standard," however; nor is it so elementary or so conclusive as to provide a "rule of thumb" for nonengineers.

Furthermore, material in this series, in distinction from a paper (which expresses only one person's observations or opinions), is the work of a committee or group selected to assemble and express information on a specific topic. As often as practicable, the committee is under the direction of one or more of the Technical Divisions and Councils, and the product evolved has been subjected to review by the Executive Committee of the Division or Council. As a step in the process of this review, proposed manuscripts are often brought before the members of the Technical Divisions and Councils for comment, which may serve as the basis for improvement. When published, each work shows the names of the committees by which it was compiled and indicates clearly the several processes through which it has passed in review, in order that its merit may be definitely understood.

In February 1962 (and revised in April 1982) the Board of Direction voted to establish a series entitled "Manuals and Reports on Engineering Practice," to include the Manuals published and authorized to date, future Manuals of Professional Practice, and Reports on Engineering Practice. All such Manual or Report material of the Society would have been refereed in a manner approved by the Board Committee on Publications and would be bound, with applicable discussion, in books similar to past Manuals. Numbering would be consecutive and would be a continuation of present Manual numbers. In some cases of reports of joint committees, bypassing of Journal publications may be authorized.

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PREFACE

This manual describes successful construction methods and procedures for installing the common types of pipes used to transport water-like fluids. Because this manual focuses on the needs of field personnel, constructors, and inspectors, it assumes the pipeline design is complete, decisions on alternatives are resolved, and the designer's concepts are now ready for conversion into a real project.

This manual has two main purposes: first, it provides an educational tool for readers with limited field experience, and second, it consolidates practical pipeline installation information into one volume.

Many recommendations are made about pipeline earthwork, and descriptions of the proper installation practices for ten different types of common pipes are provided, including steel, corrugated steel, ductile iron, prestressed concrete, reinforced concrete, bar-wrapped concrete, vitrified clay, polyvinyl chloride, high-density polyethylene, and fiberglass-reinforced pipes.

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CHAPTER 1
INTRODUCTION

Pipeline construction is complex and demanding, and requires the services of skilled contractors and craftsmen. Construction quality control and assurance are strict job requirements. The design engineer's drawings and specifications usually describe the quality and final results the owner expects. The constructor must then select the construction procedures to complete the work as envisioned by the project designer. The best results are obtained when good interpersonal relationships exist between all parties.

This manual provides help for those readers with limited technical backgrounds or those without specific working knowledge of a variety of pipe materials, although the level of detail should satisfy those who have wider work experiences. Nontechnical personnel needing basic information regarding the pipeline installation process will also find this manual useful.

Technical literature on fluid transportation often focuses on the design phase of project development. In contrast, journal articles or conference papers contain better references to field work. Brochures from pipe manufacturers are a significant source of basic facts about this work. However, distribution is limited for all these, which can be frustrating for less experienced technical personnel or the casual reader. Combining pipeline data from multiple sources of information into one book should be one of the main benefits to readers of this manual.

Discussion of oil and gas pipelines is not included here because federal mandates and regulations standardize such work. This manual does not discuss no-dig or underwater construction because of site complexities and still-evolving technology in those fields.

1.1 TARGETED READERSHIP

This manual addresses three general groups—experienced professionals, inexperienced professionals, and nontechnical decision makers, each with distinct interests.

1.1.1 Experienced Professionals

Professionals familiar with only one or two types of pipeline installation will benefit from this manual's briefings on many types of installations. Designers, consulting engineers, specification writers, and project planners will find this manual a useful source of information for cost comparisons, route analyses, and numerous other investigations.

Construction superintendents, project estimators, and foremen can also profit from this manual's descriptions, especially when working with new or unfamiliar pipe types. A constructor's staff may use the references and information in this manual to assist in preparing bids for a job.

Construction inspectors comprise an important group targeted by this manual. The text provides background for many provisions in construction specifications for pipelines, especially if the designer's reasons for using a certain procedure are not apparent or traditional. This manual is intended to help inspectors become more effective at influencing constructor performance by better specification enforcement. It also provides inspection tips on observing acceptance tests for the finished pipeline.

1.1.2 Inexperienced Professionals

Young engineers or inspectors can use this manual as a ready source of information specifically related to their work. Field persons must often rely on information from many sources, usually the spoken word. This process, though often useful, can transmit unreliable information. This manual helps inexperienced professionals because reliable technical data from many sources is bound into a single volume.

1.1.3 Decision Makers

This nontechnical group often plays a large part in developing the practical components of a pipeline project. Decision makers may consist of elected government officials or legal or financial personnel who exercise some degree of control over engineered works. Because their control may vary from casual to absolute, they cannot be ignored. This manual's realistic approach to pipeline installation procedures may help educate these young engineers and answer questions relevant to the serious responsibilities associated with evaluating a pipeline project.

1.2 TERMINOLOGY

In this manual, a *pipeline* is defined as a buried conduit formed by a manufactured pipe laid in a trench or embankment condition. This definition includes typical water transmission and distribution pipelines as well as highway culverts, sewers, and other drainage and pressure pipes.

Some entire pipeline reaches are installed in select environments by boring, jacking, or microtunneling methods. This type of work is specified in locations sensitive to disruption caused by equipment working on the surface or when a pipe is located under very deep earth cover. Pipes with diameters up to 36 in. (915 mm) or larger are commonly installed in this manner, and only the investment costs for exceptional equipment will limit placing much larger pipe sections. Trenchless methods for installing pipe are important recent developments and might be included for certain parts of constructing a traditional pipeline. However, those construction techniques differ substantially from work performed in traditional pipeline installation; therefore, discussion of this evolving technology is outside the scope of this manual.

The term *construction practice* often appears in this manual and describes typical actions or techniques a constructor might use to complete field installation of pipe. Field work included within the definition of construction practice might encompass storing unlaid pipe, excavating a trench, assembling and testing joints, and compacting backfill. The actual installation of most pipeline components described will vary based on weather, available labor and equipment, legal restraints, and other variables. All the techniques and procedures described are considered to represent practical construction practices.

Construction practice descriptions have been collected here from many sources, such as knowledgeable individuals, pipeline operating organizations, pipe manufacturers, and pipe trade associations. Most of the recommended practices have a long history of success to confirm their reliability. However, technology evolves constantly, and all procedures recommended here represent judgments based on the authors' current collective experiences and skills.

In summary, this manual strongly recommends methods and practices that have produced the most successful results for both the constructor and the project owner. The expressed goal of th manual is to guide pipeline construction in ways that allow the constructor to comply with all contract specifications while performing efficient and profitable work. A pipeline facility produced in this manner will likely have a long-term operational record of fluid delivery service with minimum maintenance costs.

1.3 TEXT ORGANIZATION

This manual progresses sequentially from general to specific topics, making information easy to find.

Chapter 2 includes some basic technical concepts regarding the uses of natural soil during pipeline installation.

Chapters 3 through 8 describe work common to all pipeline installations, regardless of the pipe material used. These procedures include excavation, use of the working area, spoil disposal, cleanup concerns, and many others. Describing this work early in the manual allows the uninformed reader to progress from the basics of pipeline installation to more complicated concepts.

Chapters 9 through 19 describe specific construction procedures required by the characteristics of the type of pipe selected. These chapters consider pipes made from steel plate, ductile iron, plain or reinforced concrete, vitrified clay, and man-made plastics. Differences in material characteristics have a significant influence on many of the construction procedures, so each chapter discusses a separate type of pipe, which allows finer technical distinctions and makes information easier to locate.

In any case, the sample projects described are illustrations of experiences selected from other actual contract work. Construction practices may change over time and, for a given actual project, the job specifications will supersede anything described in this text.

1.4 EMPHASIS ON CONSTRUCTION PRACTICES

This manual addresses field installation of actual pipelines or similar conduits, so the discussion is specifically directed to the construction components of pipeline work. Design theory is included only when necessary to provide background information or to explain construction specifications. This manual begins at the point where project construction drawings are complete, specifications are written, and materials have been selected.

Successful project design ultimately depends on conscientious, competent construction work. The project goal must involve delivering all expected hydraulic services while providing a low-maintenance pipe facility to the owner. To accomplish this goal, the field work must proceed as the designer intended. Incompetent or deficient construction will negate the designer's intentions.

Although this manual focuses on the construction aspects of pipeline installation, it is not a construction manual or a "how-to" book. Such publications are already available. Rather, the purpose of this manual is to provide better understanding of the practices used in typical situations encountered during pipeline system construction. It summarizes the composite views of typical constructors and engineers concerning those proven, effective, and practical construction practices that appear best to meet the project contract specifications.

1.5 SOURCES OF INFORMATION

Authors of this manual have considered and evaluated standard specifications from many public and private agencies and trade/professional associations engaged in work related to pipeline construction. Appendix B presents a complete list of these sources. The following is a list of some of the main sources used:

- ASTM International (ASTM) and American Water Works Association (AWWA) standards
- American Concrete Pressure Pipe Association (ACPPA)
- U.S. Department of the Interior, Bureau of Reclamation
- Ductile Iron Pipe Research Association (DIPRA)
- Steel Tank Institute/Steel Plate Fabricator's Association (STI/SPFA)
- National Clay Pipe Institute (NCPI)
- Uni-Bell PVC Pipe Association
- American Society of Civil Engineers (ASCE) Manuals and Reports on Engineering Practice:
    - Manual 37, *Design and Construction of Sanitary and Storm Sewers*
    - Manual 46, *Pipeline Route Selection for Rural and Cross-Country Pipelines*
    - Manual 60, *Gravity Sewer Design and Construction*
    - Manual 73, *Quality in the Constructed Project: A Guide for Owners, Designers, and Contractors*
- American Concrete Pipe Association (ACPA)

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CHAPTER 2

SOIL MECHANICS FOR PIPELINE CONSTRUCTORS

2.1 INTRODUCTION

2.1.1 Initial Comments

Pipelines are almost always installed underground, within the earth's natural surface known as the "soil." Although the design engineers describe the finished project in drawings and specifications, the constructor's staff actually decides which procedures will be used to install the pipe within the soil. This requires working safely within existing soils, correcting groundwater problems, and addressing many other conditions. Soils along the route will be ripped, cut, compressed, rolled, kneaded, and reworked in so many ways that a discussion of fundamental properties of typical soils is appropriate. Understanding how a pipeline is buried must also include basic knowledge of the properties of soils encountered and, especially, knowing how soil is used to control the deflection of most buried pipes (refer to Section 2.8 at the end of this chapter). This type of information can especially help field personnel with limited experience to understand the terms used in pipeline specifications and, hopefully, prevent faulty field decisions.

Modern soil mechanics has developed principles and design concepts that provide the basis for using natural soil as engineering material. Experts in this field predict how specific soils will perform in man-made applications, but these skills also require considerable experience and good judgment. Most soil mechanics professionals are geotechnical engineers and are supported in everyday construction work by soil technicians.

This manual is not intended to make readers into soil experts; the purpose here is to provide definitions and descriptions about natural soil material and to help inexperienced personnel understand how basic soil mechanics concepts relate to buried pipelines, and to appreciate the scientific work involved in producing a geotechnical report and contract specifications.

Inexperienced readers must understand one distinction about soils: Soil found in gardens or on farms is the surface variety and contains relatively high proportions of organic materials. The type of soil commonly used for engineering purposes is that found below the level of plant roots and is usually free of vegetable-type matter.

2.1.2 Basic Concepts for Soil

Soil material overlies much of the earth's surface. Natural soil is composed of discrete components—small particles derived from a natural disintegration of the underlying rock base. This particulate nature of soil is the major difference between soil and massive rock. Fortunately, trench excavation in soil is relatively easy because burying pipes in long reaches of rock material is more costly and time-consuming.

The applications of soil science to pipeline work differ from other types of construction where the usual purpose is to enhance the load-supporting properties of native soil. Soil under a buried pipe is not heavily loaded by the bare pipe because the in-service dead weight of many common pipes is less than the displaced earth. In contrast, a pipeline constructor works *with* the in situ soil material to dig and support a safe trench, handle the excavated spoil, install the pipe, and then backfill the trench in a manner that will preserve the pipe's shape and allow the specified surface uses.

For many projects, the design engineers will often identify soil-related problems along the pipeline route and will include construction specifications to make corrections. A geotechnical engineer may provide a professional soil report and an appraisal of how soil conditions will influence the job. All this data should be available to constructors in order to reduce the owner's exposure to a constructor's claims of "changed soil conditions." To reduce the possibility of change orders due to differing ground conditions, and to share risks with contractors in order to receive lower bids, owners are encouraged to implement guidelines recommended in *Geotechnical Baseline Reports for Construction.*[1]

In this manual, base rock is considered only in reference to excavation difficulties and related requirements, such as the need to place pipe

[1] Essex, Randall J., ed. (2007) *Geotechnical baseline reports for construction: Suggested guidelines*, ASCE, Reston, Va.

barrels at least 6 in. (150 mm) clear of such hard material. The space between pipe and rock must contain soil or some other yielding material that will conform to the outside shape of the barrel.

Constructors, field engineers, and inspectors often have practical knowledge of soil materials from their own experience, especially within a limited region. This chapter should refine this knowledge by describing physical rules governing how typical soils behave when disturbed, and should help pipeline constructors understand how to adjust work procedures for different soil materials, make realistic decisions, and maintain a safe workplace.

2.1.3 Practical Applications

Application of basic soil mechanics can help a pipeline constructor make better decisions about:

- Estimating machine size for trenching
- The need for ripping or blasting to fragment hard materials
- Methods to handle spoil, silts, and unsuitable backfill material
- Anticipating environmental problems regarding control of dust, mud, wind-blown erosion, sediments, contaminated soils, or operating noise
- Identifying weak soil materials and their effects on trench stability, especially from loss of soil moisture
- Predicting groundwater control problems: effects of soil permeability, artesian water
- Estimating need for extra sources of selected bedding materials, especially if excavated trench material is not suitable for compacted backfill
- Providing appropriate equipment needed to compact the types of soil available
- Construction of embankments and side-hill cuts for access haul roads

2.1.4 Chapter Organization

This chapter presents definitions and descriptions for simplified soil mechanics, ranged in order from elementary to complex, as shown in the following list:

1. Natural soil components
2. Describing a soil mixture
3. Groundwater
4. Loads in a soil mass
5. Soil compaction

6. The geotechnical report
7. Soil–pipe structure interaction
8. Pipe stiffness

2.2 NATURAL SOIL COMPONENTS

2.2.1 Soil Sources

Soil developed over several recent geological periods of the earth's history. During this time, moving water, mechanical grinding, chemical attack, heat and cold, volcanic actions, and wind degraded crystalline or other rocks into smaller particles. The range of particulate sizes is grouped for practical purposes into rock, gravel, sand, silt, and clay—the finest of materials. Classifying sizes of particles and soil minerals can help identify sources of a soil and how it was deposited during recent geological time, even if deposition occurred far from the source. Natural deposition often results in variable soil composition, at times almost erratic and in unlimited combinations. In localized areas, such as along a short pipe trench, the soil composition may appear more constant, but the constructor must be ever alert to changes in the character of soil exposed during excavations.

Geotechnical engineers use a variety of methods to determine soil properties. The most reliable information will come from testing of actual material, sampled from the job site. Field test samples represent small models of a greater soil mass, and appropriate sampling of soil materials will be determined by the requirements of subsequent laboratory analyses.

Identifying basic soil types often requires only a simple, loose volume of soil. A more thorough analysis will require that all particles in the sample's structure remain undisturbed and that original field moisture is maintained. Soil samples are obtained by drilling or by some other manner to reach the required underground locations. Additional, though limited, information about underground materials may be obtained by visual inspections at roadway cuts and at the sides of natural streams where underground strata are exposed. Bulldozer or backhoe cuts may also allow visual inspections and sampling, especially when searching for traces of geological faulting and earthquake action.

2.2.2 Particulate Material

Soil is composed of small particles, all of which may be held or molded by hand. These particles are termed *rock, gravel, sand, silt,* and *clay*. Sandy materials appear as little rocks and bear on each other in a point-to-point contact. A microscope is needed to see the particles of silt and clay. Particles of very fine clay are some of the smallest inorganic natural solids on earth and are seen only with a high-powered electron micro-

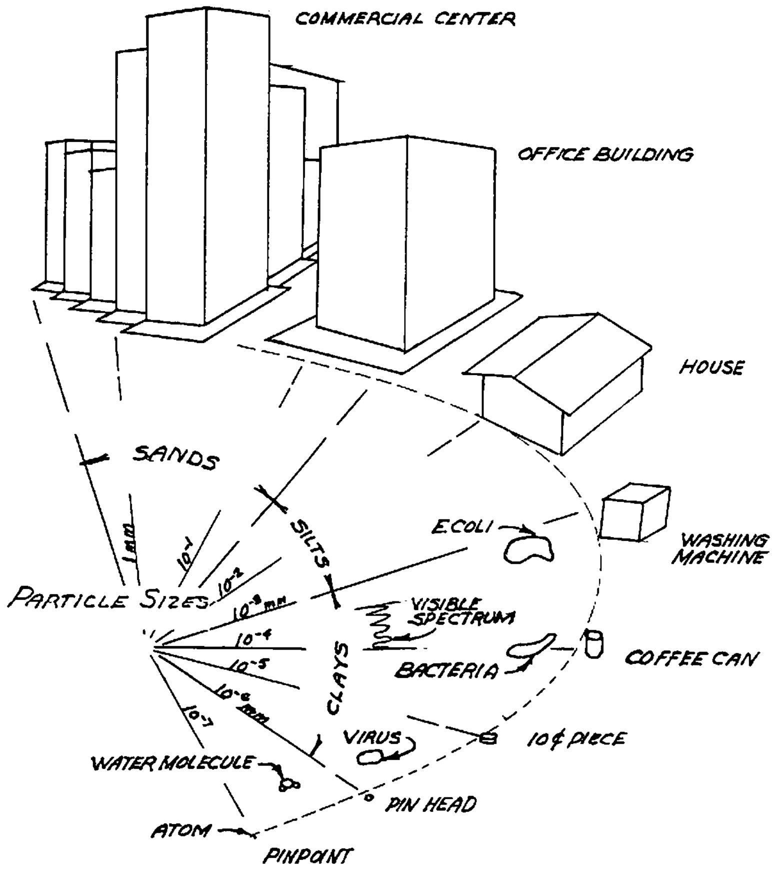

Figure 2-1. Relative sizes of particles in a porous soil medium.

scope. A graphic relationship describing the extreme differences in particle sizes appears in Fig. 2-1.

Clay particles are small enough to be held together by intermolecular forces that contribute to a clay property known as *plasticity*. Coarser sand or silt particles are free to move, fitting intimately together but not necessarily interconnected or "glued together." They do not exhibit plasticity. Occasionally, natural chemicals such as iron oxide or calcium carbonate act as cement to bind silts or sands together.

A simple test of relative particle sizes involves shaking a sample with water in a jar and allowing the solution to settle and become almost clear. The coarser granular components settle quickly, but the smaller silts and clays settle at a slower rate. The smallest, or clay-sized, particles may float endlessly in a colloidal condition as they bounce among the water molecules. The particles will arrange themselves with the coarsest on the bottom and in density approximating the distribution of sizes.

Basic soil mechanics terms related to particle sizes are easy to understand. Sand or gravel components are often identified as *granular* or *noncohesive*—obvious descriptions. These particles may be rounded or angular in shape. Clays and many silts are termed *fines* or *cohesive materials*, referring to their tendency to hold together in conglomerated masses. Clays are usually highly deformable without breaking apart and are termed *plastic*. Silts are usually, but not always, nonplastic and crumble when disturbed.

As a term used in soil mechanics, *cohesiveness* means that when water is present in the nonsolid spaces of fine materials, the spaces may be small enough to allow capillary action to occur. The same surface tension of water responsible for raising water against gravity in capillary spaces also will hold onto or restrain these particles so the particles act as if bound together. This binding action is part of the reason why clays, with very small open spaces, retain moisture and tend to stick together. Sands, which have large, open spaces, show limited capillary effects and readily lose any internal bonding when drying occurs.

Two other terms, analogous to human anatomy, are also common. The first describes the open spaces in the soil mass as the *pores* of the soil. The second is *soil skeleton*, which describes the solid components of the soil. Some technicians prefer *fabric* as a descriptor of the mix.

Other important technical concepts follow from the fact that soil is a mixture of many sizes of conglomerated particles:

- Because all particles have irregular shapes, *internal friction* exists between particles and resists movement between them. This internal friction is measurable and is one of a soil deposit's most important properties. Even clays have internal friction.
- Particulate soil contains distinct solids as well as *voids*. Voids are nonsolid spaces with measurable volume. Void spaces may contain varying amounts of water and air. The amount of water in voids is important and is further discussed in Section 2.3.3.

Even the finest of clays contain spaces between particles, but these spaces are so small that movement of water or gas within the voids is minor and occurs at an extremely slow rate of flow. Thorough wetting or drying of clay soils usually requires a relatively long period of time.

2.3 DESCRIBING A SOIL MIXTURE

Determining the relationship between soil particles is an important result of a technical investigation. Much can be learned by simply analyzing types and amounts of mineral components found in the soil mixture.

This information enables the use of charts and tables by which the engineering properties of a soil can be estimated. An excellent reference source is *ASTM Standard D 2487*, *Classification of Soils for Engineering Purposes*, hereafter referred to *ASTM D 2487*.

2.3.1 Index Properties

Experience shows that soils with a similar distribution of particle sizes and other index properties will likely have similar predictable properties and performance. Four simple tests are made to establish these index properties in the following manner:

1. Find the relative sizes and distribution of the particles by mechanical separation.
2. Estimate the nonsolid spaces in the mix.
3. Study the relative amount of water in these spaces (moisture content and liquid limit).
4. Appraise the effects of the clay portions in the soil mixture (plastic limit).

2.3.2 Mechanical Analysis

The first index property, *distribution of sizes*, is easily found by passing a dry sample through a set of wire sieves, each with successively smaller openings. This procedure is called *mechanical grading analysis* or *sieve analysis*. Standardized dimensional sizes of particles are related to the screen openings of a series of sieves. The term *passing* identifies all particles smaller than the sieve openings because they fall through the mesh. As described by the soil classification used in *ASTM D 2487*, the significant sizes are:

Cobbles: Larger than 3 in. (76 mm); hardly a "particle," but the upper limit of natural material considered to be soil.

Gravel: Passing a 3-in. (76-mm) opening but retained on a No. 4 opening (4.8 mm).

Sand: Passing a No. 4 (4.8 mm) but retained on No. 200 (0.08 mm).

Silt: Passing a No. 200 (0.08 mm) but usually found to be nonplastic by Atterberg Limit tests.

Clay: Below 0.002 mm; definitely plastic, and may be as small as 0.0001 mm.

To relate these sizes to more ordinary dimensions, a No. 200 sieve opening is close to 1/320 inch, but the 0.002-mm upper limit of clay sizes is only 0.00008 in. and difficult to visualize.

For silts and clays, separation by mechanical sieving is impractical, so particle sizes are estimated by completely mixing a sample of the soil in water. After a quiet time, the particles settle out according to their weight and size; thus the density of the water mixture will gradually decrease. A hydrometer measures mixture density at timed intervals, and the rate of density lost by the mixture can be calibrated to define the sizes of particles remaining in suspension after certain intervals.

Organic or nonmineral components are also found in some natural soils. One of these components is the humus-like material found in topsoil. This material will decay in time and is considered a defect for engineering uses of soil. A variation is peat, usually found as 100% natural vegetable fiber; it is almost never used as an engineering material. A project may require excavation in these materials but the design should specify how to compensate for their weaknesses, and these materials can never function as compacted backfill. Finding the amounts of organic material in a sample involves burning a soil sample in an oven, which leaves only mineral (i.e., inorganic) parts.

Many soil properties are determined by the distribution of particle sizes. For example, gravelly and sandy materials are generally more rigid, and clayey soils are more deformable and putty-like. Among granular soils, if the proportions of particle sizes remain constant, their properties as construction material are likely to be similar. However, this relationship becomes less reliable as the proportion of clay-sized particles increases. The term *clay* describes soils for which more than 50% passes the No. 200 sieve. Working with soil that has a high percentage of clay sizes likely requires analysis by soils engineers.

Some soil mixes are more useful for pipeline engineering purposes than others. The most useful soils often contain a broad distribution of particle sizes. Soils with a narrow distribution range of particle sizes may cause serious problems. For example, beach sand often is unstable because it will show limited particle distribution (Fig. 2-2). It is also likely to be expensive to support after excavation.

Often, constructors must decide whether the trench-excavated soil can be reused as select backfill around the pipe or even to meet other requirements in the remainder of the trench. Compacting backfill material is vital because soil–pipe structure interaction depends on achieving specified backfill densities. If the proportion of this native soil passing the No. 200 sieve exceeds 50%, problems will surely occur when working with such material around the outside of the pipe. This soil will require more intensive work to compact, it may swell if wetted, and often causes environmental problems for silt control, dust, etc. Soil–pipe structure interaction is further discussed in Sections 2.6 and 2.9 below.

Knowledge of the relative distribution of particle sizes in a soil is also desirable. Given results from the above-mentioned sieve testing, data may be plotted as shown in Fig. 2–2. This "cumulative particle-size plot," or gradation curve, is similar to Fig. 4 in *ASTM D 2487* and presents an

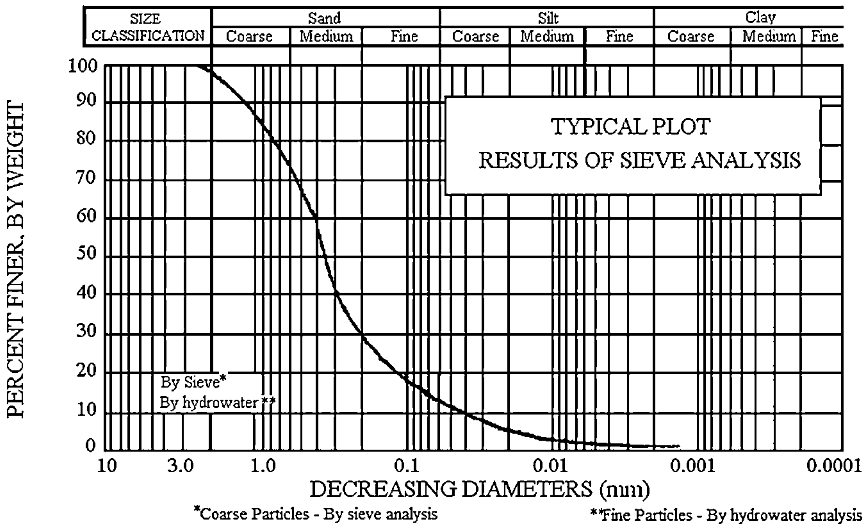

Figure 2-2. Typical plot of sieve analysis.

efficient way to compare similar data from other tests. Figure 2-2 shows results from a typical mechanical analysis sieve test. The size distribution shown is: sand, 85%; silt,13%; and clay, 2%. This sample contains almost no clay or binder material, suggesting this soil will likely be friable, or easily disturbed if used in an unconfined location.

Other information described by *ASTM D 2487* is the value of C_u, or coefficient of uniformity, which depends on the percentages passing No. 10, No. 60, and No. 80 size sieves. These values may be interpolated from plots such as Fig. 2-2.

2.3.3 Voids in Soil

Particulate materials, by definition, must contain nonsolid space, or voids. In general, this characteristic applies to sands, silts, and clay types of natural soils as well as to ash or slag used as backfill materials. The voids must be filled with gas (air) or water. Voids also allow the soil mass to act as a reservoir for groundwater. These voids are measured by simple, effective tests that provide important information to supplement mechanical analysis. Because soil is a conglomeration of solids and voids, these tests determine the effects of *the relationship between solid spaces and the voids in the soil mass*, the second index property of any soil.

Void spaces are measurable. For example, consider a dry, sandy material with a unit weight of 92 lb/ft^3. Because the sample is dry, this number represents the weight of only the mineral solids in the sample. If this material represented a solid sample, it would weigh 166 lb/ft^3. Thus, the solids comprise 55% of the volume of the entire sample (92/166 × 100), and the voids only represent 45% of the sample (100 – 55).

In soil mechanics terminology, two important ratios, or index properties, are determined from the above data: soil porosity and void ratio. *Porosity*, relating to groundwater movement, is the ratio most useful to the constructor. The *void ratio* is a number more important for technical analysis.

$$\text{Porosity} = (\text{volume of voids})/(\text{total volume of the sample})$$

$$\text{Void Ratio} = (\text{volume of voids})/(\text{volume of only the solids})$$

In the above sample case for sandy material, porosity = 45/100 or 0.45, meaning that 45% of the mass of the sample is available to contain water or to act as a conduit for water moving through the soil. This terminology will be modified in future discussions because the flow of water also depends on the relative sizes of the void spaces. Typical values for porosity may range from 0.15 to 0.55.

The void ratio for the sample sand is computed as 0.45/0.55 = 0.82. Typical values for void ratios may vary from 0.15 to 1.25, depending on the particle sizes of the particles. A value of 0.82 falls within that range. A void ratio greater than 1.0 indicates that the soil sample contains more voids than solids.

2.3.4 Moisture Content

In typical soils, the voids will hold some water. This is a characteristic index property leading to the next ratio, the *percentage moisture content*. This value is applied in many ways during compaction of soils and is found by weighing a wet sample, drying it in an oven, and then weighing the same sample when dry. The weight of the water evaporated by the oven is the difference between the wet and dry weights.

$$\text{Percent Moisture} = 100 \times (\text{wet} - \text{dry weignts})/\text{dry weight}$$

The amount of water in soils can vary. Truly dry natural soil is unusual. Normal moisture content varies from 5% to 100%. At 100%, the soil is termed *saturated* because all the voids are filled with water. For the sample values above, based on porosity, saturation would occur if 45% of the dry weight (or the moisture content) was water. Saturation is a common condition for soils residing below the groundwater table. Soils technicians may refer to the water in the voids as the *pore water*.

Moisture content must be known in soil mechanics because soil used for certain operations, usually related to field compaction, should contain an optimum percentage of water. When construction specifications require degrees of soil compaction to given densities or unit weights, native soils are commonly wetted or dried to meet requirements (see Section 2.6).

Water in the pores (void spaces) is a major factor when working with predominantly clayey soils. If the percent moisture differs appreciably from the optimum for the material, certain clayey soils may be difficult to adjust to an optimum moisture percentage because the pore sizes are so small that water entry or removal may require years to achieve. Also, working with a soil having moisture content near the saturation point is usually undesirable.

Trenches must be excavated in soil material that has a random amount of moisture content. Reusing such excavated soil for backfill may require drying or wetting it to the optimum water content. Perhaps more importantly, the moisture content of the trenched material will certainly affect trench side-slope stability.

2.3.5 Effects of Clay Size Particles

A fourth test sequence evaluates an index property related to clay components in the mixture and complements the mechanical analysis by measuring the concept of *relative soil plasticity*. Plasticity is a general term to describe how easily a soil may be deformed or kneaded without breaking apart. Plasticity depends on the proportion of smaller particles and moisture content of the sample. Sands and silts do not exhibit plasticity. *ASTM D 2487* also contains information about this property.

Plasticity is of interest only in soil components that pass a No. 200 sieve. These components are the silt and clay sizes. The old, empirical Atterberg Limit tests give numerical values for plasticity. To perform these tests, samples are prepared with varying moisture contents and the results are interpolated from the data. A description of moisture content has been given above. These tests determine:

- *The Liquid Limit (LL):* The moisture content, in percent, at which the soil changes from liquid state to plastic state.
- *The Plastic Limit (PL):* The moisture content at which the sample is so dry it cannot be deformed without breaking apart.
- *The Plasticity Index (PI):* The difference between the LL and the PL.

In regard to pipelines, soil plasticity presents problems by increasing the work needed to compact soil in trench backfill. Highly plastic soils have been used to build dams and other embankments where the working spaces allowed the appropriate machinery to be used. Pipe trenches usually provide only limited working space for compacting efforts, so nonplastic soils are much more efficient as pipe backfill.

The limit of simplified soil analysis has been reached at this point, which is only part of the way through the process of evaluating soil material. Given the above index properties for a soil, these values can be used to enter charts prepared for pipeline use. Table 1 in *ASTM D 2487* may be useful, but Tables 1 and 2 in *ASTM D 2321* are more complete. Table 2 also describes problems when working with plastic-type soils, and includes specification-like instructions that may not agree with contract specifications for a specific project.

Because the manual often refers to *ASTM D 2487* and *D 2321*, copies of these publications should be available to the reader.

2.4 GROUNDWATER

2.4.1 General Description

A farmer's simple water well depends on free water underground. The typically large volumes of void space in soils allow filling from natural water falling as precipitation or delivered from an aquifer. The constructor must know the elevation of this free water level, which will vary along the pipeline. This elevation is known either as the *groundwater surface* (GWS), *groundwater table* (GWT), or *phreatic surface*. The groundwater surface is the top elevation of saturated soil. Partial saturation may exist above this elevation because of capillary action.

A constructor must remove the freestanding water from any trench in which a pipe is laid. Exceptions only occur when pipes are designed for underwater installation, such as in an outfall sewer or at a river crossing. Free water is removed by direct pumping from the trench or by pumping through well points. These processes are described in greater detail in Chapter 6.

Well points consist of perforated tubes or pipes driven into the ground or placed in augered holes and then pumped to draw down the GWS. This procedure provides a suction gradient or slope for groundwater to flow from soil near the trench to the well point. Efficient groundwater removal by well points requires technical analysis by a competent soils analyst or hydrologist. Rates of water flowing through the voids in a soil mass must be estimated accurately to determine the number and spacing of the well points. This procedure depends on void size, which affects the soil's permeability, or the natural flow rate of water through the soil. Flow rates vary, but the following figures are typical:

- In clean sand, groundwater may move, or flow, more than 200 ft (60 m) per day.
- In silts, flow is about 3 ft (1 m) per day.

- Stiff clays allow groundwater to move at an extremely low rate, about 1 ft (0.3 m) in 3,000 days. Such clays are almost impermeable and are poor choices for well point function.

2.4.2 Soil and Groundwater Terminology

The following groundwater related terms commonly appear in the vocabulary of soils engineers:

Saturation: All of the voids in the soil are full of water.

Capillarity: Groundwater will be drawn above the saturation level, or GWT, if very small passages or openings are available in the soil. The soil must be a clay type because the interparticle openings in sands and silts are usually too large. Surface tension of the water raises fluid in the soil in the same manner as a tree raises water in its trunk.

Apparent Cohesion: Similar to surface tension forces in water, this characteristic binds finer soil particles and appears to pull the soil mass together, apparently increasing soil strength if it is not saturated. This effect dissipates as the soil dries or saturates. An example is seen at vertical excavations in wet sand, which will slump as soon as the moisture dries.

Shrinkage: Also related to apparent cohesion. As the soil dries, remaining pore water pulls the particles closer together by capillary action, thereby reducing the volume. This shrinkage occurs mainly in soils with high clay contents.

Cementation: In past geological time, pore water may have been heavy with dissolved natural chemicals. As the water dried, some chemicals remained and provided a bonding force for particles and grains, resulting in a weak form of cement. Iron oxide or calcium carbonates commonly contribute to this effect.

Migration of Fines: This effect is observed when groundwater is free to flow from a fine-grained but porous source soil into an adjacent material having larger voids. Sufficient flow will displace fine, clay-sized particles occurring in the source mixture, floating them into the coarser material. This displacement increases the underground void spaces in the finer material. Void spaces occur when coarse gravels are used as backfill around a pipe laid in a loamy base soil, or when fine-grained bedding material is underlain by rock for stability or groundwater control. Numerous pipe failures have occurred when the bedding material in the critical haunch or springline area migrated into adjacent material. Particles removed from the base soil by groundwater action may reduce the resisting strength of the natural soil material, which is providing lateral and vertical support for the buried pipe. Flexible pipes, in particular, rely on this earth resistance for support. Migration can be prevented by installing a well-graded granular material. Usually the migration is solved by installing geofilter fabric around the coarse pipe backfill to intercept fine particles before they reach the coarser material. Certain particle sizes in natural soil suggest this effect may more likely occur, and tests to evaluate this possibility appear in *ASTM D 2473*.

Expansive Soils: Soil with very low void ratios may absorb water and displace the particles, causing an increase in volume. This effect is unlikely in sand or silt.

Collapsing Soils: Dry soils with very high void ratios may consolidate if water enters the voids and the particles become rearranged.

Pore Pressure: Water confined in voids of a saturated soil will be under a pressure determined by depth below the groundwater surface, which results in a positive pressure. Negative pore pressures may develop because of capillary conditions.

Effective Stress: Developing the concept of effective stress is beyond the scope of this manual, but is mentioned here as a definition. If water in the voids of a saturated soil cannot drain away, and if a load is applied to a unit of this soil, support or resistance to this load will be divided between the water and the solids. The water in this case will develop a measurable pressure, termed *pore pressure*, and the load on the soil skeleton will be reduced by the same amount. The remaining load on the skeleton is known as the effective stress in the soil. A saturated but weak soil may then resist loads because the pore water is carrying part of the load. The weak soil may easily fail if the water somehow escapes and the effective stresses increase.

2.5 LOADS IN A SOIL MASS

2.5.1 General Description

Any large body of soil exhibits properties that can be related to those of solid material. These properties are predictable for engineering uses. Soil mechanics science describes in detail how this mass of particles is affected by gravity and how the soil mass resists external forces.

Considering gravity forces in a soil mass, the soil particles are assumed to be in an “at-rest” condition. They are acted upon by *geostatic loading*, which resembles fluid loading because the natural force of gravity applies the weight of all the upper particles to the lower ones. This loading effect increases proportionally with depth, so loads are equal at equal depths below ground surface. For example, the soil backfilled over a buried pipe is geostatically loaded.

Lateral forces also develop in the same soil mass because of the nature of the material. The random contacts between particles allow tiny sliding movements, which mobilize as lateral internal forces. As mentioned previously, this soil property resembles the lateral pressure in a fluid or, more closely, the lateral forces exerted by wet concrete inside a concrete form. In natural conditions, at any depth, all the forces are in equilibrium until excavations disturb this condition.

A tennis ball analogy may help describe the interaction among particles in an at-rest condition. When an outside force (the geostatic load) squashes a tennis ball, the ball deflects inward at the point of impact but spreads outward at the middle, which effectively produces lateral-type forces. In soils, lateral forces are often horizontal and depend on an important material property of the soil. This property is known as the *K value* of the soil, or the *coefficient of earth pressure at rest*. This soil property defines the proportion of the gravity loading that will be expressed as horizontal lateral forces. The K factor depends on the type of soil and varies from around 30% to 80% of the static vertical load. Lateral forces directly increase with excavation depth because they depend on the vertical load at any depth. In practical terms, lateral trench loads are similar to the loads that retaining walls must resist. They also are part of the loads that trench support systems must resist, although for trenches the lateral forces may be higher than those on an equivalent retaining wall and emphasize the need to have an analysis and design made by a professional engineer.

The above lateral load property of soil has positive uses because these lateral loads induce effective forces between soil particles, producing vertical frictional resistance that is used to reduce the dead loading of earth on a buried pipe. This is the basis of the Marston-Spangler theory of trench loading, which is discussed in Chapter 6.

Externally applied loads or nongravity forces also commonly act on soil at a construction site. These forces may be applied in any line of direction on limited areas, such as the load from a truck wheel, a nearby building foundation, compaction or grading equipment, an excavated earth stockpile, or even a bulldozer blade. Such loads are also resisted by the combined effect of millions of contacts between the soil particles, all at random angles between the grains or irregular particles in the mix. Soil resistance is not unlimited but, until failure is reached between these contacts, the applied loads are resisted as opposing forces acting on the same line and in the opposite direction. In soils, the intensity of an applied load decreases as it spreads throughout the particles because it is spread on a bulb-like surface, over an ever-increasing area, as the distance from the point of application increases.

Nongravity, or applied loads, also produces the "tennis ball effect" described above. Regardless of the direction of application, applied loads develop lateral forces or resistance effects at 90 degrees to the line of application. The magnitude of the resistance depends on the nature of the soil material because the internal friction between all of the particles is a measurable soil property.

Applied loads differ in that they have actual limits at the points of application, and the volume of soil acted upon may be small. This difference allows estimating specific loading at points in the soil mass and comparing these values to the resistance available from native material. Existing soil material that is inadequate for some type of loading may be strengthened in some way or replaced by better material. Another solution would be to increase the natural forces confining the soil near the point of application.

Resistance of soil to internal deformation may be measured. These are properties defined from material testing, named the *phi angle* (Φ), or the *internal friction angle*. This angle varies from 0 to about 40 degrees, and larger values represent material more resistant to deformation. Naturally, granular soils exhibit the highest friction angles and the clays tend to have the lowest values.

2.5.2 Confined Soil

The concept of soil confinement follows directly from the "tennis ball effect" described above, but applied in a reversed direction. If confining lateral forces, which are some fraction of an applied load, are developed, this effect will increase the lateral confinement in the soil and produce opposing lateral forces and increase the soil's resistance to direct loading. Consider a muddy soil confined within a steel pipe. The confining action of the pipe increases the lateral strength of the soil, which then greatly increases resistance to axial loads on the mud. Even the coarser particulate materials have a higher strength if confined. In contrast, a narrow column of sand will easily crumble without confinement because its internal friction cannot be mobilized.

In the geostatic or gravity system of loading, all the lateral loads are balanced at any elevation. As the vertical load increases with depth, the confinement also increases. A weak type of soil strata will be stable deep in the ground because the effects of lateral confinement are in balance with the large vertical loading. Excavating a trench or making a roadway cut are examples of actions that remove confining forces and thus weaken the soil as a mass, often producing a failure. This weakening is discussed in Section 2.5.2.

Natural soil is confined by the total of the enclosing lateral forces developed by internal friction among the neighboring particles. Every mass of soil will have its individual internal friction properties, largely represented by the phi angle, described above. If this friction cannot resist the internal forces, failure will result by deformations within the mass as the particles are rearranged. Soil that has only limited confinement can fail because it lacks internal soil strength to develop the required internal friction properties.

2.5.3 Disturbed Soil

In disturbed soil, the original positions of the particles in the soil mix have been changed. Excavated soil is obviously in this condition. Disturbed soils can be used effectively if some particle contact is reestablished to increase compressive strength and reduce deformation of the soil mass. Based on laboratory testing, the soil mass is made more dense by the specified mechanical compaction effort. Field density tests are used to measure the increase in soil density due to compaction work. Soil density may also be increased by noncompaction methods, such as by adding Portland cement (soil-cement). Chemical admixtures (such as lime treatment) may be used to enhance the compactibility of the backfill; however, this procedure is rarely employed. Additional comments are included in Section 2.6 below.

2.5.4 Trenching

A trench excavation results in an unnatural slot cut into a soil mass. Lateral side support is removed and the confining stresses are likely lost. This condition may be inherently unstable and actually dangerous. Like the soil remaining after some type of wall or other containment is removed, unstable conditions in a trench may cause the soil material to fail by slipping in a wedge shape from one or both sides. Failure may be sudden and catastrophic. Professional soil engineering analysis procedures are required to ensure safe working conditions in a cut. Wheel loads and spoil piles or pipe stored adjacent to the trench result in a surcharge condition that only worsens the situation. Vertical-sided trenches, especially, must have structural support designed using competent analysis.

Conditions for trench support will vary in the field. Trench supports required by Occupational Safety & Health Administration (OSHA) *Construction Standards for Excavations* may supersede an engineer's analysis and must always be considered prior to starting construction. Trench support must be continually reevaluated as excavations reveal potential changes in soil properties. Engineers need to consider OSHA requirements when evaluating trench width requirements as well as compaction methods.

2.6 SOIL COMPACTION

Engineers design compacted backfill to achieve a desirable density in a particular soil mass. This density varies from 80% to 95% of the maximum or optimum density obtained by the Proctor density test discussed immediately below. Compacted backfill around the pipe barrel is most important for soil–structure interaction to develop and is absolutely vital for flexible pipe.

The maximum relative density is determined by the Proctor density test (*ASTM D 698*). Soil samples are wetted to represent an increasing

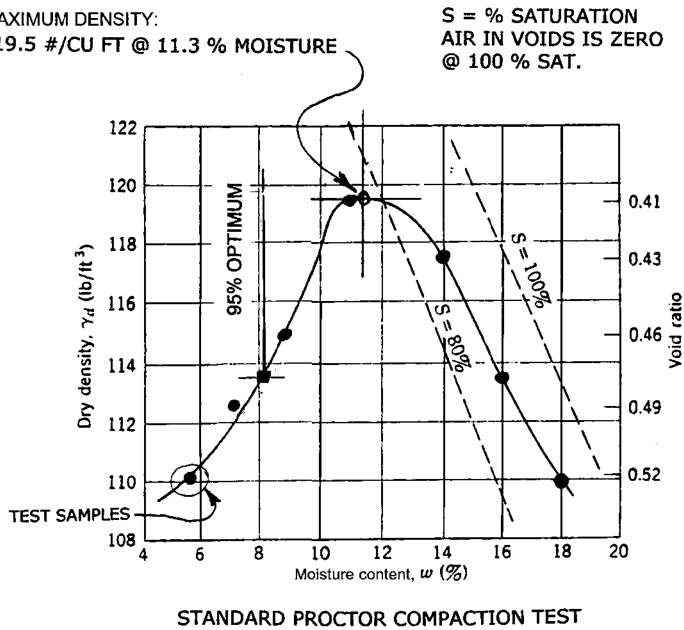

Figure 2-3. Determining maximum Proctor density.

series of moisture contents, and each sample is densified by standardized methods. Each sample is placed in a steel tube and compressed by dropping a standardized weight on the sample, 25 times on each of three lifts of sample material, which approximates a reasonable compaction effort in the field. Samples are then measured for unit dry weight and moisture content. The results are plotted using dry unit weights and moisture contents measured for each sample, as illustrated in Fig. 2-3. The plot will show a high point indicating the maximum practical unit dry weight and the corresponding optimum moisture content for the standardized test used. The plot actually describes how air is driven out of the samples and is replaced by moisture.

The optimum conditions on the graph become the 100% value, or the maximum value of compacted densities reasonably obtained for the sampled soil and at the moisture content shown. Field moisture contents are often a few percentage points over the optimum moisture indicated by the above test.

Measuring actual field density of soil compacted in a pipe trench requires skillful techniques when samples of compacted material are removed and tested to determine their compacted weight per unit volume. Only material that passes a 0.25-in. (7-mm) sieve is tested. Gross sample weight and moisture content are easily found. However, the actual volume of a sample becomes the critical measurement because most samples are so friable they cannot be recovered intact. The volume of an undisturbed sample is determined by measuring the volume of the sample hole by filling it carefully with calibrated sand. Other methods to measure the volume of a hole have been devised, such as using water to fill special balloons, etc. Nuclear devices to measure field soil densities in place are popular because they are comparatively simple to use, measure density directly, and are not dependent on field sampling methods.

Field density checks in the haunch area, under the pipe barrel, are rarely performed. Initial density tests of the trench bottom and backfill can help establish job standards for the actual combinations of material to be used and the effectiveness of compaction equipment. Specifications generally require that backfill density tests be taken every few hundreds of feet of the trench at various depths. Figure 2-4 illustrates soil–pipe structure interaction.

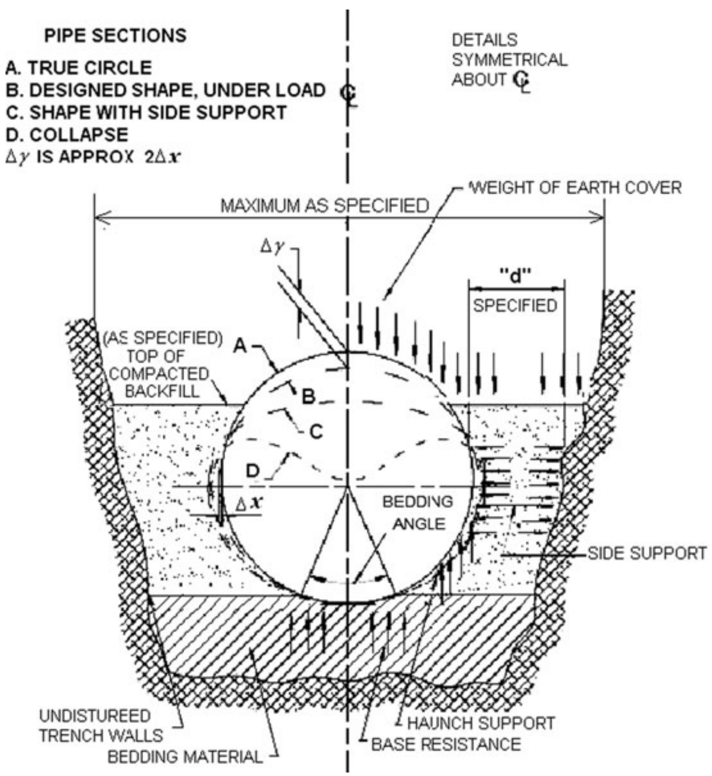

Figure 2-4. Soil–pipe structure interaction.

2.7 THE GEOTECHNICAL REPORT

Soil mechanics practice provides procedures to evaluate the engineering properties of soils and to estimate how well these soils will perform in a project. The project geotechnical engineer performs soil sampling and testing work prior to the design and makes recommendations to be used by the design engineer. The soils report information is usually made available to project bidders, although it is not uncommon for bidders to perform their own test excavations.

Soil professionals perform advanced soil testing to estimate the field strength of a soil material as either a load-supporting or load-resisting material. Soils testing considers soil samples as test models, representative of the actual, in situ conditions. For testing, engineers estimate the stress conditions at the points of interest in the field soil mass. The test equipment reproduces loading forces in these samples at moisture contents that simulate any of the alternative loads or other conditions that might occur in the field. Loading to failure is usual to evaluate all possible conditions on the work site. The professional can then estimate the field performance of a soil material and recommend improvements if necessary. The key to any testing depends on providing samples (models) that truly represent the prototype soil mass, both in density and moisture.

Two major types of tests are used. The *direct shear test* uses confined samples under direct axial loads and measures the ultimate internal shear strength of the material. Each sample is fitted inside two confining rings, which are joined axially. The soil sample is loaded on the same axis by a constant vertical force while the upper ring is pulled laterally to shear the soil across the fixed lower ring. This direct shearing gives the internal shearing strength of the soil under the applied vertical load. This test is useful for the design of sliding objects, such as an anchor relying on direct shear resistance of the soil base.

The *triaxial shear test* is used because it is versatile and relates better to active loading, especially where changes in the pore water pressure are known to occur. In this test, typical samples are small cylinders of soil, 1.5 in. (38 mm) in diameter and about 3 in. (76 mm) high. Encased in a tight rubber membrane, the pore water pressure may be varied inside the sample during the test by means of a special water connection. Next, the sample is sealed in the membrane and placed inside a larger sealed cylinder of separate water. The pressure of this water may also be varied to apply confining pressures on the sample equivalent to that in the prototype. Finally, a vertical ram is used to load the sample axially, also to simulate the field loads. Thus, three variable loads—the pore pressure, the vertical load, and the horizontal load—can be varied to recreate almost any field condition.

In the triaxial shear test, the variable loading conditions available to the operator are far more useful than in the direct shear test. Also, the ability to change the pore water pressure during a test cycle is very important. This ability allows the effect of groundwater movements to be checked and allows the broadest simulation of possible field conditions. This test is expensive but supplies useful results.

The triaxial shear test gives values needed to analyze wall stability in a pipe trench and is necessary to professionally design a trench support system. One of the main values obtained is the phi angle (the angle of internal friction) mentioned previously.

2.8 PIPE STIFFNESS

When a pipe is placed on the final grade and surrounded by bedding and backfill material, gravity loads from soil bearing on the pipe barrel deform the shape of the pipe to a variable degree. This deformation is determined by the physical rigidity of the barrel. A measurement devised to define this type of pipe barrel rigidity is known as the *pipe stiffness*.

Stiffness is a physical property of the pipe barrel that describes how much force is needed to deform the cylinder of the pipe barrel by a unit deformation. As a pipe property, stiffness expresses the relative degree that the pipe barrel contributes to resisting deformation. As the pipe stiffness decreases, the soil material bearing on the pipe sidewall must develop increased strength or resistance to compensate for the sideways pipe deformation.

Pipe stiffness for plastic pipe is measured using a the standard ring deflection test, *ASTM D 2412*, "Standard Test Method for Determination of External Loading Characteristics of Plastic Pipe by Parallel-Plate Loading." *ASTM D 2412* is similar to the "three-edged bearing test" used for concrete and clay pipe. The sample length of pipe is pressed between two parallel plates, and the force required to deflect the pipe to a given percentage of the diameter (generally 5%) is determined. The value for the pipe stiffness is written as the force per distance deflected per unit length of pipe. The units are pounds/length/length, or pounds per square inch (psi). This unit is not the same as the common unit used for intensity of stress. For gravity-flow plastic pipes, the pipe manufacturer should be required to furnish a copy of the *ASTM D 2412* pipe stiffness test results to the engineer prior to delivery of pipe.

Pipe stiffness is important for evaluating the backfill materials and relative compaction required for pipes made with a flexible barrel, such as a steel pipe or a plastic pipe such as polyethylene (PE), high-density polyethylene (HDPE), fiberglass-reinforced plastic (FRP), or polyvinyl chloride (PVC). The pipe manufacturer's technical literature may indicate the value for the *ASTM D 2412* stiffness of their pipe. Most specifications for flexible plastic pipe will require a minimum pipe stiffness to be used for the project. Flexible pipe may be classified by the level of *ASTM D 2412* pipe stiffness as follows:

- Ultra-low stiffness pipe has effective stiffness less than 10 psi (70 kPa)
- Very flexible pipe has effective stiffness less than 36 psi (250 kPa)
- Semi-flexible pipe has effective stiffness of 36 to 150 psi (250 kPa to 1,000 kPa)
- Semi-rigid pipe has stiffness greater than 150 psi (greater than 1,000 kPa)

The stiffness of thick-walled pipe may exceed 7,000 psi (48,263 kPa), so the term "stiffness" is not used when referring to this material.

2.8.1 Designer's Notes on Pipe Stiffness Terminology

Until the late 1970s, a minimum *ASTM D 2412* pipe stiffness of 46 psi was the standard for direct-burial plastic pipe. For example, the minimum *ASTM D 2412* stiffness for PVC pipe was specified as the *standard dimension ratio* (SDR) of the pipe, or the diameter divided by the wall thickness. SDR 35 PVC pipe had an initial *ASTM D 2412* pipe stiffness of 46 psi.

In about 1980, plastic pipe manufacturers developed much lower stiffness pipe, and other pipe stiffness terminology. *ASTM F 894*, "Standard Specification for Polyethylene (PE) Large Diameter Profile Wall Sewer and Drain Pipe," uses the term *ring stiffness constant* (RSC) as a measure of pipe stiffness. The ring stiffness "constant" is not constant but varies inversely with the pipe diameter. An RSC Class 40 with a pipe diameter of 30 in. (782 mm) has a minimum *ASTM D 2412* pipe stiffness of 7.8 psi (0.54 kg/cm^2), whereas a 90-in. (2,286-mm)-diameter Class 40 pipe has an *ASTM D 2412* pipe stiffness of 2.6 psi.

The *ASTM F 894* PE pipe specification calls for a modified *ASTM D 2412* test procedure. The *ASTM D 2412* test is run at a crosshead (deflection) speed of 0.5 in. (13 mm) per minute and the pipe stiffness is measured at 5% deflection. *ASTM F 894*, however, requires that the *ASTM D 2412* test be modified so that the test deflection rate is 4 in. (100 mm) per minute and the stiffness measured at 3% rather than 5% deflection The eight times faster load rate and 40% decreased deflection level at which the stiffness is measured increases the "apparent" pipe stiffness.

"RSC," "Class," or other "pipe stiffness" or "ring stiffness" designations should not be confused with the true 5% deflection pipe stiffness as measured by *ASTM D 2412*. The *ASTM D 2412* pipe stiffness of *ASTM F 894* pipe can be estimated by dividing the "Class" or "RSC" by 0.17 times the pipe inside diameter. For example, a Class 40, 120-in. (3,050-mm)-diameter pipe will have a minimum *ASTM D 2412* 5% pipe stiffness of

40/(0.17 × 120), or 40 divided by 20.4, which gives 1.96 psi. This can be verified by checking Table X1.1 in the *ASTM F 894* Appendix X1, "Relation of RSC to Pipe Properties and Pipe Stiffness," which lists the *ASTM D 2412* pipe stiffness for a Class 40 120-in. (3,050-mm)-diameter PE pipe as "2.0 to 3.1 psi (13.79 kPa to 21.37 kPa)."

Similarly, since the modulus, *E*, of plastics is a time-dependent variable, one should never depend on a calculated value for the initial pipe stiffness.

At pipe stiffness values below about 30 psi, shape control of the pipe becomes more important than the vertical deflection. When a very low stiffness pipe is installed in very stiff bedding placed under and adjacent to the pipe, and subsequently loaded with the trench backfill load, the top of the pipe will deflect downward with no movement of the pipe at the sides. The assumption of elliptical shape deformation on which all flexible pipe design is based is no longer true. The resulting flattened pipe crown creates high stress "corners" at the 10 o'clock and 2 o'clock positions, and increases the potential for "snap-through" buckling at the crown and invert. The squaring of the pipe shape can result in soil infiltration at the joints, localized collapse of the profile section, or buckling failure.

A very low stiffness pipe in a stiff embedment such as crushed rock can result in erroneous and even strange answers when the Modified Iowa Formula (Spangler deflection equation) is applied (the Modified Iowa Formula is presented in Appendix C). For example, if one assumes a modest soil modulus E′ value of 1,000 for the rock bedding, a bedding factor of 0.1, and 16 ft of 110 pcf (4.87 to 1.76 tons/m^3) meters per soil loading, the Modified Iowa Formula will show that a 72-in. (1,830-mm)-diameter, zero psi stiffness pipe will deflect only 2%. If the pipe stiffness is taken as 46 psi rather than zero, the deflection will be 1.8%. The bottom line is that at moderate to high E′ values the pipe stiffness has little impact on the deflection. Similarly, it can be shown that under the same E′ and loading condition, negative 36 psi (248 kPa) pipe stiffness will perform with no more than 5% deflection. The magic, of course, is that the rock provides all of the stiffness required, and more, hence the negative pipe stiffness result.

The important issue, as stated before, is that the shape of the installed pipe is maintained somewhere close to the elliptical shape that is the basis for all flexible pipe design formulas and, most importantly, the buckling equation.

2.9 INTERACTION OF THE SOIL AND THE PIPE STRUCTURE

Pipes that are classified as "rigid" derive a substantial part of their basic earth load-carrying capacity from the strength inherent in the rigid pipe wall. Rigid pipe includes asbestos cement pipe (ACP), cast iron pipe (CIP), concrete pipe, and vitrified clay pipe (VCP).

Pipes that are classified as "flexible" derive their load-carrying capacity from a combination of the inherent strength of the pipe and the interaction of the flexible pipe and the embedment soils. Commonly specified flexible pipes include ductile iron pipe (DIP), fabricated steel pipe, corrugated metal pipe (CMP), corrugated aluminum pipe, thermoplastic pipes such as acrylonitrile-butadiene-styrene (ABS) pipe, PE and PVC pipe, and thermosetting plastics such as reinforced thermosetting resin (RTR) pipe and reinforced plastic mortar (RPM) pipe.

More care is required in the installation of flexible pipe because the backfill is an important part of the soil–pipe structure system. Extreme care is required to ensure that the backfill placement and compaction effort does not adversely affect the shape of the installed pipe.

A buried pipe is similar to a simple cylinder submerged in a sea of soil. Analyzing deflection of the pipe barrel or cylinder usually assumes no internal pressure in the pipe. The goal is to encase the pipe by soil in a manner that ensures the cylinder remains as close as possible to a true circle, its most stable condition. The shape of the pipe will always be deformed to some degree by backfill loads, as geometry shows in Fig. 2-4. The degree of deformation shown in the figure is for relatively flexible pipe. For more rigid pipes, the degree of deformation may be much smaller, almost unnoticeable. Since the cylinder is continuous, and assuming the ring deforms in an elliptical shape, there is a definite physical and mathematical relationship ($\Delta\gamma = 2\Delta x$), as shown in Fig. 2-4 (be aware that the defined Δx is one-half the Δx used in the Modified Iowa Formula).

For buried pipes, the trench backfill becomes a cover of soil blanketing over a pipe and pulled downward by the action of gravity. This is geostatic loading, increasing with depth as previously described. The pipe is sandwiched between the upper (downward) load and the resistance of the base soil below. Resistance by the base soil occurs over an arc under the pipe known as the *bedding angle*. These vertical loads also have lateral components, which develop as described in Section 2.5.1 above.

Figure 2–4 shows how the shape of a backfilled flexible pipe can be deformed if lateral loading or side support is reduced. Usually, undisturbed earth in the trench sides can provide all the resistance needed to resist cylinder deformation. When compacted backfill is placed between the pipe cylinder and the trench sides, a column of stiff soil is formed to bear against the pipe, reduce sideways deflection of the cylinder, and in turn, help to reduce some degree of the vertical deformation. The net effect of this type of backfilling is to hold the pipe cylinder closer to a circular condition and is referred as *soil–pipe structure interaction.* This is the theoretical basis for designing pipes made with relatively low-stiffness materials, and then installed by using the backfill between the trench sides and the pipe to control pipe deformations.

Specifying a limiting amount of deflection in the buried pipe is the design engineer's method to control backfilling work and meet the specifications for proper pipe placement, especially for pipes with low stiffness values. By measuring pipe deformation in the field after backfilling, the construction engineer can evaluate the efficiency and effectiveness of backfilling methods used by the constructor. A direct type of field measurement of deflection is also discussed in Chapter 8, Section 8.10.

Other observations concerning deformation of the pipe cylinder by earth loading can be made. First, as soil stiffness or pipe stiffness increases, pipe deflections are reduced. Secondly, in a design engineer's analysis of buried pipes, the effect of internal pressure in the pipe is usually ignored. Finally, when earth applies loading to buried pipes, significant compressive loads will develop inside the wall of the pipe cylinder. It is possible that some combinations of lower-stiffness pipe made with lesser strength pipe wall material may invite local wall cross-section buckling followed by collapse of the pipe cylinder. Constructors should be aware of crown flattening or local wall buckling when making construction bids and in selecting methods of compacting the backfill.

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CHAPTER 3
DESCRIBING COMMON PROCEDURES

The remainder of this manual describes detailed procedures to install pipe underground. Chapters 3 through 8 consider working procedures so common that they are used on almost any pipeline project and are unaffected by the specific type of pipe being installed. The topics include contracting to obtain pipe; managing a pipeline project; transporting and handling pipe before laying; and some general principles to be followed when installing any pipe. Of course, the most common work, and the longest chapter, includes everything related to excavations and working with soil. Other types of common activities are: moving onto the job site; clearing of working areas; excavating the pipe trench; bedding the pipe; and the usual cleanup work.

Common procedures are followed by most constructors when working with trenches and operating powered equipment. Contract specifications covering common work, especially excavation work, are often simply written, allowing constructors to use their own skills and experiences to get the specified results. Other contract provisions may control common works in a manner that protects the owner if a constructor acts irresponsibly or abuses the property and interests of the neighbors around the working area.

For practical purposes, common work has serious aspects because it is centered on heavy equipment operation. The neighboring public sees this very visible activity along with disruptions of utility services, producing dust, noise, and so forth. All of these conditions are potential public relations problems, both for the constructor and the owner's representative. Problems of this nature require field work administrators to have superior skills in interpersonal relationships. Only part of project management is controlled by engineered drawings and specifications, so other items such as traffic controls, worker and public safety, and environmental issues must be addressed. Preconstruction meetings can establish proper relationships on these subjects between the project owner, field engineer, and constructor. Important adjacent property owners also might be invited to participate in these meetings to improve communications among all the parties.

CHAPTER 4

OBTAINING PIPE FROM A SUPPLIER

Manufacture of pipe in the sizes considered in this manual is a major industrial process. On individual projects, a single pipe manufacturer usually supplies major pipeline conveyance components, including all line pipe and pipe "specials," which are unique pieces such as bends, tapers, and valve connections. All these components will comprise 25% to 75% of the total project cost.

The pipeline constructor will make a separate supply contract with the pipe manufacturer, or the manufacturer's agent, to furnish all the pipe components for the work. The owner's engineer will inspect, approve, or otherwise accept pipe materials. However, because the pipeline owner does not recognize this supply contract, the constructor incurs a legal risk that depends on the manufacturer's reputation to meet all specifications for the pipe components.

Basic knowledge of the general terms of the supply contract between the pipe manufacturer and the constructor is vital in understanding pipeline installation. The pipe manufacturer guarantees to furnish to the constructor pipe components conforming to details shown on the original drawings and specifications in the construction contract. The supply contract does not recognize changes in the initial details. Changed work results in additional costs to the manufacturer for materials, office expenses, retooling costs, etc. The engineer and the owner of the pipeline must recognize this fact because any changes to original pipe designs will almost always be charged to the owner.

Construction contracts often specify that pipe materials shall conform to an industry standard, such as those commonly written by ASTM or the American Water Works Association (AWWA). In this case, either the constructor's inspector will inspect the pipe and recommend acceptance, or the manufacturer will provide a certificate of compliance with the specifications.

Other provisions of a supply contract may include a warranty period for the pipe, typically only 1 year, which assumes the pipe will be accepted within that time. Shop-applied pipe linings and coatings, furnishing small parts, and so forth may have variable warranties or may be negotiable items. The engineer should stipulate that the warranty for the project, including the pipe, begins at substantial completion.

The manufacturer may provide transportation of pipe to the job site, especially if the pipe has exceptional weight or length. The supply contract must specify who is responsible for damages to the pipe during loading, hauling, and off-loading.

Pipe manufacturers provide valuable engineering design services for the constructor as part of the information needed to fabricate pipes. These services may include:

- Making a complete, dimensioned layout of the pipeline.
- Determining the position of each of the pipe components and their dimensions, including direction of laying, length of field laying units, stationing and elevations of joints, and selection of pipe reaches for testing.
- Providing the time schedule for delivery of all materials.

Constructors are advised to use their own methods to evaluate production of pipe components. These methods might include checking the following items in the as-delivered condition. Constructors should know what to expect and how to determine whether something is wrong. Often, the problem will be dimensional, as given below.

- Pipe must meet correct pressure and load-bearing requirements.
- General delivery: ensure all applicable parts of the subcontract are met, including correction of damage during transport.
- Pipe joints: all joint fit-up and engagement tolerances are met, pipe ends are square or accurately beveled.
- All pipe bends are dimensionally acceptable.
- Pipe coatings and linings are adequately protected for handling and shipping.
- Branch connections for nozzles, manholes, and miscellaneous connections are accurately dimensioned.

Chapters 9 through 19 address more problems inherent in manufacturing specific types of pipes.

CHAPTER 5

MANAGING THE PROJECT

Pipeline construction is complex and demanding, requiring the services of skilled contractors and craftsmen. Construction quality control and assurance are strict job requirements. The design engineer's drawings and specifications usually describe the quality and final results that the owner expects. The contractor must then select the construction procedures to complete the work as envisioned by the project designer. The best results are obtained when good partnership relationships exist between all parties.

Prior to the start of construction, the project engineer should require a preconstruction conference to ensure that final construction results conform to the construction contract. Attendance should be mandatory for the contractor's general superintendent and project foreman, major subcontractor representatives, the owner's chief inspector, a representative of the pipe manufacturer, and the design engineer. If appropriate, the geotechnical engineer for the project should also attend.

The following generalized items should be discussed. These items will not receive detailed coverage in this manual because they are job-specific.

- Project security
- Environmental requirements
- Site safety considerations (OSHA requirements, overhead power lines)
- Engineer's office
- Pollution control, including dust, noise, and soil erosion
- Sanitary facilities for workers
- Necessary permits (obtained and pending) and permit notification requirements

- Precedence of documents
- Appropriate communication channels
- Emergency telephone numbers and procedures
- Construction zone width/limits of disturbance
- Disposal of construction debris
- Removal and disposal of contaminated materials
- Site access for personnel and equipment, parking
- The need for temporary fencing and barricades, and their maintenance
- Provisions for pedestrian traffic, bicycles, horsemen, livestock, etc.
- Provisions for resolving effects of delays, regardless of cause
- "Notice to Proceed," contract schedule, working days, and completion dates
- Notification of other utilities ("One-Call" systems)
- Alternative materials selected by the owner
- Subcontractors
- Interruption of service
- Street closings, detours, and traffic control, especially after working hours
- Public notifications, meetings, and hearings
- Highway and railroad crossings
- Payment procedures
- Change orders
- Record or as-built drawings (procedures and preparation). Record drawings can be defined as the drawings that are submitted by the contractor at the end of the project. They record all of the changes made in contract drawings during the construction and show actual dimensions, geometry, and location of the physical components of the project.
- Warranties
- Progress photos and videos
- Final authority

Items pertaining to contract specifications for pipeline installation are discussed throughout this manual. These items especially should be reviewed in detail at the preconstruction conference:

- Facilitating inspection of the work
- Contractors' equipment
- Site preparation
- Clearing and grubbing
- Name(s) of pipe manufacturer(s)
- Pipe handling, including unloading, and proper site storage at temporary sites

- Material certifications and other submittals
- Dewatering: disposal of this water and water from pipe testing
- Trench excavation and support
- Spoil placement
- Procedures for stabilizing unstable trench foundations
- Line and grade control
- Pipe joint assembly and qualifications for welders
- Backfill materials and compaction requirements
- Special structures
- Connections to structures
- Installation in tunnels and casings
- Pipeline protection during periods of project shutdown
- Minimum pipe cover for construction equipment
- Inspection and testing requirements, especially for testing pipe joints and the final acceptance tests
- Repair or replacement of damaged materials
- Corrosion control systems
- Final cleanup
- Entry into oxygen-deficient and/or confined spaces
- The importance of "as-built" drawings must be strongly emphasized

Minutes of the preconstruction conference should be recorded and distributed to all parties.

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CHAPTER 6
EXCAVATION AND BACKFILLING

6.1 THE MAJOR COMMON WORK

6.1.1 Developing this Concept

This chapter describes conditions that experienced constructors consider when planning earthwork phases of pipeline installation. Over many years, constructors have developed practical procedures to meet the usual contract specifications for pipeline installation and to solve related problems. Many of these procedures appear below as basic training for less experienced readers and give a summary of practical information that might otherwise only be acquired through a close association with many different pipeline projects.

Trench excavation is the most visible phase of a pipeline installation project and often affects many people besides the constructor. Excavation planning requires a systematic approach to understand exactly how to lessen the impacts on the neighborhood around this work. For example, what procedures are controlled only by the constructor or what will be influenced by persons other than the engineer? What facts are really known and unknown about this project? What environmental considerations does this work involve? These questions present serious challenges to the technical and management skills of any organization trying to complete the job at a financial profit.

6.1.2 Three Phases of Earthwork

Earthwork is the substance of the common work involved to bury any pipe. Earthwork includes three phases: trench excavation, permanently embedding the pipe, and backfilling the excavation. Opening the trench involves preparing the permanent location for the pipe. Embedding the pipe includes all the procedures used to support the pipe barrel, develop the specified earth densities and to secure the pipeline underground. The backfilling phase includes all work to restore the ground surface over the pipe, either to its original state or to some other useful purpose.

The first part of this chapter describes the full range of *trench excavation* work and is oriented toward open-cut installations. Other earthwork likely will occur during a pipe-laying project, aside from that needed to make pipe trenches. Examples include bulldozing of access roads; leveling working pads for backhoes; reducing the depth of cut over deep trenches; making drainage channels; and opening borrow pits. This manual will not cover such other work, even though it may represent moving significant volumes of earth. Related activities such as clearing the work site or removing right-of-way obstacles, though necessary, also do not merit separate discussion.

Embedding the pipe in position is a general term used in this text to include all the common work for fixing the pipe permanently underground. This work includes trimming the trench bottom ("fine grading"), placing granular materials for pipe bedding, and compacting or consolidating earth materials for the structural encasement of the pipe barrel. Earth encasement is the vital component for developing soil–pipe structure interaction and is discussed in Chapter 2, Section 2.9 of this manual. Pipe laying obviously occurs within the above time frame for earthwork, so the work described must be directed to making pipe laying more efficient. Actual pipe handling and installation are covered in Chapters 9 through 19.

Backfilling the remainder of the trench to the finished ground surface is the last phase or feature of pipeline earthwork considered here. The specified backfill and completion work often includes features to control surface erosion or improve the appearance of the areas over the pipe.

For the inexperienced person, understanding earthwork problems suggests grouping known and unknown facts regarding the work into related subjects. One helpful method, especially in connecting more obscure parts of the work, is to refer to checklists developed for similar projects. Experienced persons may remember most of the listed items from past jobs. Lists can act as mental triggers, suggesting new ideas and concerns for the new work. An Excavator's Checklist is available in Appendix A of this manual. Realistically, constructors cannot foresee all future problems, and some changes may be inevitable after the bid is made for a job. The key is to minimize unexpected events that may affect the costs and/or quality of the work.

6.2 EXCAVATION OF A PIPE TRENCH: THE FIRST PHASE OF PIPELINE EARTHWORK

Pipe trench excavation involves a sequence of events. Titles in the following list of chapter sections reflect the usual progression of work:

- Working Space
- Underground Conditions
- Trench Details
- Survey Control in the Trench
- Excavation Safety

6.2.1 Working Space

Is it easy to see where the new pipeline will lie? Is the route staked in the field? Does the work site appear to be completely free for the constructor's operations? These important items require consideration during initial excavation planning because every right-of-way restriction will increase the project cost.

The pipeline owner must ensure that the working area or zone is sufficiently wide and vertically free from obstacles to construction procedures normally used for this work, especially for large excavating equipment or machines. If clearing includes removal of any obstacles after construction has begun, payment must be provided to the constructor. Constructors normally have little negotiating power to deal with property owners or utility companies and cannot finance relocation works that are the owner's responsibility. However, obtaining some permits or business licenses from local governments may be the constructor's responsibility; such issues must be addressed at the preconstruction conference.

Underground indexing or identifying services can provide existing locations of underground pipes, wires, or other facilities previously installed by various utilities ("One-Call" systems). Use of these services is strongly recommended. Telephone numbers can be found in local contractors' publications and often in local telephone directories.

Right-of-way widths allocated for pipe laying must allow top widths of trenches appropriate for the pipe outside diameter. For larger pipe, safety requirements may give the most cost-efficient excavation sloping sides. Sometimes support systems are more cost-effective due to having to move less soil. Safety concerns are addressed in Section 6.2.5 below.

A method for estimating right-of-way widths for containing spoil from the trench excavation appears in Fig. 6-1, which shows estimated typical dimensions of lateral space used for installing larger pipes in a cross-country location. This drawing also shows the wide, sloping trench excavation mentioned in the above paragraph. In an urban setting, dimensions

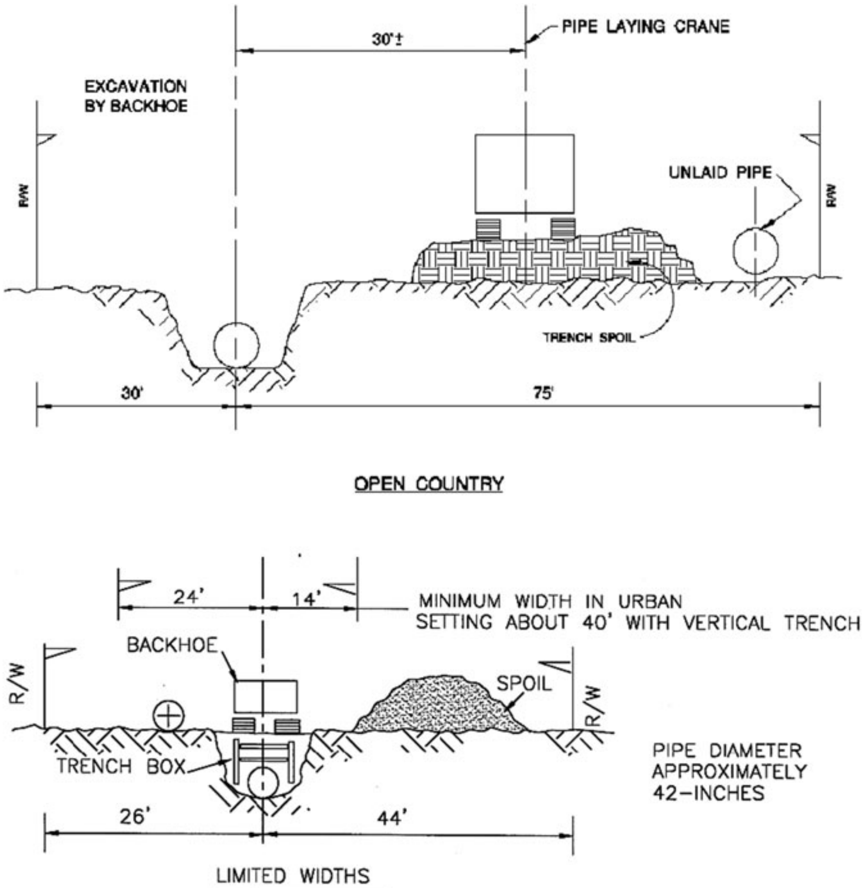

Figure 6-1. Estimated width of sample working areas. A reasonable relationship for the location of a pipeline in a right-of-way is 1/3-to-2/3 ratio of sides.

in Fig. 6-1 would be partially reduced by limiting space used for the spoil piles. Actually, on most urban sites only vertical-sided trench excavations are possible. The designers might provide alternatives to open trenching, such as pipe-jacking or microtunneling.

Other considerations affecting the right-of-way width apply in a lateral direction from the trench and are not always apparent. Some of these might be as follows:

- Backhoes with long, overhanging counterweights must have a clear swing space of more than 90 degrees to the trench to cast earth loads.
- Truck traffic must be free to traverse a zone parallel to the trench when hauling trench spoil or imported backfill material. Storage

space for unlaid pipe is always desirable near the trench, and space for a crane may be needed to unload new pipe.
- An area for spoil stockpiling may be needed for a long excavation.
- In most cases, the solution to problems of right-of-way clearances is to be generous in estimating widths of the working zone. Fortunately, vertical clearance problems usually only exist over short pipeline reaches. Clearances will depend on power line voltages.

Other general right-of-way provisions may include:

- Location of a constructor's equipment storage yard may be important if developments in the working area do not permit placing such a facility within a reasonable distance from the work.
- If storage space for unlaid pipes is not available within a reasonable distance to the job, the engineer should give this information to all bidders for the work.
- Conflicts may occur if dimensions reserved for the working right-of-way were assigned months or even years before construction begins. Potential constructors as well as the engineer must check these clearances shortly before bidding time to ensure they are still realistic and that changes have not occurred in rapidly developing communities.
- The constructor should develop an emergency procedures plan for his own protection, even if the contract specifications do not require one.

Constructors and engineers are strongly advised to make a complete set of some type of photographs of the entire working zone before *any* work begins. This record could consist of snapshots made with a small camera, videotapes, or aerial photographs to supplement surface photos. Low-level, oblique, aerial color photography provides excellent observations of the associated conditions around a busy site and is also practical for cross-country pipeline sites. Digital pictures are inexpensive and easy to store and duplicate. These prework pictures have a relatively low cost but could have an ultimate value of thousands of dollars. Of course, pictures could be taken at any time during the work.

Additional recommendations for control of the project working area are provided in Chapter 8.

6.2.2 Underground Conditions

What information is available about the subsurface earth materials along the pipeline route? This section describes processes involved in trying to estimate what lies underground, in the path of the pipe trench.

The fortunate constructor may have information available in a geotechnical report furnished by the engineer. This report may include drilling logs, testing reports, and other soil mechanics data useful to the constructor as well as the designers. Beneficial information will indicate material character as related in the "Unified Soil Classification" of *ASTM D 2487*. This information is described in Chapter 2 of this manual. Grouping soil as SM (silt and sand soil), CL (inorganic clay of low or medium plasticity), GW (well-graded gravels or gravel–sand mixtures with little or no fines), and so on gives the experienced constructor tools to compare a site with other locations and determine the equipment required.

The same data provided by the above soils classification system is important when meeting OSHA safety regulations. These mandatory specifications base the required grade of sloped excavations on the Unified Soil Classification rating of the soil in a trench.

If the working area is likely to be underlain by bedrock, finding elevations for the top of the rock line and the relative hardness of this material is a major concern. Any special features, such as types of strata, mixtures of hardness, or texture changes (such as for lava rock) are important to know. Disposal of excavated rock may cause problems, and methods for handling this rock material must be investigated. Of course, hard rock excavations may also require some safety system in accordance with OSHA regulations.

Groundwater removal is a major cost to be estimated prior to construction. Knowledge of the depths to the groundwater surface will be needed along the entire route. Saturated trench side walls will experience reduced stability. A pipe should never be installed in standing water in a trench. Additional technical reasons for keeping a trench dry are given in Sections 6.5 and 6.6.

All water should be removed to below the pipe bedding by pumping or draining away by gravity if the topography permits. Depressions or sumps for collecting water on the trench bottom are necessary on flat slopes. Distances between sumps must be minimized because water flowing in the trench invert hinders proper pipe bedding and encourages such ill effects as the migration of fines, which can be prevented only by wrapping the bedding material in geofilter fabrics, at an additional cost. An installed pipe should never be used for conveying trench drainage.

Another solution to groundwater involves cutting off the groundwater source with well points, which are sometimes effective at removing water without axial flow in the trench. Well points are small pipes driven at appropriate spacing along the excavation, which are then pumped to draw down the groundwater table in the vicinity of the pipe. This procedure works well in soil with sufficient permeability to allow a drawdown effect to occur. Typically, clay soils will not pass water fast enough to make this process effective unless lenses of granular materials occur. Other types of dewatering procedures may be appropriate; the contractor should utilize the most cost-effective method to meet the design criteria.

Most pipes are subject to flotation if the trench floods prior to backfilling. Even heavier pipe, such as concrete or ductile iron, may float if the ends of the pipe are covered. Water may collect from rainstorms as well as from seepage. An old story relates how pumps, left operating but unattended overnight, stopped for some reason and an evening rain floated long reaches of pipe at great cost to the constructor. Backfill over the pipe is helpful to hold it down (see Sections 19.17.4 and 19.17.6 in Chapter 19 for other methods of preventing pipe floatation). The engineer may be able to design the depth of cover required.

Certain types of excavated soil materials may be usable as compacted backfill, which is beneficial to the constructor. Stripping of surface materials commonly occurs to save topsoil material in an agricultural area for replacement over the completed pipeline.

If the pipe is to be installed in a man-made embankment or other form of disturbed ground, such as a highway fill section, the side of a canal, or a spoil pile, a constructor must follow the designer's details. If no earthwork details are shown, care must be taken to provide safe working conditions in the trench at these sites because of the unknown character of the soil in the trench.

Finally, understanding all of the job conditions is vital in reducing exposure to *changed conditions*, which can plague the constructor as well as the owner. In the absence of a soil report, local utility companies may have information regarding underground conditions. The U.S. Natural Resources Conservation Service reports are useful sources of generalized soil characteristics in farming areas. Constructors might sponsor private subsurface investigations by geotechnical experts, especially if warranted by the size of the work. Often, however, only experienced judgments must suffice for planning a small job in a known, localized area, and observations of the exposed soils in roadway cuts, stream banks, or erosion channels may be all that is available.

6.2.3 Trench Details

The pipe trench provides the permanent location and structural environment for a finished pipe. The constructor must assume that the combination of pipe stiffness and earth backfill specified is the optimum design for the services intended.

Embedment dimensions and details appear on the trench cross-section drawings for the pipeline work, part of the set of contract drawings. These drawings are very important because they provide instructions to the constructor for work that must be repeated over the entire length of the project. Cross-section details and excavations for larger pipes are specially designed for each job, but agencies that contract for many small projects,

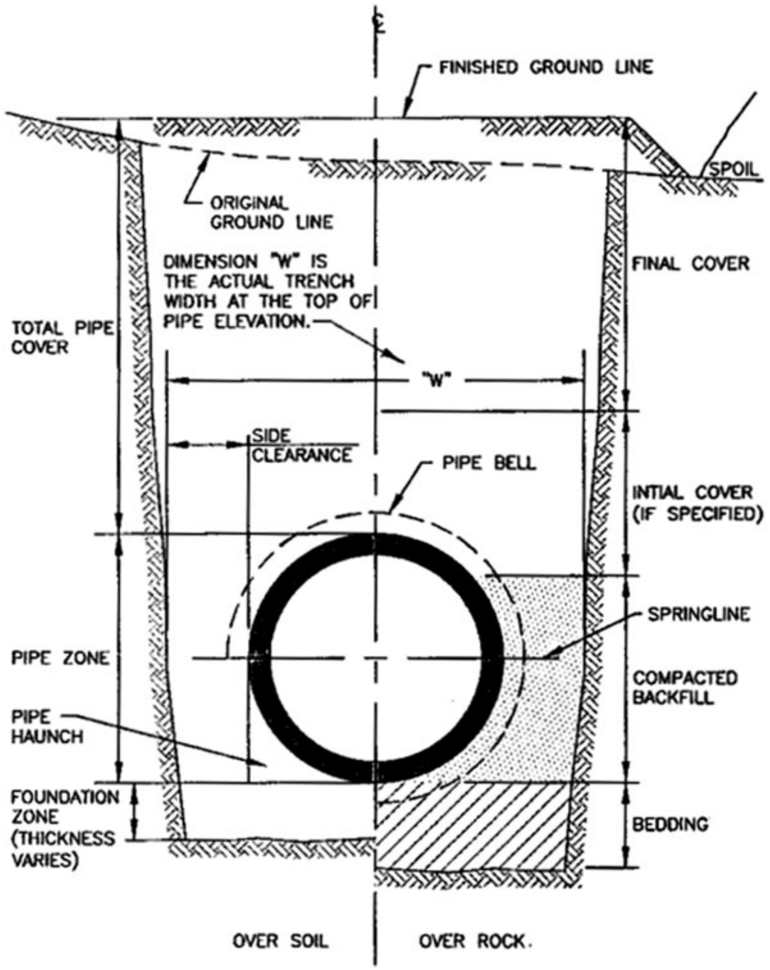

Figure 6-2. Basic trench cross section.

such as routine sewers, often use standardized cross-sections to control this work.

Typical terms and nomenclatures used in the pipeline industry for the type of contract details shown in Fig. 6-2 may be summarized as follows:

- *Foundation Zone:* This area, which includes the bottom of the trench, provides the foundation to resist the weight of the pipe and the trench backfill, including wheel loads. Normally, zone thickness is determined by the bedding material, but if the bottom is especially hard (rock or other jagged material) or if low-density soils or artesian conditions are encountered, the zone may be enlarged as directed by the engineer and backfilled with suitable granular materials.

- *Bedding:* This granular material, often specified in 3- to 6-in. (75- to 150-mm) thicknesses, must provide full and uniform support for the entire pipe barrel, except under pipe bells or large pipe couplings where overexcavations are usually as specified.
- *Pipe Haunch:* This zone is located under the lower half-arc of the pipe barrel and below the pipe *springline* (mid-diameter). Backfill placed in this zone must transfer lateral soil forces to the pipe barrel to prevent the pipe barrel from assuming an oval shape (refer to Fig. 2-4 in Chapter 2). Compaction operations and equipment will vary to meet specifications because of limited space between the trench wall and the pipe exterior.
- *Compacted Backfill:* Easily compacted granular materials are used to transfer lateral forces between undisturbed earth and the pipe wall. Achieving the specified soil density here is the basic goal of all backfill specifications and is vital for flexible as well as semi-rigid pipe designs (Chapter 9).
- *Pipe Zone:* Design term for the depth of trench wall that actively resists pipe deflection.
- *Finished Ground Line:* If specified; may be raised over original ground line to dispose of surplus spoil. In a roadway, pavement base materials must be considered.
- *Initial Cover:* Compaction may be specified here and particle sizes may be limited so as to provide uniform bearing on the pipe barrel and to avoid sharp contacts, especially on pipe with soft coating material, such as coal-tar enamel.
- *Final Cover:* This space absorbs most of remaining trench spoil. Maximum sizes of solids may be limited. Erosion must be resisted and waste materials cannot compromise ground surface finishing specifications. Disposal of broken concrete, asphalt paving, etc. may also be prohibited in this zone.
- *Total Pipe Cover:* Actual vertical dimension over the top of the pipe. Maximum or minimum values may be specified.
- *Side Clearance:* The actual space needed for the trench support system and backfill compacting equipment.
- *Trench Width, Dimension W:* Often specified because the pipe design assumed this width of earth cover on the pipe. The dimension must allow realistic side clearances to the outside diameter of the pipe, including belled ends and trench support systems. Excessive widths caused by careless excavation increase paving, loads on the pipe, quantities of earthwork, and possibly the top width of the trench, affecting right-of-way, surface finishing, etc.

The above terms appear often in contract specifications or drawings and should be familiar to construction management personnel. Actual jobs would include numerical dimensions.

Operations to compact backfill in pipe trenches require minimum clearances between the outside of the pipe and either the undisturbed soil in the trench wall or members of the trench structural support system. The nature of the compacted material and the efficient operation of compaction equipment govern these clearances. For typical backfills using sand-clay mixtures, 8 in. (200 mm) of clearance is commonly specified for pipe diameters less than 24 in. (610 mm). Pipes greater than 24 in. (610 mm) usually require at least 12 in. (305 mm) of clearance. Working with other materials requires different clearances. For example, consolidating clean sand by water jetting requires 10 in. (250 mm). Cement slurries need at least 6 in. (150 mm) clear around 24-in. (610-mm) pipes and up to 12 in. (305 mm) for pipe diameters greater than 42 in. (1,065 mm).

Maximum trench widths may also be specified for technical design reasons when vertical trench cuts are specified. If the pipe barrel has been designed to support the weight of trench backfill, but this load has been assumed as reduced by friction effects at the trench sides, a maximum trench width will be shown, measured at the top of the pipe. This design will have been based on Marston-Spangler theory, commonly used for vitrified clay and concrete pipes. Load-reducing sidewall friction can only develop properly if the trench remains as narrow as shown on the drawings. If the trench excavation is too wide in the initial cover zone over the pipe, the pipe design may actually become overloaded, causing pipe wall failure. Excess trench widths also require a higher volume of excavation and backfill work.

The reader should note that the vertical-sided trench in Fig. 6-2 is useful for illustration but is not typical of overall pipeline installations. Vertical sides are more common when the excavation must be held to a minimum, as for city sewers. Sloping of the trench sides is common for larger and longer water-related projects. Vertical cut sections must be fully braced for safety reasons and can be a work-restricting and time-consuming issue. Unsupported vertical trenches are common in oil or gas pipeline installations, but normal working procedures on such installations only require persons to enter the trench at limited locations, which can then be supported or braced. When using a trench shield, consideration should be given to the possibility of a void being created when the shield is moved forward.

More than one pipe may be specified for placement in a single, extra-wide trench. Support for the side slopes and the backfill design must meet these conditions.

An accurate trench cross-section description is also important to determine quantities of earthwork. Quantities are easily computed. Calculations first determine cross-sectional areas at a series of surveyor's stations. The length of a short reach is multiplied by the average of cross-sectional areas within this distance, and the result is an estimate of the volume to be excavated in that reach of trench.

Information required to calculate cross-sectional areas already appears on the construction drawings for any particular station. The bottom elevation of the trench is uniformly below the pipe's profile grade line—a feature included for all jobs. Elevation of the original ground surface at the same station can be estimated from topography included in the drawings or from actual surveyor's data. Differences between these two elevations are the depth of the section. Dimensions for trench widths are taken from the actual cross section used. Thus, the areas are easily calculated. If depths of cut for the pipeline are constant, the volume per foot of trench is easily calculated and may be used to estimate the rate of progress expected by the excavating machine used.

The next concern is to provide temporary storage space for the earth removed from the trench (the spoil). Estimated values for the per-foot volume of in situ excavation must be increased by a swell factor because the spoil will have lost its compaction. Swell may be estimated by increasing the loose volumes as follows:

- Clean sands: add 10%
- Average loamy soils: add 25%
- Predominantly clayey soils: add 40%

The easiest way to store trench spoil is to simply cast the material from the excavating machine to the side of the trench. This method is commonly used in rural locations where the toe of the spoil pile need only clear the top of the trench cut by an appropriate distance, currently a minimum distance of 2 ft (0.6 m) by OSHA requirements. Often, this pile is leveled and used as a roadway for other construction traffic. To estimate widths of a spoil pile to be driven upon, a maximum of 6 ft (1.8 m) high may be assumed, and the required width may be estimated by dividing the excavation volume at that particular location by the height of the pile, 6 ft (1.8 m) in this case. Some adjustments will be needed for the sloping sides of the pile.

The appropriate distance from the toe of the spoil pile to the top edge of the excavated trench is often an important factor. The pile of earth creates a surcharge load on the surface that could produce exceptional loads on a trench support system, even if the trench has wide, sloping sides. Minimum clearance distances used between the top of the trench cut and the toe of the spoil pile should be consistent with the design of the trench support system. These clearances should never be less than 3 ft (1 m) or, for any case, less than one-half the total depth of the excavation. This latter value may also help in estimating right-of-way widths.

Environmental protections may also be specified, most commonly to control movement of fine-grained clay and silt material, otherwise known as *sediment*. Wind or rain may move sediment from exposed positions in spoil piles and into natural waterways, where it degrades natural conditions. Controls may vary, such as covering the offending materials in the spoil pile with plastic sheeting or installing silt fences made from straw bales or geofabrics designed to prevent movement of sediment beyond the fences.

Urban locations are usually unfavorable for spoil storage and often require loading and hauling excavated materials to temporary, off-line storage—an expensive part of the work considering the reloading and rehauling. The temporary storage site probably involves rental payments, etc. Another problem with urban hauling is the obvious mud and dust nuisance added to the nearby environment.

Disposal of hard rock or any earth materials unsuited for backfill will also increase costs. The most expensive disposal will involve any spoil considered contaminated. Such disposal may only be available at distant locations and at a premium price.

6.2.4 Survey Control in the Trench

Horizontal and vertical alignments must be given for pipeline installation. Horizontal layout and stationing are easily seen on plan views. Vertical control on any stationing is shown by the elevations of a point on the pipe cross section and indicated on the pipe profile. This point is usually either the pipe centerline or the inside pipe invert. Using pipe dimensions, the trench bottom elevations can be located from the profile grade line.

Although the pipeline construction drawings describe horizontal centerline locations as well as vertical dimensions all along the route, they rarely locate the pipe joints. In practice, laying out a pipeline for field construction really involves laying out the position of the joints because, between joints, all pipes are straight pieces and standardized products. Some form of surveyor's work will be needed to locate the pipe joints that are critical to control the field layout of the pipe and, especially, trench excavation.

Pipe is produced in large quantities, uniform lengths, and straight pieces. Otherwise, the pieces are pipe "specials." The pipe manufacturer uses the design engineer's drawings to make a separate pipe layout, fitting their pipes to the design engineer's drawing as closely as possible on their shop drawing layout. On straight reaches, the manufacturer's layout will agree almost exactly with the design engineer's, but curves in the pipeline will require approximations to fit straight pieces of pipe as outside tangents to the curving center line. After approval by the design engineer, shop layout drawings will show the exact field location of each pipe joint. The constructor must then excavate trenches to fit this horizontal and vertical field alignment. This coordination is important for a successful project.

Some projects, especially those using plastic or ductile iron pipe, might receive only straight sections of pipe, which are intended to be cut and fitted in the field. Attempting this process without an accurate paper layout, equivalent to shop drawings, may be inefficient and may lead to careless mistakes by the constructor. The pipe-laying schedule should be derived from the survey information available on the plans. If the survey information has not previously been verified, it should be before the laying schedule is developed.

Survey work to locate pipe joints is simplest if installation occurs on a simple pattern using standard fittings, such as elbows, bends, tees, etc. In this case, locating the horizontal positions at pipe centerline intersections and providing the correct elevation for all the joint fittings is relatively easy. Elevation control will be critical if the pipe is used for gravity flow, such as a sewer. More detailed surveys will be required for pipes that extend on cross-country routes, including many bends and curves on which pipe laying units must be fitted. The excavation for such cross-country work is proportionately more difficult to control.

Prudent constructors decide before beginning work who will control the survey for the pipeline installation and how payment for this work will be made. Surveyor time needed for such work is estimated by experience.

Good surveying practices will prevent common field problems, such as control over improper joint spacing during pipe laying. Many pipes are manufactured to maintain specified insertion dimensions (the *joint stab*) or, for other designs, certain small, uniform clearance spaces between pipe ends. Careless joint spacing will cause cumulative errors, especially if the pipe is a type not easily cut in the field. For example, a 0.25-in. (6-mm) spacing error at each joint will enlarge to 6 in. (150 mm) after 25 joints are laid. If the pipe has to mate with a lateral pipe, meet a joint closure, or match pipe installed at structures, the 6-in. (150-mm) difference in length could be expensive to correct. If the surveyor's markings are used properly, the locations of joints may be checked often and errors may be prevented.

The most serious problems occur if the excavated trench does not fit the layout dimensions of the manufactured pipe, especially on a difficult alignment. This error might be solved by a revised pipe layout. At worst, the only solution may involve backfilling and recompacting the length of improper trench and then re-excavating a corrected trench.

Typical surveying procedures require establishing a controlling survey line at a safe distance parallel to the pipeline. Bench marks will provide the vertical controls as needed. Electronic survey instruments have greatly reduced surveying time. Improvements in laser leveling instruments have simplified the process of measuring up or down from the projected laser beam. Laser devices also can directly control backhoe or motor grader depths of cut. Large surveying problems, such as laying out access roads, excavating side-hills with backhoes, or establishing borrow pits may be efficiently controlled by geopositioners operating from satellites overhead.

Additional pipeline survey considerations include the following:

- Pipes with large belled ends require extra excavations for bells to be located by the surveyors.
- Underwater crossings will require a unique set of surveys.
- When staking the pipeline in the field, surveyors can also check right-of-way clearances needed later for project work.
- Surveyors can take an active part in dealing with the special service organizations (e.g., One-Call systems) that provide information on buried utility installations and lay out the information received.
- An especially sensitive problem requiring close survey control occurs when excavating near existing piping, fiberoptics, cables, or wires. Watch out for cathodic protection wires and control systems operated by others.
- Surveyors can measure dimensions for earthwork quantities or other contract payment items if necessary.

6.2.5 Excavation Safety

Practical safety problems occur during pipe installation because trench excavations can be risky places. The risk is often soil-related because the trench creates a large void space inside the surrounding mass of soil material. As described in Chapter 2, internal forces exist in all large soil masses that are in natural equilibrium. The confining horizontal forces are lost at the edge of the void space, and gravity forces in the soil mass are freed to act in a manner that pushes soil away from the face of the excavation. If the trench is made in clean sand, movement and failure of the trench side will likely be immediate. Slope failure also occurs if the soil contains larger proportions of clay, but after a longer period of time. The difference in failure times is largely the result of internal soil properties. In practice, so many other variables exist that one can never assume any cut slope is absolutely safe.

The probability that a vertically trenched cut slope may stand in clay soil for a short time has been exploited by constructors interested in saving time and money. Trenches have been excavated at extraordinary depths based on a gamble that the work could be completed before the inevitable collapse. Workmen have been killed by this type of wager. Today, taking such risks will result in great financial penalties.

To increase awareness of trench safety problems, consider all the work that might be done by hand labor inside a pipe trench. Assume a 24-in. (610-mm) pipe installation.

- Surveyors: set points for line and grade.
- Laborers: hand-grade the earth bottom; place and compact bedding material; guide and release pipes from the lifting crane; mate and/or force the pipe joints together; place and compact the structural backfill; fill outside joint spaces with mortar.
- Painters: repair damaged coatings on pipe.
- Pipe fitters: install valves and flow meters.
- Technicians: test degree of compaction and make wire connections to install cathodic protection systems.

Other personnel working in the pipe trench excavation could include:

- Constructor's foremen and superintendents
- Soil technicians
- Engineers and inspectors
- Pipe manufacturer representatives
- Emergency personnel
- After hours: trespassers, wild animals, grazing livestock

The above tabulation emphasizes how many different individuals may be at risk in an excavation and the seriousness of this problem. Past safety abuses have caused federal and state governments to enact rules and specifications applicable to pipe trench excavations designed to keep all parts of the working place as reasonably safe as possible. These specifications are summarized in the *Construction Standards for Excavations*, 29 CFR, Parts 1926.650 to 1926.652, distributed by OSHA. Any other applicable legal regulations must also be followed. These standards specify minimum conditions for workplace safety, but they really only make requirements out of procedures that competent constructors have used. They also specify monetary penalties for safety violations.

Excavation safety is the constructor's responsibility. The constructor must follow OSHA rules and protect every worker in a trench, even if this is only one person. The goal of excavation safety is to protect trench workers by installing a system that prevents lateral movement of the soil and subsequent failure of the trench wall. This process involves providing earth support systems that bear directly against earth at the side of the trench. In most cases, supports are installed at a uniform spacing, but some soils may be so weak (mud, for example) that the only solution is to provide a temporary solid wall of steel or timber to prevent any movement.

It is particularly important for others at the construction site to understand that the constructor is required to follow OSHA regulations to also protect others not working directly for the constructor. Any such person entering the excavation in an unsafe manner places themselves at risk and their employer in violation of OSHA regulations.

The basic excavation requiring support is a vertically sided trench. In the OSHA construction standards, a *vertical trench* is defined as one in which either earth wall has a side slope ratio steeper than 0.75 horizontal to 1 vertical and the trench is excavated more than 5 ft (1.5 m) deep. In this trench, the sides must be supported by a system of vertical and/or horizontal members that can bear against the soil with more force than the soil can laterally mobilize. Commonly, this cross-bracing system is called *trench shoring*.

A simple shoring unit consists of two vertical members made to bear directly on each trench wall by jacking forces acting across the trench. Conditions will dictate shore spacing along the trench. Manufactured shoring devices are readily available to press the flat backs of steel or aluminum channel sections against soil when actuated by hydraulic jacks. These devices offer the advantage of permitting installation into the trench by workers at the ground surface as the trench is excavated. Older methods required workers to enter an unsupported trench just to install the support system—defeating all purposes for safety. Removal of the newer devices is easy from above the trench by releasing the jacking pressure. Trench shoring design varies as widely as the engineering specialists who design them. Note that trenches less than 5 ft (1.5 m) deep may also require a support system if some unsafe condition exists. The OSHA rules also require inspection of the trench support system at frequent intervals by a person competent to evaluate trenching supports.

Weak soil may necessitate a support system that completely covers the trench wall by what is known as *sheeting*. Timber or steel sheet piling members are used for this process and are supported by their own support system. Sheets are often driven to an elevation below the normal trench invert. This technique may develop into a construction problem because eventual withdrawal of sheets will disturb earth at the side of the pipe and at the haunch zone, where the pipe design may depend on earth resistance to control pipe deflection. Serious void spaces can develop as a result. Solutions include cutting off sheets above the top of the pipe or only raising sheets at the same rate as the compacted backfill material rises around the pipe.

In addition to earth support, the OSHA rules also require ladders or ramps to allow a rapid escape from the trench if necessary.

Shoring a trench is impractical unless the excavation sides are close to a vertical slope. One alternative to support systems used inside a trench is to make the excavation with sloped sides and allow natural conditions to hold the soil in place. The degree of side slopes allowed by OSHA depends on the type of material as described in *ASTM D 2487*.

To the constructor, all the labor to handle the support system is avoided by sloped excavations. In exchange, much more earth must be removed and backfilled. For larger-diameter pipes, trenches with sloping sides are almost a requirement if the laying lengths for pipe units preclude threading pipes through the crossed trench supports.

Rock excavations are not normally supported unless smaller pieces of rock are likely to fall off from the greater mass, which requires some type of wire netting arrangement to catch the smaller pieces. An accurate determination of what constitutes "rock" at a particular site may require a decision by a geotechnical engineer.

Time delays caused by handling trench supports and the costs of excess excavation prompted *trench boxes* to be designed and developed. These temporary or portable support systems serve as safety devices to catch soil slip-outs before they can affect the workers. They are used in conjunction with steeper sloping trench sides than otherwise could be allowed.

Trench boxes consist of two wall-like structural steel plate members rigidly joined at the top and sides to other steel members or pipes. The units are designed to maintain clear space between sides and are open on each end. Two or more may be stacked for greater depth. Usual heights are 6 to 8 ft (1.8 to 2.4 m), and lengths range from 6 to 58 ft (1.8 to 17.5 m). They are lifted by the excavating backhoe or a separate crane and are moved ahead as pipe laying progresses. Refer to Fig. 6-3.

Excavations do not need support for worker safety if personnel do not enter the trench. This has produced a procedure for installing larger pipes, such as large concrete sewers, in clayey material that will temporarily stand on a steep side-slope. Laser-based equipment attached to the backhoe dipper stick can closely control depths of cut and final grading in the clay soil. Accuracy is such that fine-grading the trench by hand is not necessary. After the grading of the invert, bedding material also can be installed by the backhoe within allowable tolerances.

When pipe is installed later in the excavation process, a short trench box is used at each joint as a pipe is placed to protect the two or three workers making the joint. The pipe-laying crane can easily move the box to the next location as the pipe is laid. Completing the backfill around the pipe requires a special type of crushed rock materials that allow minimal compaction from above the pipe without human aid.

A sample trench section for large pipes installed in firm ground is shown in Fig. 6-3. This figure shows the result of cooperation between the constructor and safety inspectors. The outer diameter of the pipe is 42 in.

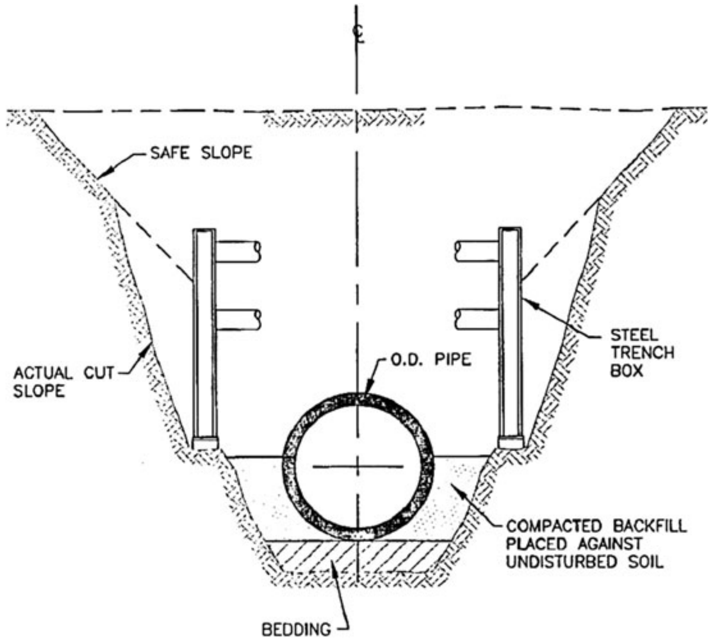

Figure 6-3. Alternative use of a trench box. The maximum allowable unsupported trench wall under a trench shield is 2 ft (0.6 m) per current (2009) OSHA standards.

(1,065 mm) and the trench traverses flat, open country. The deep section shown has been widened to provide more working room needed to meet the exacting standards for compacting the backfill, to allow haunching to bear on original soil, and to accept the trench boxes available to the constructor.

Two other lesser known OSHA requirements should be mentioned. One is for ventilation; it applies to work inside completed pipes, such as when removing internal pipe bracing, inspecting or finishing inside pipe joints, or checking for pipe deflections. Certain pipe materials always specify removal of the inside pipe struts or braces only after the backfilling is complete. Manhole accesses are the usual location for fans to induce air flow.

The second requirement is to provide ladders for quick escape from an excavation as well as trench side support.

6.3 OTHER IMPORTANT EARTHWORK DECISIONS

Additional conditions concerning earthwork should be mentioned because they are important to consider for good management of a pipeline installation project.

6.3.1 Construction Time Allowed

In a normal sequence of work, the trench excavation is a relatively simple process, occupying only two or three persons during this slowest part of the work. When actual pipe laying begins, many more persons, large supplies of special materials, and expensive, single-purpose equipment must be melded into a routine that the constructor can profitably follow. Experience is the key factor to help scheduling this work.

Total time or days allowed to complete this work is the first limiting condition considered. All work must be organized to be completed within the working time. If the allowable working time is inadequate, excavations and pipe-laying operations could occur simultaneously at more than one location. However, simultaneous operations will increase management problems for the project.

6.3.2 Problems with Open Trenches

A serious factor affected by job-site conditions is the elapsed time a trench can remain unfilled after the initial excavation. Right-of-way conditions in working areas and provisions in contract specifications may define controlling factors for this problem, including fencing. At one extreme, jobs in city streets often require complete backfilling after each day's work. Each day, a vertical-sided trench is reopened, a small number of pipe units are laid and embedded, and the backfilling work is done before leaving the area. The other extreme occurs on cross-country jobs, where a sloping-sided trench is excavated that may be open for weeks before pipe is installed.

Many factors will surface in the constructor's planning regarding the optimum time between excavation and pipe laying. One item is the high exposure to liability for public safety created by the open ditch. Also, after a certain time period, excavated side walls will dry out and possibly become unstable. Free water may collect in the trench and require pumping. Once a pipe is installed in the trench, backfilling must begin as soon as possible to protect completed work, but never beyond 2 or 3 days after pipe laying. Unsettled weather conditions are especially threatening if the compacted backfill is uncompleted.

6.3.3 Severance

Another concern is the temporary severance of all the working right-of way by the trench because costly bridges and safety fencing may be mandatory. Severance also means cutting of utility services to homes and businesses. Maintaining temporary sewer connections for more than minimum time is undesirable from a cost standpoint, and major complaints about severance are usually directed through the owner or engineer. The constructor's plans must include ways to reduce severance problems. Backfilling the trench in certain pipe reaches could be accelerated to reduce exposure to any or all of the above problems.

6.3.4 Temporary Pipe Storage

Manufacturers can usually make pipe faster than it can be installed, so pipes are often shipped to the job site many weeks ahead of scheduled pipe laying. One reason for this timing is to receive a partial payment for the delivered material. If space is available around the trench site, *lay-down storage* is usually located within the reach of the laying equipment, which will require handling pipe only once on the job site. Limited space will require a separate lay-down area and yet another piece of equipment to unload or transfer pipe onto a job-site hauler. Smaller pipes may be nested or delivered in bundles, which also presumes some rehandling. Again, the efficient method is to lift and move these pipes only once.

6.3.5 Miscellaneous Excavation Comments

- *Hard rock* requires specialized procedures to remove. Such procedures could include blasting, trenching, or an excavator-mounted hydraulic impact breaker. Soils reports may contain elevations of underground rock strata. Shot holes need only be drilled to depths needed to clear the trench. Drilling a series of in-line holes may allow shattering of hard material by a backhoe. Use of explosives requires many permits, especially near urban areas. For practical purposes and protection of the constructor, blasting effects must be recorded by instruments that will show the blast effects on nearby areas. These instruments include air accelerometers, seismographs, etc., operated by trained personnel.
- *Side-slope failures* or *slip-outs* of the trench side present potential problems, especially for flexible pipe, because of the possible loss of earth side support in the pipe zone. Such failures require immediate attention from the engineer because, theoretically, development of lateral support by soil resistance requires a width of sound soil material. Solutions to this problem involve backfilling the trench with suitably compacted soil and re-excavating the trench to the proper dimensions. A third alternative involves backfilling the void with a mix of Portland cement and soil stiff enough to fill the void. The trench-side must be returned to a condition that will not deform more than the original earth.
- Variations on the trench failure problem include *displacement of pipes* recently laid or *entrapment* by the slide of a trench box or other

support shoring. The goal is to return the trench-side to original condition, and cleanup in this case will be labor-intensive.

- *Thrust anchorages* (*thrust blocks*) may be used in pressure pipe installations. These devices are made from concrete placed directly against undisturbed soil, both on the trench bottom as well as the sides. Side bends, vertical bends, and valve structures typically require thrust restraint. If thrust blocks are used, and if the concrete will not be placed immediately after excavation, prudent constructors often coat the subject soil with air-blown mortar or gunite, which usually maintains the soil in its original condition.
- Other hazards arise when working in *man-made embankments* such as canal banks or highway fills. This reworked earth material must be treated with caution because the internal lateral strength of normal, in situ soil may not exist. Because these cuts are usually vertical, support systems must be used, subject to OSHA rules.
- Excavations for very deep pipe trenches may invite *claims from adjoining property owners* for damages caused by earth movements. An inventory of likely sites for such claims should be made and the conditions should be photographed as protection against false claims.
- In a fully supported trench excavation, water or native soil escaping between sheets indicates *voids behind the sheets*, which must be filled with some type of compacted backfill. Because well points behind sheeting can also cause removal of fine-grained soils, any voids created by the well point system must be filled with granular soil.

6.3.6 Excavation Prepares for Pipe Laying

Although pipe laying is not an earthwork operation, it occurs within this phase, so some appropriate notes are included here. Pipe-laying work is simplified if excavated materials are placed to allow pipe storage beside the trench. Commonly, pipe pieces to be installed are moved to a laydown location within lifting reach of the machine used to lay the pipe. Usually pipes are stored on one side of the trench, either on existing ground or on spoil material. If the top of the spoil is graded to a flat surface, unlaid pipes are transported and stored at the proper stations until needed. If the existing ground is used for storage, the topography governs and minor leveling may be needed to allow safe and stable pipe storage.

An alternative common procedure involves delivering pipe by truck hauler directly to the trench-side where the laying equipment can lift them from the truck and set them into the trench. This procedure requires an adequate haul road and close coordination between the pipe storage facility and the truck operation.

The act of *picking* (lifting) a pipe, lowering it into the ditch, and engaging the pipe joint is almost common for all materials using rubber gasketed or welded joints. Some plastic pipes are heat-fused or glued together at the field joints and pulled, snake-like, into the trench. In the trench, a longitudinal force will be needed to force a "new" end of the pipe joint into engagement with the "old" (previously laid) joint end. The laying equipment may supply this force, but attachments either wedged inside or chokered outside the two pipes may also be needed to allow pulling the ends into engagement. A small tractor may even be required for pushing.

During this time, the lifting connections or slings must never be released from around the pipe. If the pipe requires repositioning, rewrapping the attachment around the pipe barrel could be difficult. In addition, a small depression cut in the pipe bedding will help to slip a heavy sling from under a pipe. Testing of individual joints will require that the pipe sling remain in place in case the pipe must be removed to replace a faulty gasket. Delaying joint testing for several pipe joints behind the most recently laid pipe is not recommended because of the extensive trouble and damage resulting from removal and relaying of several pipes to correct only one joint.

Pipe laid on steep slopes may need some restraint to reduce *longitudinal creep* or other movements, especially in hot weather. Placing partial backfill under the pipe or using sandbags as an anchor around the pipe has been used to reduce this effect.

A more complete commentary of good practices for pipe storage and handling appears in Chapter 7.

6.4 MOVING EARTH

When the planning stages are complete and the constructor has decided on the equipment to use, conditions must be considered that consolidate late-developing knowledge about the work, to conform to laws and regulations, and to make the most effective use of powered equipment. Only after these considerations are addressed should the trench be opened.

6.4.1 Considering Underground Conditions

- Final dimensions, shapes, side-slopes, and trench safety in the excavation must be acceptable to the engineer and meet OSHA requirements; support systems and equipment required for safe vertical excavations must be at hand.

- Information and facts from technical soil reports should be checked for exceptionally hard or rippable materials and materials needing blasting or extra preparation for removal.
- Groundwater elevations above trench depth require pumping equipment and the water disposal method may be important, especially if the water is contaminated. Consider saving water to settle dust or for normal compaction purposes.
- All methods for spoiling excavation must be determined, and storage sites and trucks must be ready if hauling is required.
- Special soil handling: Stripping of soils that have poor properties may require different loading equipment and/or disposal, especially if the soil will not support heavy equipment. Special handling also applies to excavated soil saved for compacted backfill and topsoil saved for farming. Store such soil differently than lesser-qualitymaterials.

Use One-Call services as often as possible to identify buried utilities. Where needed, vacuum locating techniques may be appropriate for preverifying the exact location of underground appurtenances or obstructions in advance of trench excavating. This becomes extremely important when the pipeline being installed is required to be laid at a specific grade or has a pre-engineered design and layout.

6.4.2 Public Relations and Use of Right-of-Way

- All licenses, permits, and insurance coverage must be in place.
- Communication with the general public and public agencies must take place before work starts. This communication includes police and fire departments, ambulance services, school districts, local utility service providers, newspapers, street and road departments, irrigation districts, etc.
- Public utility operators with facilities near or across the trench must be advised of the work, and emergency telephone numbers for repair services must be noted. Provide a list of telephone numbers for all local police, fire, ambulance services, etc.
- Some form of small hand excavations (potholing) should be made to locate major underground crossings of any pipes or cables in the work area. Prepare to support any pipes that cross the trench excavation.
- Have trench crossing bridges or plates available.
- Have equipment ready for temporary utilities services if damage is likely.
- Temporary fencing, gates, cattle guards, barricades, roadway signs, and safety devices also must be available.

- Rights-of-way must be flagged or marked for equipment workers. Identify and mark any obstacles that will not be moved. Mark clearance problems for last-minute wire conflicts, for example.
- Environmental work, such as tree preservation, must be considered

6.4.3 Large Initial Excavation

Trench excavation is often preceded by initial mass excavations to simplify more confined trenching operations. For example, as shown in Fig. 6-4, backhoe operation on a side-hill is inefficient. Earth material is often removed to level the working surface along a side-hill pipe route. The drawing shows a typical side-hill cut made before the remainder of the trench is excavated. Side-hill cuts are usually not backfilled to the original shape, and the remaining space provides an access route for maintenance vehicles.

A similar situation using mass excavation may occur if a pipe trench must be excavated to depths below the reach of a backhoe excavator and the related trench support system becomes excessive. Often, the area can be economically cut down by bulldozer work or wheeled scrapers at lesser cost. This process is also shown in Fig. 6-4. Backfill occurs according to specifications.

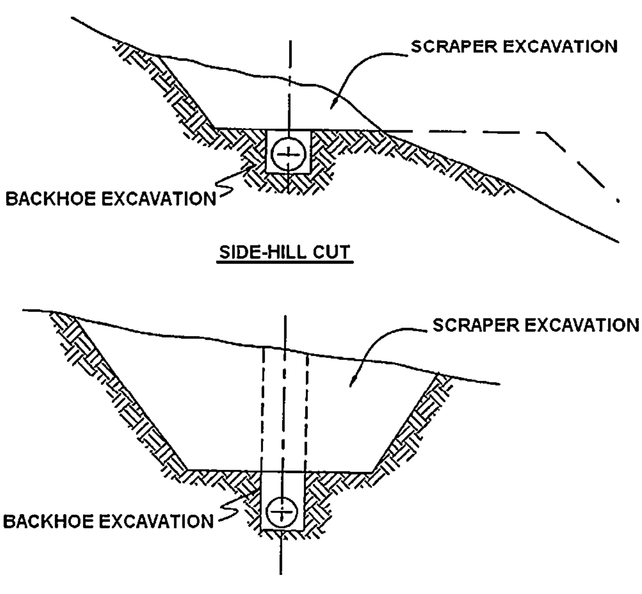

Figure 6-4. Special trench cross sections.

6.4.4 Characteristics of Earthmoving Equipment Related to Pipeline Construction

Pipeline construction, especially for pipe diameters greater than 24 in. (610 mm), uses a group of typical machines. Most of these machines are described below. Profiles of these machines appear in Fig. 6-5.

6.4.4.1 The Most Common Machines

Backhoe Excavator: This basic excavating machine for pipe trenches works in a full circle and is made in all sizes to handle from 1/10- to 6-cubic-yard and larger bucket capacity. These machines usually roll on tracks, but wheeled versions are available. A smaller version, known as a *backhoe loader*, is extremely mobile, efficient, and common for smaller pipeline work.

A backhoe pulls earth toward itself using a downward stroke—an efficient way to remove every type of soil or broken rock. The backhoe can only advance by moving backward on the center of the trench while resting on firm ground. It cannot safely straddle an excavated trench or re-slope an excavation cut beyond its reach. Spoil is easily cast away or loaded into trucks. Operation on sloped terrain is possible but efficiency greatly increases if the machine rests on a level surface.

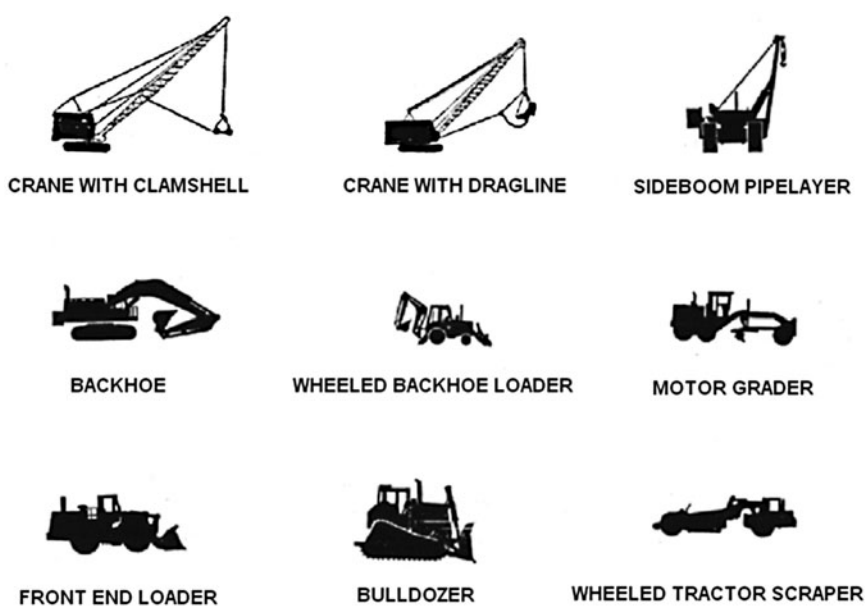

Figure 6-5. Pipeline construction equipment profiles.

Some backhoe buckets have curved edges rather than normal steel teeth. This edge is efficient in clay soils because it does not tear up the soil and may allow smooth side cuts.

The most attractive feature of medium-sized backhoes is their mobility over rough ground. If passage is too rough, they can excavate their own working area. Useful additions to backhoe efficiency include use of laser-beam controls for elevation control and earth-compacting devices or other machines, which can be attached to the backhoe's boom or "dipperstick." Some major agencies, such as the Los Angeles County Flood Control District, do not permit the use of stick-mounted compaction rollers due to previous problems with pipe damage they can cause.

Crane: The crane operates to lift vertically over a full circle. Lifting capacity depends on "tipping distance," or the distance of the load from the center of the machine. Smaller cranes ride on wheels and are mobile; the largest cranes are always on tracks and are less mobile. Cranes may lift with cables only or by telescoping parts moved by hydraulic cylinders. When handling and laying the heaviest pipes, the distance from the center of the crane to the center of the pipeline is often critical.

Some cranes excavate with a clamshell bucket that drops vertically into the excavation. Bucket sizes are similar to backhoes. Production is slower than with a backhoe but spoil can be cast farther from the trench. An alternative to clamshell excavation is the dragline bucket, operated by casting the bucket out from the machine and pulling back to load the bucket. This arrangement, best used for excavation in water, requires a long boom to increase the casting range but results in slower production.

Front-End Loader: These fast, mobile machines are furnished in wheeled and tracked types, and are most useful for scooping and moving granular materials about the work site, especially backfill materials. Front-end loaders can make trench excavations but the minimum trench width will equal bucket width or total machine width, whichever is larger.

Bulldozer: This old, reliable, track-driven machine moves earth materials by horizontal brute force applied by the cutting blade, sliding or shearing soil materials over ground. Bulldozers can excavate with an accuracy of 2 to 3 in. (50 to 75 mm) in most soils. Attachments to rip furrows in hard soils can be fitted on the rear of the bulldozer.

Motor Grader: Another old standby, motor graders can be used for finishing embankments and roads by accurately cutting soil to level surfaces to within 0.25 in. (6 mm) when laser-controlled. These machines could work inside a trench to level grades for extremely large pipes.

6.4.4.2 Less Common Machines

Chain or Belt Trencher: These powerful machines work best in hard or rock-like formations to literally scrape small pieces out of in situ conditions. These machines are best for trenching in material where the trench does not require support.

Side-Boom Pipe Layers: These machines are the primary pipe-lifting device used for oil and gas steel pipe. They have high lifting capacity but limited mobility, limiting their use on water or sewer projects.

Wheeled Tractor Scrapers: These highly mobile excavators are used for moving large masses of earth. Smaller machines are often used inside an excavation on large pipelines and are especially useful for excavating trenches as shown in Fig. 6-4. Wheeled tractor scrapers are also known as *paddle loaders* or *carry-alls*.

6.4.5 Pipe Laying Equipment

For the city street job, the excavating backhoe is the choice to lower small pipe units into final position because it is so close to the limited work. Use of a wheeled excavator will require a separate crane or similar device. A separate pipe-laying crane is usually selected for most other jobs because of its flexibility, stability, and power. Side-boom tractors are powerful but often too inflexible for practical use. Pipe diameters and weight of units will be deciding factors for selecting the power and stability of the pipe-laying machine. For safety, crane outriggers and wheels or tracks always must be placed away from the top of cut slopes because the concentrated loads from these earth contacts can easily cause soil failure.

6.4.6 Using Powered Equipment

Excavating machinery should be selected based on excavation quantity expected per day. For backhoe work with a given bucket size, allowing about 50 dips per hour will give a production rate for excavation in average soil.

Choosing the best machine to lift the pipe during installation is another consideration. On smaller projects using 24-in. (610-mm) and smaller pipes, digging the trench and laying pipe with the same machine, such as a backhoe, is economically feasible. Smaller backhoes may experience stability problems when picking (lifting) large pipes at 90 degrees to the trench. Obviously, unlaid pipe must be available at the time of excavation, which may present storage problems.

An alternative involves laying pipe with a separate machine, usually a crane. This alternative is probably more efficient because pipe bedding and backfilling can be performed after excavation in a continuous manner rather than in a slow "dig and lay" method.

Steep slopes present problems to all machines. If possible, bulldozers should cut level working pads so cranes or backhoes can swing about a vertical axis.

6.5 EMBEDDING THE PIPE: THE SECOND PHASE OF PIPELINE EARTHWORK

6.5.1 Introductory Remarks

This second phase of common earthwork is most important for all pipeline installations. This work will ensure that each pipe unit is in the correct underground position and is always in a rounded condition to deliver fluid at the expected rates of flow. Working procedures used in phase two are in sharp contrast to the brute-force aspects of trench excavation, so properly completing this cost-intensive part of the work can be a challenge for the constructor.

This second phase includes specialized types of earthwork because, except for handling the pipe units and making pipe joints during the same time period, important engineering requirements are met through the use of soil or soil-like materials. Procedures for actually handling, laying, and jointing the specific types of pipes considered in this manual are described in Chapters 9 through 19.

One important requirement, as mentioned above, is to hold all pipes permanently fixed or anchored in one underground location. Another even more important requirement is to ensure the cross-sectional shapes of all pipe sections remain close to circular and are not pressed into a flattened oval by the weight of the earth backfill. Preserving roundness of a pipe depends not only on the pipe's internal strength or stiffness; the density of soil surrounding a pipe also has an important effect.

Pipes with a variety of stiffness properties may be specified. Rigid or high-stiffness pipes are relatively easy to hold to a circular cross section when properly installed. However, pipe materials with less stiffness or more flexibility depend on soil-type materials as an efficient encasement to help limit any deflections. If the soil is properly compacted, even these pipes will operate under relatively deep covers of earth.

A constructor must assume that successful installation of the pipe design shown on the drawings seriously depends on achieving all of the results specified for backfilling processes around the pipe. The type of pipe and the specified backfill work for a project are probably the optimum combination for the project. Project designers often optimize project costs by comparing, for example, more expensive pipes that need lower-cost backfilling efforts versus similar designs that combine a less expensive pipe barrel with the need for more costly backfill work. Even some standardized pipe designs reflect this type of trade-off. For example, common standards for low-pressure concrete pipe might provide four specific pipe barrel design strengths paired with work representing four alternative degrees of backfill densities, each representing four levels of contract cost.

6.5.2 Earthwork for Embedding a Pipe

Drawings for well-designed pipeline installation projects will include an earthwork cross section of the trench along with engineering specifications for embedding the pipe—all appropriate for the pipe's diameter and the material used in the pipe barrel. This cross section may be similar to Fig. 6-2, which has vertical sides, or it may show sloping trench sides. In either case, the terms and notations in the trench zone will not change. Key notations are the minimum bottom width, a controlling factor for excavation, the depth of compacted backfill, and the degree of compaction to be achieved. Earth-like materials for backfilling may be specified in detail, but related conditions are often not obvious, such as the need for large volumes of water to work with granular products. Rigid or strong-walled pipes always need a good foundation bedding. At the other extreme of pipe stiffness, flexible or semi-flexible pipes are likely to depend completely on full side support from compacted earth backfill to maintain circular integrity.

Understanding backfill work begins with the terminology. Refer again to the typical trench detail in Fig. 6-2. The more important terms shown on this drawing—foundation zone, pipe bedding, and compacted backfill—are explained below. Other parts, such as the pipe haunch and initial cover, are referenced here to define relative position or location pending later use in this chapter. Actually, the pipe zone area is the center of interest for all of this discussion.

The term *compaction* of soil requires definition in particular because it is used so often. This term was defined in Chapter 2 but will be repeated here. Compaction means to apply external energy to a confined mass of soil to increase its density. The results of compaction are measured by increases in unit density of the soil. Soils are much more effective in resisting deformation under applied loads when they have a higher density, or higher degree of compaction, and become much more useful for engineering purposes. External energy is applied by some device or machine that presses, vibrates, or beats on the soil. The effect is to drive the soil particles closer together while driving the air in the void spaces out of the soil. Specific equipment for compacting soil will be described in Section 6.5.5.

Effective soil compaction requires confinement, usually provided by adjacent soil material or some immovable item such as concrete. Field testing has shown that the most effective compaction in pipeline work occurs at 0 to 12 in. (305 mm) below the point of energy application on the loose soil's surface.

Density is measured by the unit weight of the soil mass. Earthwork specifications call for compacting, or densifying, a soil material to a percentage of its maximum optimum density, which is the greatest density obtainable by practical or conventional construction methods. Maximum values are determined by laboratory testing. Final densities expected for various applications to pipelines will range between 80% and 95% of the maximum optimum density. For example, if the maximum optimum density is 110 lb/ft^3, 85% compaction means the soil will have an in-place density of 93.5 lb/ft^3 (1,500 kg/m^3). Field testing is used to verify in-place values. This has been covered in Chapter 2.

Costs for installing earth around a buried pipe are then proportional to a given scope of backfilling work, which represents the total work effort to achieve an in-place density. Costs are easily evaluated by the total of costs for the materials used and the labor and equipment expended to achieve the specified densities in the encasement of soil around the pipe. Estimated costs for this work provide important input data for optimizing pipe designs, as described above.

Returning to Fig. 6-2, the *foundation zone* shown is a part of the pipe trench normally assumed to be adequate if soils data do not predict problems. However, the entire weight of the pipe and backfilling earth bears on this material, and actual excavations may expose some defect in the earth at the trench invert. Organic soils, artesian conditions, or low-density natural materials may all prompt the engineer to direct removal of such materials and replace them with suitable granular or bedding materials.

While appraising conditions in the exposed trench foundations, the engineer will consider the density of the earth at the lower trench walls. Conditions have occurred where this side-wall material was actually weaker than the compacted backfill expected to bear against it. Compacted backfill is further described near the end of this section. This condition should have been identified during the exploration work for the project, but errors and omissions do occur. Weakness at this point could be a great complication for the work because a correction might require lateral overexcavation of the trench wall and backfilling the void up to the depth of the pipe with compacted backfill. Backfill with some form of concrete-enhanced backfill is another possible solution.

Pipe bedding allows pipes to be easily laid over very rough excavations; it acts as a cushion or cradle for the pipe, so the loads from the upper earth flow through the pipe and onto the foundation zone. Pipe bedding will establish the profile grade for the pipe and is easiest to conform to any elevation. Earth materials used here will have the character of granular soils and will contain only small amounts of clay.

Pipe bedding is thinly placed, often only 3 or 4 in. (75 or 100 mm) thick. Occasionally, some projects may use greater bedding thickness, perhaps equal to the pipe outside diameter divided by 12, expressed in inches.

Spreading and densifying pipe bedding has traditionally been a hand operation, but to reduce the time that persons are in the trench, machinery is now available to do this work—even operating from outside the trench. These thin layers of granular bedding material may be compacted by several methods, including vibrating plates and small sheep's-foot wheels attached to a backhoe boom.

Also, if a pipe has belled joints, trench excavation must be lowered under each bell to provide clearances to ensure that vertical loads are only resisted by the pipe barrel—not only by the bell ends. These deeper excavations are called *bell holes*.

Compacted backfill fills the remaining space around the pipe. The required in-place density will be given in the work specifications. Total depth of this backfill component will be shown on the earthwork cross section for the work. At least depth, the material will rise up to about three-eighths of the outside pipe diameter, often to the springline (horizontal centerline). At greatest depth, this material may rise to about 1 ft (0.3 m) over the pipe.

Soil-like material for compacted backfill is used to firmly hold the buried pipe by a grip or bearing force that helps keep the pipe closely in its original shape. This force is necessary to allow the soil–pipe structure effect to occur. This effect has been described previously in Chapter 2, but will be briefly reviewed here.

The pipe barrel shape is assumed to be round (or nearly so) upon delivery to the job site. However, the cross sections of all buried pipes deform under the weight of the backfilling earth in a manner that moves the top (crown) of the pipe vertically downward while the sides are moved laterally outward (Fig. 2-4 in Chapter 2). The invert (bottom) of the pipe remains fixed and movement does not occur unless the pipe bedding or foundation fails, which is unlikely and is not considered here. The amount of vertical and sideways deformation is related geometrically because the circumference of the pipe barrel is unchanged except for pipe material that is very weak in compression. A small amount of vertical deflection is acceptable. Various specifications usually allow about 2% to 5% of the pipe's diameter as limiting values. Allowable sideways deformation on each side of the pipe is about one-half of the vertical.

The backfill is compacted to densify soil immediately around the pipe to the degree that it actively bears against the pipe wall on one side and the natural earth in the trench excavation on the other. This densified soil has a reduced capacity to deform, and long experience shows that a dense, compacted backfill acts as a strut that resists sideways pipe deformations to materially reduce vertical deflection of the top of the pipe. Without adequate support from the earth at the side of the trench, some low-stiffness pipe materials may overdeflect, assume irregular shapes, or collapse completely. Relatively weak pipe materials are held in a circular shape without excessive deflections if side support is adequately developed.

Significant changes in pipe shape may adversely affect the hydraulics of the flow conditions, but more likely will allow leaks at the joints. Once a pipe barrel begins to deform, the movement may become progressive and lead to complete collapse. Loose soil is not effective to transfer compression forces from existing soil of the trench-side to the outside of the pipe in a manner that resists the sideways spread of the pipe.

The specifications should give the maximum depths of freshly placed and uncompacted backfill material (lifts) because the compaction work is largely influenced by the depths of placement. Shallow lifts give much better results because energy input is more effective and material is moved more effectively under the haunch of the pipe. Material to be compacted must be spread uniformly and simultaneously on each side of the pipe to resist lateral displacements or uneven deformations of the pipe barrel. These operations are subject to great variations among constructors. The actual maximum depths of lifts may be based on the contractor's methods and the effectiveness thereof, with the engineer's approval.

Effective compaction also requires certain moisture contents in the materials. Water should only be added in the material stockpile because that is the only way to ensure uniform distribution throughout the mass.

Other means to densify backfill soils have been used, such as the *flood and jet method* using clean sand. These methods can be very effective for rigid and heavy pipes, but providing the properly graded sand and large amounts of cheap water can be difficult. Also, all water that does not infiltrate into the ground or run out by gravity must be removed to prevent flotation of lighter-weight pipes.

In summary, placement of compacted backfill has two important components: first, to ensure that the pipe haunch area is filled; and second, to achieve specified density throughout the zone of compacted backfill. Successful placement combines careful workmanship with the proper tools. A diligent inspector also helps.

6.5.3 Material for Backfill around the Pipe

Specifications for earth materials around the pipe usually require some form of granular material, but do allow a range of particle sizes. The best materials will have less than 50% passing a No. 200 sieve, because silt or clay materials are often impractical or too costly to compact up to the densities commonly specified for a pipe trench. If the constructor is fortunate, the trench spoil will meet specifications without further processing. Of course, at some sites only clays and silts will be available. Perhaps the designers will have recognized this and subsequently redesigned the backfill as appropriate for clay-like materials. The key is to obtain, at least cost, the best material that meets specified soil grading and achieves acceptable density. Commercially processed sand is a premier material, but equivalent products, such as screened natural soil, washed beach sand, and crushed blast furnace slag, lava rock, and fly ash, have all been commonly installed. Often, commercial aggregate producers have excesses of certain-sized materials available at minimum costs, especially in the increment between the No. 4 and 0.5-in. sieve sizes.

Crushed rock below 0.75-in. (19-mm) size also has been used for compacted backfill if allowed by specifications. Because backfill is densified to resist deformation, some engineers may require evidence from the constructor that the placement methods for installing crushed materials will truly result in the rigid mass expected.

Regarding crushed material, constructors in the oil and gas pipeline industry have helped develop rolling (movable) rock-crushing machines that reduce rocky trench spoil to the smaller sizes they refer to as *padding*, for use around steel pipes. On-site processing may be an efficient source of materials for any pipeline.

6.5.4 Handling Backfill Materials

As is applicable for almost all earth materials, backfill should be lifted only once on the job site and then moved by gravity through chutes to the underground site. This process requires location of storage piles on-site close to the trench. Commonly, a front-end loader is used for this. If the pipe bedding and compacted backfill materials are not the same, two storage piles are needed. If a firm supply of these two granular materials is questionable, large on-site storage piles may be needed to avoid shortages.

Dropping materials directly into the trench without a chute may damage the pipe, and is wasteful and inefficient because the materials have to be moved again in the trench to provide the specific lifts of uncompacted materials.

6.5.5 Densifying Equipment

A labor-intensive but workable method to densify granular materials around a pipe is by hand-held, curved tampers or even by shovels. This is known as *slicing* along the pipe barrel. However, a wide variety of machinery is available to give impact energy to loose soil materials. Optimum use requires that the equipment be compatible with the type of material compacted and that lateral spaces or widths are available in the trench. Clay-type soils respond best to tamping or impacting blows; granular materials are best densified by vibrators. The lightest-weight compactors are hand-held, air-operated tampers, which deliver 100 to 200 blows per minute and are easily used in small spaces. These compactors are best adaptable for work in the haunch area under the pipe. Heavier devices include gasoline-operated tampers using a free piston, which imparts energy as a miniature pile-driving hammer. Vibrators are usually furnished as vibrating plate devices operating at a frequency that is best to move granular soil particles. A wide variety of compaction methods are also available to the contractor. The required density is the goal with whatever method works in a cost-effective manner.

Pipe with low stiffness must be inspected often to ensure the pipe shell is not being distorted by the compactive effort. Also, lightweight pipes may be actually lifted out of position by compaction work. If the granular backfill material is mainly clean sand, and water is available, very effective compaction has been achieved by groups of three or four very large, mass concrete vibrators suspended from crane-like equipment at the trench-side and inserted into an almost saturated loose mass of the sand. This operation does not require persons to be in the trench. At times, constructors have attempted to drop heavy weights as compactive devices. This technique, although effective under some conditions, may be counterproductive if the effect is only to punch holes in the soil mass and not to provide meaningful overall increases in soil densities. The prime caution is to avoid hitting the pipe with the compactor. Pipe protective coatings can be damaged by such blows, or some pipe materials may be damaged by these outside impacts.

6.6 PROBLEM CONDITIONS DURING BACKFILLING

6.6.1 Groundwater in the Trench

Pipe must not be laid or backfilling attempted if free water lies in the excavation. Pipe laying in this event can only be allowed if the project design provides special details and procedures. Working in free water can cause the following problems:

- Trench water is most likely clouded and muddy, so hard spots at the invert and the condition of the pipe bedding cannot be seen to ensure that pipe bells will clear the trench invert and that the pipe barrel will receive proper support.
- Soil materials cannot be properly compacted if their moisture content exceeds optimum amounts.
- Joining pipe under water produces a strong possibility of trapping sand or mud in the gaskets, allowing future leaks. Joints cannot be properly inspected or tested under such conditions.
- Most pipes may actually float free from the bedding, which can subsequently cause loss of bedding under the pipe and potential damage to the pipe itself.

- Welded or bolted joints are impossible or impractical to make under water.

One solution used when working in free water has been to overexcavate sumps at the invert, and fill with crushed rock materials. Pumping from the sumps holds the groundwater below an elevation where it is a problem for pipe laying.

6.6.2 Live Loads over a Recently Installed Pipe

Many projects will require earth-moving equipment to operate in the vicinity of the pipe and pass over the trench before finished grade is attained. These off-highway wheel loads may exceed designed loads, so the engineer must determine the minimum cover completed over a new pipe before these loads can occur. Placing backfill and trench backfill may have to be accelerated at certain locations up to depths of cover that allow these crossings over the new pipe.

6.6.3 Removing Major Trench Shoring

Sheet piling or other closely spaced earth supports cannot be removed if this will disturb the effect of compacted backfill necessarily placed against these materials. These supports cannot be pulled out without damaging the effects of soil compaction required to reduce pipe deflection. One solution is to leave the support system in place. Buried wooden material left in this manner must be treated for permanence underground. Another alternative is to pull up or raise the sheeting at the same rate as the backfill rises so that backfill directly contacts the trench wall.

Similarly, backfill cannot be compacted against any part of a trench box because moving the box will also reduce the compacted earth's ability to resist pipe deflection. The trench box must be installed to rest above the top of the compacted zone, or the lower side walls of the box must be cut out to provide the same effect. A better method is to carry the box along on a special berm, as shown in Fig. 6-3. However, whatever method is employed must adhere to OSHA requirements.

6.7 COMPLETING THE TRENCH: THE THIRD PHASE OF PIPELINE EARTHWORK

The typical earthwork cross section will show how the remainder of the trench will be backfilled over the compacted backfill. One of the functions of this backfill is to absorb remaining trench spoil up to finished grade elevation. However, the volumes displaced by the pipe plus imported backfill materials and the natural bulking of excavated earth almost always results in surplus earth. Usual disposal is to spread the surplus over the right-of-way in a manner that accommodates natural drainage, aesthetics, and so forth. Allowances must be made for any topsoil returned over the site. Special erosion protection on steeper locations is common.

Compaction of trench backfill material depends on the specifications and is always required under streets and roadways. If the pipe runs longitudinally under a street, a relative compaction to 90% is usually required to within several feet of the street subgrade, and 95% for the remainder up to the roadway subgrade is recommended. Rarely, some municipalities allow only minor compaction work to be provided and the surface is repaired with low-cost asphalt. After a certain amount of natural settlement, a repair with better surfacing will be made. This procedure does little to enhance the neighborhood because depressions over the pipe seem to always remain.

Returning the ground surface to certain conditions should be well defined in the contract specifications. Returning topsoil, replacing all of the original surface development, or even improving facilities in certain areas are examples of work that occurs late in the project, when the constructor may be close to reaching his budgeted financial limits for the job. If the contract does not provide a strict method to ensure payment for this completion work, written understandings or agreements must be reached at the beginning of contract work.

The upper backfill zone must not be used to dispose of assorted construction junk. Tree stumps, broken concrete, and asphalt paving are examples of prohibited materials that should not be placed in the pipe overfill. This material would likely hinder future trench excavations or contribute to unstable trench conditions. Some types of this junk material might help control erosion over a small pipe, but the protection should be applied at the surface, where a bulldozer could easily remove it.

6.8 NOTES TO INSPECTORS

6.8.1 General

- A thorough understanding of the contract drawings and specifications is vital.
- A prime recommendation for construction inspectors on a pipe installation project is to always work in a safe condition with respect to excavations and enclosures. Earth support and ventilation are not always required during an accelerated project, and a single inspector may stumble into a dangerous condition. Likewise, attachments to

moving equipment, such as counterweights and cables, must be avoided. Again, safety is the constructor's responsibility. The inspector should communicate any potentially unsafe conditions to the constructor's management.

- The preconstruction meeting is most important to establish the lines of authority or management in the constructor's organization. This meeting is also helpful to determine exactly what the constructor views as their standard working procedures. Often, field-level employees are not as well informed on details of the specifications as the top managers.
- Obtain as many of the pipe manufacturer's guides, recommendations, and pipe details as possible. This information may not agree with the project specifications,it can substitute for otherwise poorly detailed engineering work. Be very familiar with the manufacturer's shop and field layout drawings for the pipeline, numbering systems, etc.
- A main duty of an inspector is to keep good written notes, especially dimensions and data needed for as-built records. One result of a pipeline project is to hide all of the work from view. These notes often provide the only information regarding what is underground.

6.8.2 Initial Test Section

Some engineers provide in the project specifications for a demonstration test section to demonstrate whether the constructor is properly organized to complete earthwork around the pipe, especially the compaction of backfill. Experience shows that although the specifications define certain results for compaction work, there are many combinations of equipment, methods and materials that can meet the specifications. Finding the proper combination for a given project should be an orderly process and not left to trial and error.

Actual acceptance testing is then performed on a short reach [about 100 ft (30 m)] of the first pipes installed. This demonstrates whether the constructor's proposed combination of materials, methods, and equipment will actually meet the specified degree of backfill compaction or any other requirement. An additional test section may be ordered later for larger projects or if materials are significantly changed. Test pits must be provided for technicians to sample compacted earth under the pipe haunch. These pits will need special earth supports for worker safety.

If the constructor is successful in passing this test, specific procedures for the subject job, materials, and equipment can be established and the inspection process simplified because both the constructor and the inspectors can work with the same project rules for meeting the specifications.

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CHAPTER 7
PIPE SHIPPING AND HANDLING

7.1 CONTROLLING PIPE DELIVERY

Each project may include a variety of pipe designs representing different materials, diameters, strength ratings, joint types, or other features. To minimize errors, the manufacturer typically marks the pipe in accordance with applicable project specifications to indicate key features of each piece of pipe, as shown on the pipe layout drawings.

Typical markings include the manufacturer name or trademark, the diameter, the pressure rating or class, and the standard to which the pipe was manufactured (for example, *AWWA C 151*, *Ductile Iron Pipe*). Additional markings may include a sequential number for the pipe, a code indicating joint types, a "mark number" indicating a class of pipe with particular properties, and other specialized markings. Large-diameter pipe may be marked both inside and outside; small-diameter pipe is usually marked outside only. Inside markings should be made with National Sanitation Foundation (NSF)-approved inks if used inside municipal water pipe.

Pipe may also be color-coded either by tinted material or color stripes applied to the base material to indicate key features such as type of service, pressure class, or unusual features on the pipe (such as outlets or unusual joint type). A sample of pipe marking is shown in Fig. 7-1.

Markings should be inspected for each pipe as part of the constructor's receiving and acceptance inspection at the site.

Figure 7-1. Pipe markings inside a concrete pipe. Courtesy of Price Brothers Corporation.

7.1.1 Transporting Pipe

Pipe typically arrives at a job site by truck, but rail shipments may be available. In any case, the pipe should arrive in useable condition, without deformations, scratches, breaks, cracks, or similar signs of damage.

Protection of pipe during transportation is usually the manufacturer's responsibility. Some pipe materials are relatively flexible and tend to deform during shipment, requiring support to prevent excessive deformation. Support may consist of internal bracing, sometimes called *stulling*, or external bracing. The pipe barrel material alone may not be the determining factor in the need for support because certain linings and coatings may even be more susceptible to damage by deformation than the pipe barrel itself. For example, cement-mortar materials may be cracked or even separated from the pipe by excessive deformation or impact.

Small-diameter pipe may be stacked during shipment. Typically, flexible pipe is stacked with surrounding wood forms at appropriate intervals. Rigid pipe may be stacked with or without forms. The pipe is then secured to the hauler using padded straps or chains.

Large-diameter pipe is typically heavier and is not stacked because of the shipping widths and unbalanced loading. Chocks, blocks, or sandbag bedding may be used with straps or chains to prevent rolling (Fig. 7-2).

Coatings, because of their exposure to the elements, require protection. Straps and forms are padded to minimize coating damage. Pipe position may be staggered to minimize potential bumping or rubbing during shipment. In addition, certain coatings for underground service may not be UV-resistant and may require covering during shipment and storage.

Figure 7-2. Large-diameter pipe shipped by truck. Courtesy of American Cast Iron Pipe Company.

Certain pipes require end closures by, for example, plastic sheets during shipment to allow the lining to cure in a controlled environment, to protect against debris or exhaust, to provide UV protection for an unusual lining, or to prevent accumulation of rainwater in the pipe or fittings.

The engineer must approve nesting of various diameters for hauling because these conditions can cause shipping damage to pipes and pipe coatings.

7.1.2 On-Site Inspection and Storage

Pipe must be inventoried and inspected upon receipt and after unloading to prevent installation of damaged products. Items and methods of inspection are typically indicated in the construction specifications and/or provided by the pipe manufacturer. Questions to answer during inspection may include:

- *Support:* Were the pipes supported reasonably to prevent damage in transit? Were specific support requirements of the contract documents met? Are any visible signs of deformation, cracking, or other damage evident?
- *Securing:* Were the pipes secured in a fashion to reasonably prevent damage? Did securing straps or chains bear against the pipe or against pads/supports? Were loose ends secured? Is pipe damage from supports visible?

- *Markings:* Are markings clear and consistent with the project specifications and standards? Appropriate for the project? As listed on shipping tickets? Consistent with the visible features of the pipe?
- *Coatings and Linings:* Are these as specified (type, material)? Have they been damaged during shipment (cracks, abrasions, gouges, tears, separation from the pipe)?
- *Pipe Condition:* Is any sign of deformation or cracking evident? Are the pipe ends and barrels free of dings, nicks, and scars? Is the pipe clean? Proper size?

Pipe damage may be corrected by repairs at the job site in accordance with the pipe manufacturer's recommendations and the project documents. The damage may cause rejection of the pipe. Pipe damaged prior to unloading is a problem that the manufacturer and the shipper must resolve. Damage during unloading may change the responsibility for repair and/or replacement of damaged pipe. Filing a notice of damage prior to unloading is recommended.

Once accepted, the pipe is stored for use on the project. Smaller-diameter pipes may be stored at a central location or off-site until needed. Larger-diameter pipes are typically laid out along the work area to minimize handling.

Site storage, like shipment, requires that the pipe be protected from damage and stored in accordance with the project specifications and the manufacturer's recommendations. Pipes may need blocking to prevent rolling. The storage area should not contain hard, sharp materials that could damage linings or coatings. If freezing is possible, pipes should be arranged so water cannot accumulate inside. Pipe ends should be closed in extremely dirty conditions or where so specified, but pipe markings should remain, to the extent possible, readily visible.

Storage areas should be protected against vehicular and pedestrian traffic and vandalism. Power line conflicts must be avoided.

7.1.3 Job-Site Handling

Handling of pipe units refers to the specific means by which pipe pieces are lifted and moved about the job site before actually being placed on the trench invert. Procedures for handling all pipe pieces are based on a unit's material, diameter, laying length, and weight. Equipment and methods used must support the pipe in a manner that always prevents damage to joint rings, linings, and coatings. Pipe manufacturers will provide specific recommendations for approved field handling of their products.

The constructor should coordinate the delivery schedule to avoid excess handling. Lifting larger pipe sizes usually involves the expense of an extra crane. Clear storage areas are needed as close to the trench as possible, and where the pipes may be picked by the laying crane. For example, on one project, pipes of 48-in. (1,220-mm) diameter weighed about 8 tons (7,300 kg) per piece of pipe, so avoiding extra handling costs demanded careful planning. Extra handling also increases the potential for pipe damage.

A crane or backhoe outfitted with a nylon sling on the bucket may be used to unload and lay pipe. Multiple slings may be used in handling large pipe and fittings. A forklift with cushioned uprights may also be used if allowed by the manufacturer and the specifications. Again, support for the pipe and protection against damage to linings and coatings are the key considerations.

Regardless of the handling equipment used, the installation of any pipe is potentially hazardous. The constructor's equipment should lift the pipe only from a balanced position, and a clear area must be maintained around and under lifted pipe to prevent accidental crushing or pinching. Spotters may be needed on specific job sites to keep the area surrounding a lifted pipe clear.

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CHAPTER 8

GENERAL INSTALLATION FOR ALL PIPES

8.1 BASIC WORKPLACE CONTROL

The engineer should establish survey markers for baselines and bench marks to control the pipeline system alignment and grades along the construction route. The constructor or others may perform this work if approved by the engineer. Control points should be well identified, should provide both vertical and horizontal control with elevations and coordinates, and should be referenced to permanent objects.

Prior to the start of work, rights-of-way, work areas, clearing limits, and pavement cuts should be laid out by surveyors to recognize and protect properties adjacent to the work. The location and condition of fences, yards, gardens, trees, and other private property within the right-of-way must be established early in the project.

Easement accesses and entry locations for work forces and equipment should be identified and opened for use (refer to Chapter 6 for further discussion). Restrictions on the use of these easements must be available to the constructor and engineer.

Surface drainage patterns along the route may need to be established to control backfilling and earth disposal. Geologic features that may provide information on subsurface conditions need to be identified.

The extent, nature, and locations of utilities and substructures owned by others must be verified. The local One-Call system must be advised of the nature and location of the project. One-Call systems provide a central office where many owners of underground ducts or pipes have recorded locations of their hidden facilities to help prevent damage by other excavations.

Street, highway, and railroad departments need to be advised of scheduling, and permission must be obtained for crossings. It is generally the responsibility of the owner to obtain right-of-way crossing agreements, and the constructor to coordinate the timing. It should be noted that proceeding with a project without such agreements in place—a process which can take months to complete—may be justifiable cause for a delay claim. Access roads, detours, bypasses, and protective fences and barricades may need to be located and constructed.

Telephone numbers of responsible people or offices for nearby ambulance, fire, police or sheriff, water and sewer, and other service providers should be posted for use in an emergency.

8.2 GENERAL PIPE INSTALLATION

The following recommendations apply to the types of pipes covered in this manual. Specific installation details for various materials are found in Chapters 9 through 19.

The pipe manufacturer should supply basic procedures for installing its own pipe because the wide spectrum of available pipe materials requires different procedures for different types of pipe. These pipe producers are uniquely aware of the advantages and limitations of their own products. All of this information must be made available to both the engineer and the constructor.

The manufacturer's criteria must agree with the contract specifications. At times, the design engineers may disagree with pipe producers, especially if an alternative type of pipe proposed by a constructor has questionable merit and is not suitable for the service intended. Any and all of these specification differences must be resolved before work begins.

In day-to-day work, a project with permanence is best achieved by avoiding common accidental pipe damage that will likely result in future maintenance problems. The goal is to provide a project pipeline with permanence and freedom from maintenance costs. Ongoing visible inspections of unlaid pipes by an inspector are strongly advised to find problems before burial.

8.3 HANDLING AND OPERATIONAL ISSUES

8.3.1 Careless Handling

Careless handling can damage all pipe components. Any kind of high-impact or point loadings create a hazard for sensitive elements of pipe joints, linings, or coating systems. Specific examples include:

- Ends of concrete pipes are sensitive to impact damages due to the large weight of each pipe section.
- Pipe coatings made of relatively soft materials can be damaged during handling and backfilling. They may also become brittle in cold weather and must be handled with extra care.
- Rolling of any pipe should be subject to the engineer's approval.
- Soft pipe linings can be scarred by workers' boots; harder linings may be cracked by pipe flexure when lifting or from barrel deflections during backfill.
- Rubber gaskets are subject to damage from sunlight or improper lubricants.

8.3.2 Storage

Chapter 6 covered storage of pipe sections and fittings within the right-of-way to avoid interference with other construction operations and damage from dirt and debris. Some pipe may require special support during aboveground storage.

Pipe in central storage must be uniformly supported and protected. Aboveground storage should be easy for smaller pipes, but most pipe storage assumes some machine will lift stored pipes, so maneuvering or operating space will be very important, especially for the heaviest pipes. Sand bedding has been used to allow rolling of very heavy pipe into position for loading.

8.3.3 Lifting

Constructors must always provide adequate equipment for lifting and placing pipe in position, such as an excavating backhoe, a separate laying crane, or an equivalent machine.

All pipes or other loads must be lifted (picked) steadily at the required maximum distance from the machine. Loads must be held in a uniform manner, without any suggestion of lack of control, imminent tipping, or straining of the machine. The load must always be well controlled, especially when making the small and precise movements required to engage pipe ends ("stabbing" a joint) without damage to either pipe end. Crane booms should not show signs of past buckling in the compression members, or other weaknesses.

8.3.4 Pipe-Handling Attachments

Slings or harnesses must not damage the exterior of pipe. Steel cables, chains, or straps must always be padded to avoid concentrated loads on the pipe coating. Attachments must be easy to make before lifting and easy to release in the trench. A small excavation across the trench bottom will allow a large sling to pull out without damage to the pipe bedding. Single cables must only be used as approved by the engineer because this method allows the pipe to become a cantilevered beam with high stress concentrations at the point of attachment. Certain linings or coatings can be damaged by this effect. A spreader bar to allow use of lifting attachments at two or more locations may be recommended. Forklifts with narrow support can produce the same cantilever effect and require some attachment to spread the points of support and prevent vibrating flexures in the load.

8.3.5 Trench Conditions

Prior to lowering into the trench, pipe sections or fittings should be inspected for damage and repaired or replaced as necessary. In the trench, pipe should be laid on firm bedding, true to line and grade, with uniform bearing under the full length of the barrel. Pipe may need to be held during the jointing process to avoid disturbing the subgrade. Previously excavated bell holes will receive the pipe bells, collars, or joint bands so bedding support can be confined to the pipe barrel. These appurtenances will be backfilled later, as specified. Fine adjustments to line and grade must be made by scraping away or adding compacted foundation material under the pipe—never by using wooden wedges, blocks, and soil mounds. Lowering the pipe elevation by raising and dropping or even by beating on the pipe barrel is completely unacceptable. Uniform bearing and support for the pipe barrel is always of prime importance.

8.3.6 Direction of Laying

This procedure depends on the constructor's preferences. Decisions will be made early in the work and will be shown on the pipe layout plan made by the pipe manufacturer. On steep-profile grades, laying uphill is preferred to ensure that any downhill pipe slippage can be controlled to keep correct joint spacing. Small wooden blocks in each joint can ensure proper joint spacing.

Usually, pipes with some form of bell and spigot field joints will be oriented for laying so the spigot ends will be inserted into the bells. The gasket in rubber-gasketed joints is better compressed by this method. However, opposite laying, or sequence, has been performed successfully.

8.3.7 Making Joints

Extreme care should be taken when jointing unwelded, threaded, or unfused pipe to ensure the joints remain free of any foreign materials.

Relatively small particles of foreign material can cause joint leaks, especially during high-pressure testing.

For some plastic or steel pipe, joint welding or fusion is made aboveground and the pipe is then snaked into place at the contractor's option. Steel and plastic pipes will often be subjected to effects of temperature changes, which can disturb joint spacing.

Pipe joints using rubber gaskets are especially sensitive to contamination by any loose earth. These gaskets require a large amount of grease-like lubricant and must be placed in accordance with the manufacturer's recommendations. Preventing gasket contamination must be part of the constructor's plan. This lubricant must conform to the manufacturer's criteria because joint failures have occurred when certain types of rubber were attacked by the chemistry of improper lubricants. Most rubber gaskets are also subject to damage from the sun or even extreme temperatures, so they must be stored in a protected location. The manufacturer should be consulted for recommendations about joints required to meet specific testing pressures.

Laying pipe on a curved alignment often requires the joint to be "pulled," which means a squared spigot end will be installed by skewing it inside an adjoining bell end. Inspectors should ensure the tolerances allowed for this on the pipe supplier's layout plan are closely followed.

8.3.8 Internal Bracing

Many pipes that have low stiffness or relatively brittle linings or coatings require internal bracing maintaining roundness when being handled and until backfilling is complete. The manufacturer will install these braces, but removal usually should not occur until the backfill is placed.

Internal bracing is removed by passing material out of manholes. External supports to control deflection must be subject to approval by the engineer.

8.3.9 Heavy Wheel Loads

Wheel loads of equipment operating around the construction site often exceed that allowed on highways. Operation of these machines over a partially backfilled pipe requires approval by the engineer. Extreme loads require special designs.

8.4 MAINLINE CONNECTIONS

All connections to the mainline should be made in accordance with the manufacturer's recommendations. All pipeline connections, including taps, should be accomplished by experienced crews using industry equipment and supplies that are specifically manufactured for that pipeline material. All taps should be made in accordance with local codes.

When excavating for a mainline connection, excavate material from above the top of the mainline pipe before removing material from the sides of the pipe. Backfilled material should then be removed uniformly so as to maintain balanced lateral loading on the pipe. Backfill of the excavated area should conform to the specifications for the existing mainline pipe.

Valve, fitting, and hydrant weight should not be carried directly by the piping system unless the engineer has specifically designed the system to carry these loads. A concrete cradle or concrete block with anchors should normally be used to support this weight.

When deep, vertically oriented laterals are built, special construction methods are needed to eliminate the effect of heavy dragdown axial loads in the lateral pipe. These loads can cause localized buckling or punch-through into the mainline pipe. The specifications should provide special construction procedures, such as compression sleeves, at these locations.

8.5 REACTION OR THRUST BLOCKING

Concrete reaction or thrust blocking should be provided in locations determined by the specifications or the engineer. The blocking should be accurately formed and poured or placed at these locations. The earth surface against which the thrust block bears should be undisturbed. Joint harnesses, anchor rings, or other types of restrained joints may be specified instead of concrete thrust blocks.

8.6 CONNECTION TO STRUCTURES

Where the piping system connects or passes through a rigid structure, provision must be made to allow for movements and differential settlement. The specifications must provide the connection or passage so as to maintain system integrity. In the absence of instructions in the plans and specifications, the system used must allow the line to continue to function if movement or differential settlement occurs. Short sections of pipe and flexible couplings have been used successfully at these locations.

For manholes or other concrete structures, a sleeve, boot, or other type of gasketed, watertight system should be cast or grouted into the structure wall. If a flexible, watertight wall attachment system is not available for a particular piping system, then two gasketed joints should be located within two pipe diameters of the face of the structure. For critical lines and poor foundation conditions, both a flexible wall attachment system and a flexible joint outside the wall should be used.

Extra care is required to provide the proper support under and around pipe that enters or exits a rigid structure. Compressible or otherwise unsuitable foundation material should be overexcavated to a depth determined by the engineer. This unsuitable material should be replaced with bedding and structural backfill materials. The bedding and structural backfill should consist of crushed rock or other high-quality granular material, uniformly placed and well compacted. This high-quality material should be used for a minimum distance of 3 ft (1 m) or one pipe diameter (whichever is larger) from the face of the structure.

Manholes and vertical risers that connect to the pipeline should be designed so surface loads are not transferred directly to the pipe. The pipe itself may need reinforcement to resist these loads. For heavy traffic loads, concrete relieving slabs should be designed for the structure–surface connection.

8.7 INSTALLATION IN CASINGS AND TUNNELS

Pipe installed inside casing pipes or tunnels can be either pushed or pulled into final position. During the installation process, care must be exercised to prevent damage to pipe joints, pipe bells, or the barrel of the carrier pipe.

Skids or casing spacers are required to prevent damage to the pipe and to create clearance so the pipe does not rest on its couplings or bells. Skids should be securely fastened to the pipe. Properly selected lubricants can be used to facilitate pipe installation.

If grouting of the annular space between the carrier pipe and the casing is required by the engineer, it must be carefully planned and accomplished by experienced personnel. The pipe should be blocked or filled to resist flotation. Block size and spacing must be selected to prevent localized deformation under flotation forces. Stage grouting of the carrier pipe may be necessary. The pipe manufacturer should determine grouting pressures, which must be carefully controlled to ensure that excess grouting pressure does not cause deformation or collapse of the carrier pipe. For example, Table 19-3 in Chapter 19 provides maximum allowable grouting pressures outside a fiberglass-reinforced pipe.

At the ends of a casing pipe or tunnel, the pipe can be considered a rigid structure, so the engineer should provide a design to accommodate differential settlements.

8.8 OTHER CONSIDERATIONS

Where temperature changes can occur, such as in exposed crossings, the specifications must provide for pipeline expansion and contraction. In extreme conditions, the pipe may need to be set on rollers.

The contract specifications should show all bridge-like crossings and show specific details on the construction drawings. These details should include anchor locations, support or guide spacing, saddle support details, tie-down details, provision for expansion/contraction, protection against damage by external forces, and protection against freezing. Some pipe materials and coatings may also require protection against long-term ultraviolet exposure.

Subaqueous pipelines are special applications beyond the scope of this manual. The pipe manufacturer should be contacted for specific installation guidance.

At the close of each day's work, or when pipe is not being laid, the pipe ends should be sealed in some manner to keep the pipe clean and to prevent unwanted materials from entering the system. Adequate precautions must also be taken to prevent or control uplift from flooding.

8.9 CORROSION

Pipeline coatings and linings that are specified for corrosion protection need to be protected against damage during all construction operations. Damaged coatings must be repaired in accordance with the pipe and/or coating manufacturer's guidelines.

When necessary, cathodic protection systems should be supplied and installed in accordance with the project plans and specifications. A corrosion engineer should be retained to monitor the installation of all cathodic protection systems. After installation and throughout the life of the pipeline, the cathodic protection system must be checked for proper operation.

Tube, dielectric, or insulating encasement material and test stations for pipeline corrosion control should be installed in accordance with the manufacturer's recommendations. Appurtenant structures must be encased similar to the pipe sections. The earth backfill material must be selected to minimize damage to the encasement material. Rips, punctures, or other damage to the encasement material must be repaired in an acceptable manner, although it is not the intent of this material to be watertight.

8.10 MEASUREMENT OF PIPE DEFORMATION

On certain projects and especially for more flexible pipes, the design engineers may be concerned that the final inside shape of the backfilled pipe is within specified limits. The deflection calculation is based on dividing the loss of inside diameter after backfilling by the inside diameter of an unloaded pipe. This is expressed as a percentage.

To inspect for pipe deflection of pipes too small for workmen to enter, one common method is to pull a mandrel-like ball, or similar tester, through the completed pipeline. This allows checking the deformed shape. This tester will have a diameter representing the smallest internal dimension allowed. If the tester will not pass, the pipe has deformed beyond the allowable amount. Application of this test depends on the actual specifications for the project.

Deformation of completed pipes that allow entry by workers can be measured by recording actual inside dimensions. A simple telescoping arrangement of pipe or sticks can be devised to record the diametric measurements at any station. For rigid pipes, the nominal diameter of the unbackfilled pipe may be used in the calculations. Some flexible pipes may have initial deformations (out-of-roundness), so the average of diameters before loading is calculated. In these cases, maximum outward and inward deformations may not be on either the vertical or horizontal axis of the pipe. Specific applications for measurement of deformations will depend on the actual project specifications.

8.11 FIRST FILLING OF PIPES

Filling an empty pipeline with water requires careful planning. This can be visualized by inspecting the pipe profile to determine the safe rate of water inflow. This is especially important if the profile has a long series of flat crests and valleys. The location of inflow is not as important as the rate of filling.

Consider whether the pipe is filled from an upstream location. Every valley of the pipe will be filled in two parts as water flows over each upstream crest. Downstream valleys will fill with at least two volumes, so each leg fills at half the rate (or less) of the flow upstream of the crest. This is a closed system and, when each valley is completely filled, water in each valley may have to rapidly double its velocity. At this instant, accelerating the downstream flow can only be provided by increased pressure head at the crest. In extreme cases, these sudden pressure rises have caused serious shock waves in a pipeline. Actual bursting of pipes has occurred.

Air release valves will release trapped air but often cannot pass the volume of air needed to reduce the pressure. Large standpipes are much more effective in relieving this pressure.

All this can be prevented by adequate planning to visualize the above potential effects and filling an empty pipe at a rate slow enough to allow the pipe to absorb extra shock pressures within the allowable strength provided in the design.

For a treated-water pipeline, bacteriological tests are typically specified. First, the pipe must be flushed to remove potential contaminants. The amount and rate of flushing should be given in the contract documents. Second, the pipe must be disinfected, typically by using chlorine (either as tablets, liquid, or gas) placed into water for certain lengths of pipe. Highly chlorinated water is swabbed onto surfaces of small areas. The highly chlorinated disinfectant solution is then flushed to an appropriate disposal area and bacteriological tests are taken to check the degree of sterilization. The pipe owner should provide these tests.

CHAPTER 9

GENERAL INSTALLATION PROCEDURES

Chapters 10 through 19 describe features and construction procedures used when installing pipes made using 10 common designs, which are listed in Table 9-1.

All these pipes will give good service if designed, manufactured, and installed to capitalize on their best properties. Some types will contain the highest pressures, some are best at resisting external loads, and some materials have the lowest initial cost. The goal of the following chapters is to show how each pipe should be installed to provide the highest level of service.

Not all of these 10 materials are suitable for all sites and conditions. Occasionally, a design is proposed that is not suited for the service intended. Experienced constructors will consider how the design fits field conditions when bidding on such a project.

Chapters 10 through 19 describe detailed work to install the 10 specific pipe types. Some chapters describe installation details using an anecdotal style of reporting on representative sample projects. This presentation results in a text oriented to job experiences. Other chapters describe work in a more traditional manner and develop recommendations through an item-by-item sequence of construction procedures. Both methods are intended to lead an inexperienced reader through a whole project by describing the general sequence of pipeline installation operations.

All the procedures described in the previous chapters are applicable to Chapters 10 through 19. However, actual project specifications always supersede anything in this manual.

Description of work for each type of pipe is given in a uniform sequence. This sequence describes work to manufacture the pipe, transport it to trench-side, lay it in the trench, secure the required bedding and backfill,

Table 9-1. Types of Pipes Addressed in Chapters 9 through 19

Name of Pipe Material	Standard Used
Group 1 Rigid Wall Designs	
• Reinforced concrete pipe	*AWWA C 302, ASTM C 361,*
Noncylinder (Chapter 14)	*ASTM C 655*
Cylinder (Chapter 14)	*ASCE 15-98*
	ASTM C 300
• Prestressed cylinder pipe (Chapter 13)	*AWWA C 301*
• Vitrified clay pipe over 12 in. (305 mm) (Chapter 16)	*ASTM C 700*
Group 2 Semi-Rigid Designs	
• Bar-wrapped concrete cylinder pipe (Chapter 15)	*AWWA C 303*
• Steel pipe (Chapter 10)	*AWWA C 200*
• Ductile iron pipe (Chapter 12)	*ANSI C 151, AWWA A 21.51*
Group 3 Flexible Pipe	
• Corrugated steel pipe (Chapter 11)	*ASTM A 798*
• PVC pipe over 12 in. (305 mm) (Chapter 17)	[a]*AWWA C 901, C 906*
• PE pipe, high-density	*ASTM F 714, D 3035*
for water (Chapter 18)	*ASTM F 894, F 1759*
for sewers (Chapter 18)	*ASTM C 950, D 3517*
profile wall (Chapter 18)	
• Fiberglass-reinforced thermosetting resin plastic pipe (Chapter 19)	*ASTM D 3754*

[a] AWWA specifications vary for service:
For water: *AWWA C 900, C 905, C 909*
For sewers: *ASTM D 3034, F 679*
Profile wall: *ASTM D 794, F 949, F 1803*

and then make final acceptance tests. The methods cited are based on industry standards and specifications used by major purchasers of pipeline projects. Experience shows that these methods result in optimum pipeline service.

Construction procedures used to install each type of pipe are intended to preserve the conduit's permanent position and circular cross section. A properly installed pipe will not move underground or exhibit excessive deflections of the cross section. This requirement can be met by the following combined effects:

1. Under-pipe support and soil–pipe structure restraint is provided by specified backfill methods.
2. Bending resistance in the pipe wall is provided by the structural stiffness of the wall.

Design engineers will select the optimum economic combination of pipe and earthwork for a project based on the initial cost of pipe delivered to the trench-side and the degree of backfilling work to create the proper soil–pipe structure effect. In other words, given a certain degree of pipe wall stiffness, the backfill must be appropriate to hold the pipe in the optimum rounded condition.

If backfill materials must be imported to create the proper soil–structure interaction effect, this will have major impact on the costs of a pipeline project.

The best method used to reduce deformation of lower-stiffness pipe barrels is soil–pipe structure interaction, described in Chapter 2, Sections 2.8 and 2.9. This effect is attained if the soil at the sides of a buried pipe is exceptionally well compacted, such that increased lateral earth forces acting sideways against the barrel try to mold the pipe into a negative, or upward, deflection, providing a counteraction to squashing effects. Soil–pipe structure interaction is also related to the stiffness of the pipe barrel material. For this reason, Table 9-1 is grouped according to the relative stiffness of each pipe.

When discussing controls for pipe barrel deflections, the effect of internal pressure provides little benefit because this pressure can never push a backfilled barrel completely back to a circular shape. Also, this pressure does not exist in the empty pipe condition, when earth loads are initially mobilized against the pipe.

In summary, all pipes deflect when buried—some appreciably more than others. Therefore, not all pipe types should be used at all locations because the deflection may not be appropriate. Constructors should expect that the project designers have recognized this fact and have provided appropriate design and installation specifications.

Appendix B provides contact information for the primary organizations that can provide more specific information on pipeline installations.

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CHAPTER 10
STEEL PIPE

10.1 GENERAL BACKGROUND AND DISCUSSION

10.1.1 Description

Steel pipe was first used in the United States in California in 1858. Records show that some installations from 1863 have been in continuous operation. Early production of steel pipe consisted of short sections of plate rolled to form longer lengths, with the diameters of the individual sections offset to allow the shop circumferential and longitudinal seams and the field joints to be riveted.

In 1905, lock seam pipe came into existence. This product was formed by rolling longer sections of plate into two half-round troughs, with the two longitudinal seams joined by compressing an H section across each seam. This product was popular until the advent of welding.

In the early 1900s, electric welding practices were being developed and, by 1932, welding had largely replaced the lock seam and riveted processes. Early welded pipes were generally produced using short sections of rolled and welded pipe that were shop-butt-welded together to form longer pipe lengths. Joints were initially riveted or flanged until field welding became commonplace.

Spiral-welded pipe was developed in Germany prior to World War II. Initial welding was accomplished from just one side of the seam (the outside), creating a somewhat weaker seam than the steel shell. In time, techniques were adopted to be able to weld from the inside as well, and that was the beginning of modern spiral-welded steel pipe.

Today, the vast majority of larger-diameter steel water and wastewater pipes [larger than 24 in. (610 mm)] are produced by the spiral process.

Short runs of pipe may still be made by the process of producing short lengths of short-rolled “cans” and shop-welding these sections together to form longer pipe lengths.

Smaller-diameter oil and gas pipes [up to and including 24 in. (610 mm)] are produced by forming steel coils that are sheared longitudinally to a width equal to the correct pipe circumference, and gradually forming the circular cross section and butt-welding the longitudinal seam using electric resistance welding (ERW). Larger-diameter pipe may be spiral-welded; however, due to the higher pressure requirements in the petroleum industry, these pipes are frequently produced from rolled and formed heavy plate. The spiral process demands that pipe be made from coiled steel, and coils in the United States are only available up to 1 in. (25 mm) in thickness.

10.1.2 Applications

Steel pipe has an almost infinite variety of uses, from oil, gas, water, and wastewater transmission pipelines to structural piling and supports. The excellent beam strength of steel pipe improves the cost-effectiveness and system flexibility when considering exposed suspended pipelines. However, the basic purpose of this manual is to address the installation of buried pipelines; the variation in installation methods and methods of support for exposed piping would require a separate text. Several excellent references that address exposed piping are *ASCE Manual 79*, *AWWA M 11*, and the Steel Plate Fabricators Association (SPFA) *Penstocks Manual*.

In buried service, common uses of steel pipe include:

- Potable and raw water transmission mains
- Sewer force mains
- Circulating cooling water power plant piping
- Makeup and blowdown power plant piping
- Hydroelectric penstocks
- High-pressure pipelines for the delivery of petroleum products, gas, and various chemicals
- Slurry and freight pipelines

10.1.3 Trade Associations

Specific contact information for the following relevant organizations is found in Appendix B:

- The Steel Tank Institute/Steel Plate Fabricators Association (STI/SPFA), a merger of two major manufacturers’ organizations, represents most of the steel water and wastewater pipe manufacturers in the United States.

- The American Water Works Association (AWWA).
- The American Petroleum Industry (API) represents the oil and gas industries.

10.2 PRODUCT INFORMATION

10.2.1 Standards

AWWA, the American Society of Civil Engineers (ASCE), API, STI/SPFA, and the American Society of Mechanical Engineers (ASME) provide standards for the manufacture of steel pipe for various applications. The most common standards pertaining to steel pipe come from AWWA, covering pipelines for all water and wastewater conveyance. These standards include various coatings and linings as well as appurtenances, connections, and installation practices. A complete listing includes:

- *AWWA C 200, Steel Water Pipe*
- *AWWA C 203, Coal-Tar Enamel Coating and Lining*
- *AWWA C 205, Cement Mortar Lining and Coating*
- *AWWA C 206, Field Welding*
- *AWWA C 207, Flanges*
- *AWWA C 208, Dimensions of Fabricated Fittings*
- *AWWA C 209, Cold Applied Tape for Fittings*
- *AWWA C 210, Liquid Epoxy Coating and Lining*
- *AWWA C 213, Fusion Bonded Epoxy Coating*
- *AWWA C 214, Cold Applied Tape Coating for Pipe*
- *AWWA C 215, Extruded Polyolefin Coatings*
- *AWWA C 216, Heat Shrinkable Sleeves*
- *AWWA C 217, Petrolatum/Petroleum Coatings*
- *AWWA C 218, Coatings for Aboveground Pipe*
- *AWWA C 219, Bolted, Sleeve-Type Couplings*
- *AWWA C 220, Stainless Steel Pipe*
- *AWWA C 221, Fabricated Slip-Type Expansion Joints*
- *AWWA C 222, Polyurethane Coating and Lining*
- *AWWA C 223, Tapping Sleeves*
- *AWWA C 224, Polyamide Coating*
- *AWWA C 225, Fused Polyethylene Coating*
- *AWWA C 226, Dimensions of Stainless Steel Fittings*
- *AWWA C 227, Split Sleeve Couplings*
- *AWWA C 602, Cement Mortar Lining, In-Place*
- *AWWA C 604, Standard for Installation of Steel Water Pipe 4 In. (100 mm) and Larger*
- *AWWA M 11, Steel Pipe Manual*

The list of AWWA standards continues to grow as new coatings, linings, and connection devices become available. Although stainless steel pipe is included above and is gaining in popularity, it still only addresses a very small niche market and will not be further addressed in this manual. The recently published American Iron and Steel Institute (AISI)/STI/SPFA *Welded Steel Pipe Manual* (revised edition 2007) further assists the engineer in the design of steel pipe as well as gaining an understanding of the pipe-to-soil mechanism for buried flexible pipe.

ASCE Manual 79, *Steel Penstocks*, and the Steel Tank Institute/Steel Plate Fabrication Association *Penstocks* are excellent resources for the designer working with hydroelectric facilities as well as with exposed pipe on supports. *AWWA M 11* addresses exposed piping, and ASCE Manual 79 and SPFA *Penstocks* add helpful information for pipe on supports.

ASME standards are primarily associated with high-pressure and high-temperature applications. Although steel pipe is largely mandated for these applications, the pipe sizes and methods of installation are quite different from standard water, wastewater, and cooling water pipeline installations (however, they do relate closely with oil, gas and chemical pipelines). That said, it is common practice to refer to ASME guidelines for welding procedures, qualifications, and certifications.

API Spec 5L, Specification for Line Pipe, covers the manufacture of oil and gas pipe with either longitudinal- or spiral-welded seams.

10.2.2 Dimensions and Pipe Wall Thickness

Steel pipe is available in an infinite variety of diameters and wall thicknesses. The spiral welding and "can" welding processes employ a freestanding application that allows for any diameter above 24 in. (610 mm) to be produced (see Fig. 10-1). While this gives the designer some additional flexibility on extremely large projects, it is best to maintain the use of standard diameters for consistency and conformity. Water and wastewater projects generally require a finished inside diameter of the pipe after lining to comply with 6-in. (150-mm) increments [36 in. (915 mm), 42 in. (1,065 mm), 48 in. (1,220 mm), etc.]. Oil and gas piping use the outside diameter of the pipe when referring to a diameter but still use the 6-in. (150-mm) incremental designations. The ERW process does not permit the same flexibility with diameters because the equipment to contain the specific outside diameter would require modification.

Wall thicknesses for pipelines are governed by the *thin ring formula* ($t = PD/2S$), where t is the shell thickness, P is the pressure, D is the diameter of the pipe, and S is the allowable stress in the pipe wall. Again, there is wide variation in the supply of a pipe produced from coils because the contract order is generally large enough to warrant a direct purchase

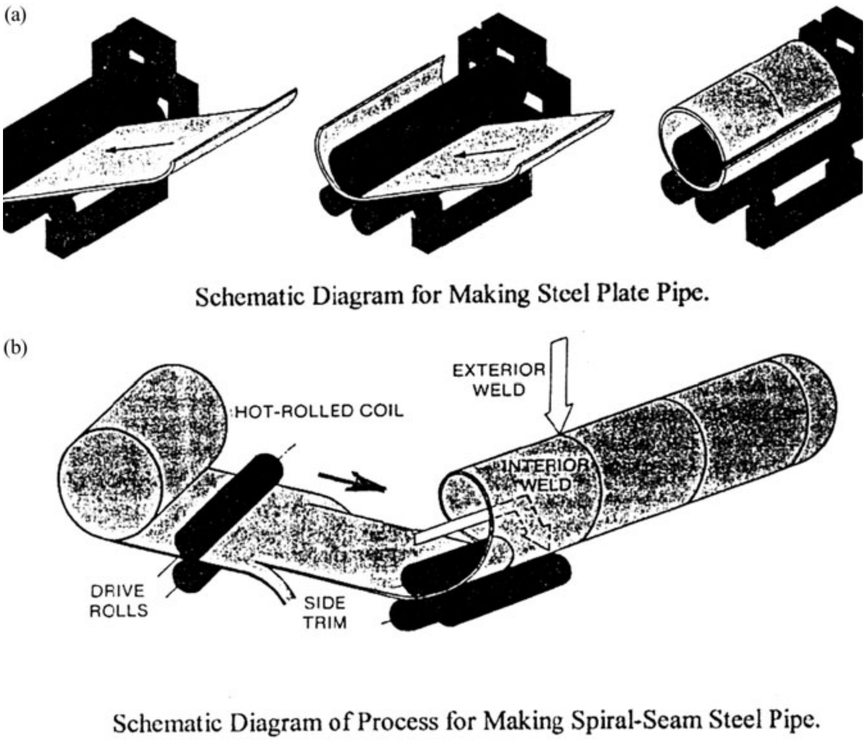

Figure 10-1. Methods of producing welded (a) steel pipe, and (b) spiral-seam steel pipe. Reprinted from AWWA M 11, Steel Pipe: A Guide for Design and Installation, with permission. Copyright © 1987, American Water Works Association.

from the steel mill with the thickness specified to the nearest 0.001 in. (0.25 mm).

The ability to resist the external loads is developed by the soil support. Although it is not in the purview of this manual to provide specific design information, it is beneficial to the installer and engineer to understand the soil–pipe structure relationship to ensure the correct pipe is being installed in the proper location with the proper installation methods and with the appropriate bedding to provide adequate support to resist external loads.

10.2.3 Types of Joints

For water and wastewater pipelines in the range of diameters to about 72 in. (1,830 mm), gasketed joints are generally accepted up to about 250 psi working pressures as long as thrust restraint for unbalanced forces is not a consideration (see Fig. 10-2). For higher pressures, larger

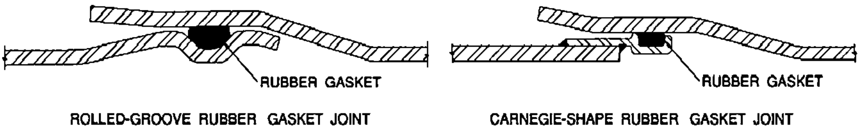

Figure 10-2. Typical rubber-gasketed joints. Reprinted from AWWA M 11, Steel Pipe: A Guide for Design and Installation, with permission. Copyright © 1987, American Water Works Association.

diameters, or for any restrained joint area, welded joints are specified. Restraint is required wherever the pipeline has a bend greater than about 5 degrees, and at dead-ends, tees, and valves. This can be accomplished using thrust blocks or restrained joints. For large-diameter pipelines, economy and conservatism usually dictate the use of welded joints. For buried pipe, the preference is for a lap-welded joint for all these situations.

With a lap-welded joint, one end of the pipe is expanded roughly to the barrel outside diameter plus two times the wall thickness. This allows the joint to be made up by slipping the bell end over the plain end of the previous pipe at a slight angle and "snapping" the joint to make the connection. This joint then requires a fully circumferential, watertight, full-fillet weld on either the inside or outside of the joint. Sometimes a specification requires a double-lap-welded joint (welding inside and out); however, this is generally not required for buried water and wastewater pipelines. Considerations that may require double-lap-welded joints include the size of the pipe, the internal pressure, and the wall thickness, and external factors such as temperature differential. The design engineer should consider all relevant factors and make a design appropriate for the conditions.

Butt-welded joints are required for all oil and gas pipelines and for water pipelines with extremely high pressures. They are also recommended where the pipe is subject to bending stresses, such as with exposed pipe spanning individual supports.

A wide assortment of joints are available for connections to valves and other appurtenances. Generally, for connections to valves, either a steel pipe end conforming to the dimensions of a ductile iron spigot, or a flange end, is required on the steel pipe. Plain ends for couplings are also a common connection, particularly for in-line joints where some added flexibility is warranted, such as at connections to structures. Where restraint is required, a restrained coupling may be used or a standard mechanical coupling can be employed with harnessing ears attached to the pipe and bolts spanning the coupling and attaching to the ears. This latter arrangement is well detailed in *AWWA M 11* (see Fig. 10-3).

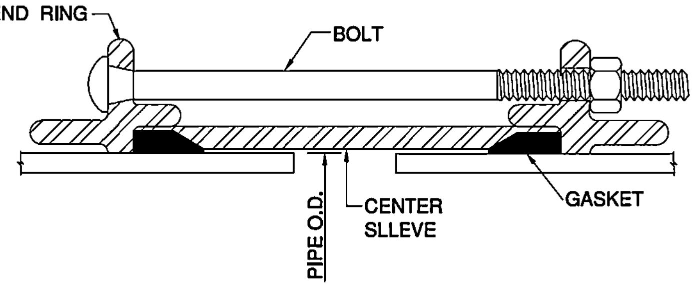

Figure 10-3. Section of a large-diameter sleeve-type coupling. Reprinted from AWWA M 11, Steel Pipe: A Guide for Design and Installation, with permission. Copyright © 1987, American Water Works Association.

10.2.4 "Specials" and Fittings

Steel pipe fittings and "specials" (custom-designed elements) come in an almost limitless variety of shapes and dimensions to match the requirements of the contract plans. In general, fittings are made from hydrostatically tested, lined, and coated pipe and then modified by cutting and welding to produce the desired shape. Fittings are also longer in length than many of the competing materials because of this ability to cut and weld longer sections of pipe. Also due to this property, field modification is readily accomplished when unforeseen obstructions or critical points of connection or deflection are encountered. It is common practice to accomplish small directional changes by the use of pulled joints or beveled joints. *AWWA M 11* discusses generally accepted tolerances for pulled and beveled joints.

The wall thickness and grade of steel of the specials and fittings are usually consistent with that of the adjacent pipe. For reducers, the wall thickness is consistent with that of the largest member.

Where fittings are required, depending on factors such as internal pressure, pipe size, wall thickness, and the type of fitting, it may be necessary to provide reinforcement in the area of the wall openings. This is commonly done through the uses of collars, wrapper plates, or crotch plates.

10.3 LININGS AND COATINGS

As can be seen from the AWWA listings in Section 10.2.1, there are many linings and coatings available to the designer. Several are new and not yet perceived as industry norms. Many are for unique or exposed pipe applications, whereas others are commonly used for buried pipelines.

For water pipelines, interior lining is usually specified as cement mortar in accordance with *AWWA C 205*. For pipes up to about

120-in. (3,050-mm) diameter, this lining may be centrifugated into the pipe at a high level of rotational force (forces from about 60 Gs to 80 Gs or higher). After the pipe is laid and the joint welded (if appropriate), the interior joint is filled with a plastic nonshrink cement mortar in a 2-to-1 ratio of sand to cement. A plasticizer is added to this mix to improve the workability of the mix in the overhead position. Prior to applying the mortar, the exposed steel and existing cement-mortar edges are frequently coated with an epoxy bonding agent to enhance the adhesion of the field-applied mortar to both the bare steel and the plant-applied lining. Pipelines may also be field-lined with cement mortar in accordance with *AWWA C 602* after the pipe is in place.

Minor cracking of the lining is not a concern because these cracks will disappear once the lining is immersed. *AWWA C 205* allows for cracks up to 1/16 in. (1.59 mm) and states that larger cracks do not have to be repaired if it can be shown that they will "heal" after immersion. Repair, when necessary, consists of cleaning any loose material and filling the crack with a cement-rich mortar paste.

Dielectric coatings are generally *AWWA C 214*-specified tape coat, although *AWWA C 222*-specified polyurethane is becoming popular in parts of the United States. The plant-applied tape coating or polyurethane coating can have the exterior joint completed with similar material (either two layers of 35-mil cold-applied tape conforming to *AWWA C 209*, or with a two-component polyurethane conforming to *AWWA C 222*). However, it has become common practice to complete these joints with a heat-shrinkable sleeve conforming to *AWWA C 216*. These sleeves are delivered already cut to the proper joint circumferential dimension. They are then wrapped around the pipe joint, overlapping the plant-applied coating. There is a release material covering the adhesive side that is removed as the tape is applied. After the tape has been wrapped around the joint and a closure patch is applied on top where the ends of the heat-shrinkable sleeve meet, the tape is heated using a wide-mouth propane torch to have the tape shrink against the pipe joint. The use of a small roller is encouraged to aid in equalizing the shrinkage. Applying the heat-shrinkable sleeve is quite easy and very cost-effective, and it provides an assured superior coating. An inspector can witness the adhesive being exposed at the tape edges to verify that the application was correctly performed.

Cement-mortar coatings conforming to *AWWA C 205* are also used. The exterior joint is protected after engagement by tying a circumferential "diaper" to each end of the pipe and pouring a high-slump cement mortar into the annulus, making sure that the diaper is completely filled.

For wastewater pipelines, cement-mortar lining has been successfully employed where the liquid was not overly aggressive or where the pipe would always run full, but it is more common to see either polyurethane or an amine-cured epoxy lining, conforming to *AWWA C 222* or *C 210*, respectively. Amide-cured epoxies are an energy source (food) for the sewer sulfide bacteria; they last 5 years at most in a sewer sulfide environment. See AWWA manuals mentioned above for more information. A cement-mortar lining would be completed as described above. For *AWWA C 222* or *C 210* linings, the installer must complete the joint using a two-component material compatible with the lining. This type of application is somewhat more complex because some mixtures are very sensitive to the proportions of the components, and some materials are also very sensitive to humidity, temperature, and cleanliness conditions. Engaging experienced personnel (possibly even a coatings subcontractor) may be warranted.

For other pipelines, such as for oil and gas, heat-shrinkable sleeves are commonly employed for the exterior coating. The joints of interior film linings (such as epoxies) may be finished as described above or, where heat is required or diameters do not permit ingress, special equipment may be employed.

Coatings for oil and gas pipelines generally conform to the owner's preference. Lining may or may not be required.

10.4 PIPE SHIPPING AND HANDLING

10.4.1 Markings and Layout Schedule

Steel water and sewer pipe is an engineered product, with each piece manufactured to match the laying schedule developed from the contract drawings. Pipe is marked for location in the line, pipe class or wall thickness, and, where critical to the orientation of the pipe, with the top centerline. Steel pipe for the oil and gas market is frequently shipped in straight lengths with bends produced by bending in the field.

10.4.2 Transportation

Pipe may be shipped by either truck or rail. In general, rail becomes uneconomical when pipe cannot be shipped side-by-side [this limitation occurs at approximately 72 in. (1,830 mm) in diameter]. Most steel water and sewer pipe is shipped with internal stulls for bracing during shipping and installation.

To prevent excessive drying of cement mortar lining during shipping, plastic sheets are attached at the ends of each pipe. This prevents an alligator-type appearance on the cement mortar which, although not damaging to the lining, would give an aesthetically displeasing appearance until placed in service.

10.4.3 On-Site Inspection and Storage

Pipe and fittings should be inspected by the installer and/or engineer prior to unloading. The shipper is responsible for any damage that occurs during transportation. Once the pipe is off-loaded, that responsibility shifts to the constructor.

On-site storage may be at a storage yard or by stringing along the side of the trench. In either case, it is good practice to store the pipe with support near each end of the pipe. Earth berms, sandbags, rubber tires, wood ties, etc. work well for this purpose. This keeps the coating off the rough ground and allows the constructor to place his lifting slings around the pipe without having to roll the pipe.

For pipe that is to be stored trench-side, it is wise to orient the pipe in a manner that will keep each piece relatively close to its intended installed location.

10.4.4 Handling

Unloading should be accomplished using nylon slings or cushioned forks to prevent undue damage to the coating. A common method of cushioning forks is to tape carpet on the top of the tines, with the front edge of each tine particularly protected. Carpet-coated wood beams can then be strapped to the carriage to cushion the impact of the pipe rolling onto the tines.

When using nylon slings for unloading and installation, the slings should be wide enough to prevent damage to the coating. It is good practice to use a wider sling, but modern coatings are generally not susceptible to damage as long as chains or cables are not employed. Slings can be used in a choker manner with the connection to the bucket forming an inverted V, or by two slings supported by a strong-back beam. These slings only require sufficient spreading to balance the pipe. Single extra-wide cables have been employed successfully, but generally require more effort to locate the balance point of the pipe.

10.5 INSTALLATION

10.5.1 Site Verification and Utility Conflicts

Although steel pipe may be modified in the field, it is beneficial to the installer to have this pipe be provided with accurate dimensions. Therefore, field verification of essential points of stationing and resolution of utility conflicts is advised prior to pipe fabrication. Utility One-Call systems can provide some of this information, at least providing general locations of local underground services. However, to accurately locate potential large utility conflicts, it is usually necessary to do some exploratory excavations or potholing. *ASCE Manual 38–02* discusses identification and depiction of existing utilities on design plans. When the practices identified in *ASCE Manual 38–02* are followed, the constructor can better assess the quality of the representation of the existing utilities on the design drawings. Design engineers, owners, and constructors are advised to become familiar with and follow the guidance provided in *ASCE Manual 38–02.*

10.5.2 Pipe Placement and Assembly

10.5.2.1 Water and Wastewater Pipelines. Following excavation of the trench, the pipe is placed on the prepared bedding, taking care to ensure there are no high spots or rocks that will come into point contact with the bottom of the pipe. Joining the new sections of pipe with the existing pipe in the trench is commonly done in one operation with a backhoe. For most installations, the trench excavation is within one length of the pipe being installed, which eliminates any concern about expansion and contraction forces in an all-welded pipeline. For cross-country pipelines, individual pipe lengths may be 50 ft (15 m) or longer. Cranes are usually not necessary except for very large pipelines (see Fig. 10-4).

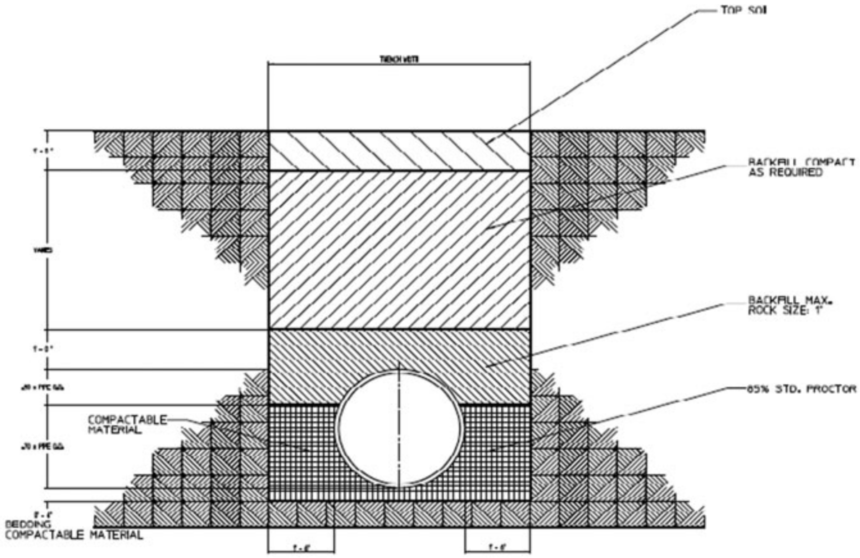

Figure 10-4. Typical trench detail. Courtesy of American Cast Iron Pipe Company.

The two basic joint configurations for steel pipe are bell and spigot gasketed, and bell and spigot lap-welded. For bell and spigot gasketed joints, the pipe is usually laid "bells ahead" (the bell ends facing the direction of laying). The O-ring gasket is well lubricated, using the lubricant supplied with the pipe. The gasket is then placed around the spigot and tension is relieved by placing a round object, such as a large screwdriver shank, under the gasket and rotating it twice around the joint circumference. The bell end is then also lubricated. Should manufacturer-supplied lubricant not be available, a vegetable oil such as Crisco may be substituted. However, gaskets should never be substituted—they should only be those supplied with the pipe.

The spigot end of the pipe being installed is aligned with the existing bell and pushed straight home. The joint is then checked using a feeler gauge (a flat-bladed instrument such as a long spatula) on the outside of the bell. It is rotated completely around the joint to ensure that the gasket has not rolled out of the groove. The gasket is in place if the feeler gauge does not indicate any protrusion, because the gasket would roll toward the face of the bell. If the gasket has rolled, the joint must be disassembled and the gasket replaced prior to reinstalling the pipe. Any allowable joint deflection may then be measured.

Electrical continuity across a gasketed joint is generally recommended. This can be accomplished by welding several Z clips to the inside of the spigot and bell prior to grouting the interior joint. An alternative is to cad-weld two wires near the top of the pipe to the outside surfaces of the bell and spigot (see Fig. 10-5). This is accomplished by first removing the coating by grinding to bare metal and attaching the wires by the use of a small, hand-held crucible. The weld metal and powder are charged into the crucible as it lies across the wire, and are fired with a flint gun.

Bell and spigot lap-welded pipes are frequently installed in the same prepared trench as described above, with the plain end (spigot) facing the direction of laying. The bell end is then placed over the existing spigot at an upward, shallow angle, just sufficient for the bell to overlap the joint within the prescribed distance while keeping the bell off the spigot on the bottom of the pipe. The joint can then be snapped home by lowering the

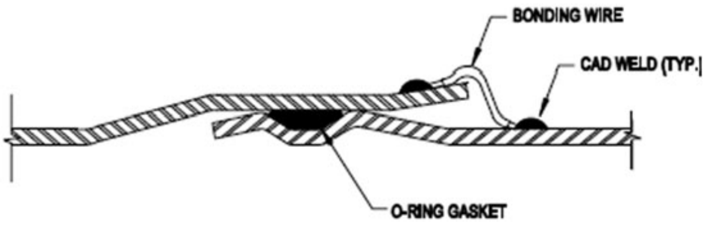

Figure 10-5. Cad-welded joint bonding.

pipe. This operation is recommended because the lap-welded joint, unlike the gasketed joint, is not self-centering. In situations where the pipe is to be welded on the inside, a slight flare or chamfer may be made at the face of the bell to assist in the joining operation. Some installers find it advisable to weld a short portion [4 to 6 in. (100 to 150 mm)] of the joint on the top of the pipe to act as a hinge to assist in controlling the pipe lowering. The unwelded joint should then be checked to verify whether some centering is required to equalize the gap between the faying surfaces. There should be no gap exceeding 1/8 in. (3.17 mm) at any point around the circumference. The use of multiple screwdrivers can assist where centering is required. The lap-welded joint should not be lubricated because this would interfere with the subsequent welding operation.

The lap-welded joint must be welded with a full-fillet, circumferential, watertight weld on either the inside or the outside of the joint. Some specifications require welding *both* inside and outside with full-fillet, circumferential, watertight welds that are tested with air through a small, threaded outlet in either the bell or spigot end. For single welded joints, magnetic particle testing by a qualified welding inspector is usually required.

Prior to installing either gasketed or lap-welded joints, it is good practice to mark the top of the spigot end with the recommended engagement or to set joint spacers (small metal or wood blocks cut to match the recommended joint gap) in the interior of cement-mortar-lined pipe. A further requirement is to check the exterior coating to verify that there is no damage or that all damage has been properly repaired.

10.5.2.2 Oil and Gas Pipelines. Oil and gas pipelines, as well as those conveying hazardous materials such as chemicals, are butt-welded. Generally, this welding takes place on supports aboveground and the welded pipeline is then serpentined into the trench using multiple sideboom cranes. These welds are checked before installation, usually by radiographic analysis, to ensure the quality requirements have been met.

10.5.3 Joint Completion

After installation, the exposed portions of the joint must be coated and lined to prevent corrosion or tuberculation (internal corrosion). The interior surface of a cement-mortar-lined pipe is to be pointed up with a 2-to-1 sand-to-cement mixture. A plasticizer may be added to provide ease of workability, and an epoxy bonding agent may first be applied to the adhering services to enhance the bond of the new mortar to the joint. This operation should be conducted after the pipe has been bedded and backfilled to ensure there is no movement that could dislodge any portion of the mortar.

For other linings, such as polyurethane or epoxy, the joint should be completed using the same material as required for the interior barrel of the pipe. This operation may require personnel well-versed in this type of operation because temperature, humidity, and cleanliness all influence the quality of the application. The mixing of the components and the method of application may also require a certain level of expertise.

The exterior joint surface should be protected in a manner consistent with the type of protection afforded the exterior pipe barrel. Where the pipe has received a dielectric coating, such as tape wrap, polyurethane, or epoxy, specifications often require that a heat-shrinkable sleeve be applied. This material is usually cut to the required circumferential length, with a width adequate to ensure at least a 4-in. (100-mm) overlap onto the existing coated pipe. The sleeve is then heated with a broad-mouth propane torch so the material shrinks against the pipe exterior and closely bonds to the pipe. Some rolling or flattening to assist with equalizing the joint exterior is recommended. This method of joint protection is very easy for the installer to accomplish and provides assurance of a quality application for the inspector.

Other methods include the application of a primer layer and two layers of tape wrap conforming to *AWWA C 209*, or the application of the same polyurethane or epoxy coating as was required on the pipe barrel. This latter requirement for the exterior joint protection is rarely required except for exposed pipelines. Any exterior electrical continuity wires should be incorporated under the protective sleeve.

For cement-mortar-coated pipelines, the joint is first diapered with a burlap or cloth material that straps around the joint. The cement mortar is then poured into the annulus from one side until the mortar rises in the other side. The material should be rodded to ensure complete coverage all around the joint. If the mortar coating is an armor coating over a dielectric coat, the dielectric must first be completed on the exterior joint, as described above.

10.6 BACKFILLING

Following completion of the exterior joint protection, the pipe should be backfilled as described in Chapter 6. The contract documents should specify the compactive results required. Recommended testing practices and procedures for assuring proper compaction and pipe support are also described in Chapter 6.

In some circumstances, controlled low-strength material (CLSM) or flowable fill may be used as the pipe zone backfill. CLSM is frequently used where improved bedding is required to provide adequate support for the pipe, and in many cases it is required within road rights-of-way to prevent settlement at road crossings. If CLSM is used, common practice is to overexcavate the trench by 6 in. (150 mm) or more, place the pipe on sandbags during laying, make the joints as described above, then place the CLSM. The CLSM should be placed uniformly from one side and forced to fill the space below the pipe and flow to the opposite side to ensure full encapsulation and support. Common practice may include vibrating the CLSM during placement to ensure good filling of the space and consolidation; however, overvibration should be avoided because it could result in higher than desired material strength. Care must be taken in the placement of flowable fill to prevent movement and/or floating of the pipe.

For lap-welded pipe, the interior weld may be completed after the pipe has been coated and backfilled. The soil surrounding the pipe acts as a heat sink to allow welding without damaging the coating. An in-situ welding and coating procedure must be followed; the pipe manufacturer can provide details for this method.

10.7 TESTING AND ACCEPTANCE

Completed water pipelines are usually pressure-tested to ensure there is no visible or excessive leakage and the joint restraint is adequate to withstand the thrust forces. The test pressure is usually some value greater than the pipe will experience during normal operation, but not necessarily as high as it might experience during a transient (surge) condition. A common multiplier for the test pressure to the operating pressure is 1.25 Pw. Gasketed joints for all products have a leakage allowance that must be met. Welded joints, however, should be bottle-tight. AWWA standards address appropriate allowable leakage during acceptance testing and test procedures. The design engineer may enhance these requirements to meet project-specific requirements.

Because oil and gas pipelines are all butt-welded with radiographic testing of the welds, there is no need to pressure-test those completed pipelines.

Following testing, the pipeline may be disinfected, if applicable, and the pipe alignment restored to the specified condition, if necessary.

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CHAPTER 11
CORRUGATED METAL PIPE

11.1 GENERAL BACKGROUND AND DISCUSSION

11.1.1 Description

Corrugated metal pipe (CMP) provides a strong, durable, economical selection for the construction of culverts, storm sewers, and other drainage systems. Introduced in 1896, countless miles of CMP now provide reliable service throughout the U.S. transportation system and in large and small municipalities across North America. Flexible metal conduits play an important role in the form of culverts, storm sewers, subdrains, spillways, underpasses, conveyor conduits, service tunnels, grade separation structures, free-span structures, detention chambers, and recharge systems.

A wide range of CMP products can be selected to meet exacting job requirements. Factory-made pipe in sizes up to 144-in. (3,700-mm) diameter is available to meet most needs with a variety of corrugation profiles that provide optimal strength and hydraulic capacity. For larger structures or arches, up to 50-ft (15-m) spans, structural plate pipe can be furnished for field-bolted assembly. Shop-fabricated fittings, long lightweight sections, and reliable and positive coupling systems all contribute to quick, economical field installations. In addition, a range of protective coatings is available to meet service demands.

Information on many of these applications is available from various manufacturers, the American Iron and Steel Institute (AISI), or the National Corrugated Steel Pipe Association (NCSPA).

11.1.2 Trade Associations and Standards

Both the American Association of State Highway and Transportation Officials (AASHTO) and ASTM publish CMP specifications, which are updated regularly. The most commonly used specifications for installing this pipe are:

- *ASTM A 798, Standard Practice for Installing Factory-Made Corrugated Steel Pipe for Sewers and Other Applications*
- *ASTM B 788, Standard Practice for Installing Factory-Made Corrugated Aluminum Culverts and Storm Sewer Pipe*
- *ASTM A 807, Standard Practice for Installing Corrugated Steel Structural Plate Pipe for Sewers and Other Applications*
- *ASTM B 789, Standard Practice for Installing Corrugated Aluminum Structural Plate Pipe for Culverts and Sewers*
- *AASHTO M 243, Field Applied Coating of Corrugated Metal Structural Plate for Pipe, Pipe-Arches, and Arches*
- *AASHTO Standard Specifications for Highway Bridges*, 16th Edition, Division II, Section 2, "Installation of Metal Culverts"

The National Corrugated Steel Pipe Association (NCSPA), headquartered in Washington, DC, conducts field investigations and research on topics that relate to improved performance of the products manufactured within the industry. NCSPA also publishes technical manuals and other specialized information to assist engineers, constructors, and inspectors in proper use of CMP products.

Specific contact information for ASTM, AASHTO, and NCSPA is found in Appendix B.

11.1.3 Flexibility

All CMP products are flexible and are installed in accordance with contract specifications usually based on accepted practices for flexible pipes. Both AASHTO and ASTM specify maximum flexibility factors for CMP products based on corrugation profile and material. Flexibility factor (*FF*) and pipe stiffness (*PS*) are related as follows. *D* is pipe diameter in inches.

$$PS = 53.69/[FF(D)]$$

Division I, Section 12 of the *AASHTO Standard Specifications for Highway Bridges* or *ASTM A 796* can be referenced for flexibility factors that pertain to various corrugated materials, corrugation profiles, and installation conditions. The flexibility and stiffness of CMP products does not vary with normal construction site temperatures, time, stress, or strain level. Minimum stiffness and maximum flexibility must be considered for all flexible piping systems.

11.1.4 Joints

Division II, Section 26 of the *AASHTO Standard Specifications for Highway Bridges* describes required properties for both "standard" and "special" CMP joints. Shear and moment capacity is specified for erodible and nonerodible soil types. The most commonly specified bands index (match) the pipe corrugations to provide positive pull-apart resistance. Coupling bands with gaskets can be furnished for applications up to 100 ft (30 m) of operating head. Levee bands are supplied where high pull-apart resistance and moment capacity across the joint are required. Flanged joints for adapting to other materials are available.

11.1.5 Coatings and Linings

Interior linings to meet hydraulic, abrasive, and corrosive effluent requirements are supplied. Available linings include cement mortar, asphalt, and polyethylene.

Durability considerations are addressed through the use of both metallic and nonmetallic coating systems. For large, high-profile projects, the appropriate coating systems are specified based on site-specific testing. The U.S. Army Corps of Engineers, the Federal Highway Administration (FHWA), and NCSPA publish guides for installing various coating and lining systems.

11.2 SHIPPING AND HANDLING

11.2.1 Shipping

CMP is either palletized or shipped in sections, depending on the product diameter. The size and length of individual sections are generally limited by transportation clearances imposed by highway agencies. Manufacturers have successfully transported individual sections with spans greater than 15 ft (4.5 m) and lengths greater than 80 ft (25 m). Special fittings are prefabricated and shipped as required. Structural plate products are normally shipped with plates palletized and erection hardware stored in kegs or cartons. CMP is usually shipped without internal bracing.

11.2.2 Unloading

Pipe sections must be handled with reasonable care to prevent damage to the body of the pipe and pipe ends. The pipe sections are normally palletized for unloading with some type of forklift arrangement, or slings may be used. Lifting lugs can be supplied when specified or requested by the purchaser. The manufacturer's written instructions for unloading should be followed. All unloading procedures must be conducted in a safe manner. CMP with nonmetallic coatings should be handled in a manner that will avoid coating damage and in strict accordance with the manufacturer's instructions. Field coating repair must be made if the coating is damaged.

11.2.3 Job-Site Storage

The pipe should be stored at the job site in a manner that will prevent damage or movement. During storage, the pipe should be uniformly supported throughout its length so as to prevent sagging or other types of barrel deformation. Outdoor storage should be minimized for pipes with nonmetallic coating. To minimize handling, the pipe sections can be placed directly alongside the trench. The pipe should be uniformly supported and blocked, or anchored to prevent movement.

11.2.4 Special Marking

The individual pipe sections can be marked with station or mark numbers to indicate field locations. Pipe ends can also be match-marked when special joint requirements are specified.

11.2.5 Field Handling

The pipe sections must be lifted and placed in such a manner that the individual pieces are not distorted, dented, or otherwise damaged. Coatings and linings must be protected as recommended by the pipe manufacturer. The use of nylon slings is recommended. Longer pipe sections should be lifted using spreader beams that connect to the pipe at two or more locations, as approved by the engineer.

11.3 INSTALLATION OF CORRUGATED METAL PIPE

CMP should be installed in accordance with the requirements of *ASTM A 798, A 807, B 788,* and/or *B 789*.

The load-carrying capacity of any type of flexible pipe depends upon proper installation, with special emphasis on backfilling. Corrugated metal pipe is a flexible ring supported by the compacted surrounding soil. All flexible pipe installations are composite structures that rely on inherent pipe strength and support from the backfill materials to carry the imposed loads. Pipe strength and backfill quality are closely related—the more flexible the pipe, the higher the quality of backfill material and compaction practice is required to prevent pipe distortion. Refer to soil–pipe structure interaction described in Chapter 2.

11.3.1 Trench Excavation

The contract drawings should specify maximum and minimum trench widths. Trench width must allow space for pipe jointing and compacting backfill materials in the haunch and springline areas. This width also must provide space for a support system or sheeting, a trench box, or all of these. A minimum of 3 in. (75 mm) on each side of the pipe is required when backfill materials are used that do not require compaction, such as slurries or controlled low-strength material (CLSM). CLSM is discussed in detail in Chapter 10, Section 10.6.

11.3.2 Foundation Considerations

The trench bottom or embankment foundation should be constructed to provide firm, stable, and uniform support for the full length of the pipe section. Rock encountered during excavation must be removed and replaced with suitable material. Soft, unstable material that will prevent the pipe from maintaining grade must be removed from the foundation area for a width of at least three pipe diameters.

Performance of flexible pipe is enhanced by allowing the pipe to settle slightly under load compared to the columns of soil alongside. A beneficial process for larger pipes involves purposely creating a foundation beneath the pipe that will yield under load more than the foundation area beneath the columns of soil on each side of the pipe. This procedure is especially important in high fill situations. In other cases, an arched profile for pipe culverts may be specified so water will always drain freely from the conduit after future earth settlements.

11.3.3 Bedding

CMP may be placed directly on a fine-graded foundation. Material in contact with the pipe should not contain rocks larger than 3-in. (75-mm) diameter, organic matter, frozen material, chunks of highly plastic clay, corrosive material, or other deleterious material. If specified, the bedding must be shaped to the pipe geometry. In the case of pipe arches, the bedding is shaped to fit the flat bottom arc of the pipe arch, or the foundation fine-graded to a slight vee shape.

11.3.4 Pipe Laying and Assembly

All pipes must be installed in accordance with the manufacturer's recommendations unless specifically modified by the engineer. Care should be taken in joining the pipe sections to ensure that the joint surfaces are free of any foreign materials. Soil-tight joints that meet AASHTO/ASTM requirements may be specified in erodible soils. Gasketed joints can be used under especially difficult conditions, or the joint can be wrapped with geotextile fabric.

11.3.5 Structural Backfill

The structural backfill is an integral part of the corrugated pipe system. The structural backfill material shall be fine, readily compacted soil excavated from the trench, select material, or granular fill material. In general, the more flexible the pipe, the higher the quality of structural backfill material required. The compaction of structural backfill is intended to provide a soil structure around the pipe to uniformly apply overburden pressures on the crown of the pipe and provide uniform bearing for the pipe side walls and lower haunches. The necessary width of structural backfill depends on the quality of the trench wall or embankment fill material, the type of backfill material, and the compaction equipment used. The methods and equipment used in placing backfill materials must be selected to prevent pipe distortion, dislocation, or damage.

All pipe-arch structures require excellent backfill support at corners. High-quality material that requires minimum compactive effort should be used. Flotation or other movement by the pipe must be prevented if slurries or flowable low-strength materials are used for backfill.

The pipe shape should be monitored at all times during installation procedures. Any installation procedure that results in excessive pipe deformation or deflection should be disallowed. Field measurement of pipe deflection is described in Chapter 6.

The manufacturer should be consulted for the amount of minimum cover required over the pipe to protect it against damage from heavy construction loads.

11.3.6 Connection to Structures

Many special types of structures can be fabricated directly into the pipe sections. Anchor bolts can be placed into pipe sections for use in attaching to other types of structures such as headwalls, slope collars, and toe walls.

When the flexible CMP piping system connects to a rigid structure, provision may be needed to allow for differential settlement or other movement. The engineer should select the method, which must maintain system integrity. Extra care is required to provide the proper support under and around pipe that enters or exits a rigid structure. The bedding and structural backfill materials should be granular material that is uniformly placed and well compacted. This high-quality material should be used for a distance of 3 ft (1 m) or one pipe diameter (whichever is larger) from the face of the structure. Short lengths of pipe with gasketed joints are also specified at these locations to allow differential movements between pipes and structures.

Manholes and vertical risers that connect to the pipeline should be designed so surface loads are not transferred directly to the pipe through the vertical shaft. The pipe itself may need reinforcement to resist these loads. For heavy traffic loads, concrete relieving slabs should be designed for the manhole/riser-to-surface connection.

11.3.7 Installation in Casings or Tunnels

CMP installed inside casings or tunnels can be either pushed or pulled into final position. During the installation process, care must be exercised to prevent disjointing. Skids can be used to facilitate the installation process.

If required, grouting of the annular space between the carrier pipe and the casing must be carefully planned and executed. The pipe should be blocked, filled with fluid, or stage-grouted to prevent flotation. Block size and spacing must be selected to prevent localized deformation under flotation forces. Grouting pressure must be carefully controlled at all times.

Differential settlement must be addressed where the carrier pipe enters and exits the casing or tunnel. Two or more pipe joints may provide the articulation necessary.

11.4 INSPECTION AND TESTING

11.4.1 Inspection

The pipe sections and fittings should be inspected before and after all shipping, unloading, and installation activities. Damaged material should be repaired in accordance with accepted specifications or manufacturer's recommendations, or should be removed from the job site. During installation, the pipe must be monitored to ensure that the constructor's installation methods do not result in unacceptable pipe deformation or pipe deflection. Damaged coating should be repaired in accordance with the coating manufacturer's recommendations.

11.4.2 Testing

Acceptance testing should be completed as required by the project specifications. Pipe deflection may be measured as described at the end of Chapter 8.

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CHAPTER 12
DUCTILE IRON PIPE

12.1 GENERAL BACKGROUND AND DISCUSSION

12.1.1 Description

Cast iron pipe was introduced in the United States around 1815. Waterworks engineers continued to use cast iron until ductile iron, a more ductile and equally durable piping material, became available around 1948. Because of its higher strength and ductility, ductile iron rapidly replaced gray cast iron in the marketplace.

Ductile iron pipe (DIP) is manufactured using a centrifugal casting process. Casting machines rotate the pipe mold around its centerline axis while molten iron is introduced. Centrifugal force places the iron against the outside wall of the mold, forming the pipe. As the iron is poured into the mold, the point of introduction of the iron changes along the length of the mold, either by movement of the casting machine or by shifting the channel through which the iron is poured down the length of the mold.

DIP manufactured under American National Standard Institute (ANSI) *C 151* and American Water Works Association (AWWA) *A 21.51* has a minimum ultimate material strength of 60,000 psi (413 MPa), a minimum yield tensile strength of 42,000 psi (290 MPa), and undergoes a minimum elongation of 10%. This product is designated as 60–42–10 ductile iron.

12.1.2 Applications

DIP is used for numerous applications, such as raw water supply lines, transmission mains, distribution mains, fire mains, force mains, pump station piping, power penstocks, intake lines, gravity sewers, treatment plant piping, and outfall mains. Various papers and reports have been published concerning routine as well as nonstandard applications of DIP. Data on many of these applications are available from engineering handbooks, journals, manufacturers' catalogs, and the Ductile Iron Pipe Research Association (DIPRA).

Various types of linings and coatings are available for applications in which interior or exterior degradation of iron pipe is a concern. This issue is discussed in Section 12.2.4.

12.1.3 Trade Associations

DIPRA provides testing services, conducts research, and contributes to standards development in the DIP industry. The Cast Iron Pipe Research Association (CIPRA), established in the 1920s, became DIPRA in 1979. Appendix B provides specific contact information for this organization.

12.2 PRODUCT INFORMATION

12.2.1 Standards

Since 1890, ANSI, AWWA, ASTM, and the Manufacturer's Standardization Society (MSS) have published standards for manufacture and installation of cast iron and DIP fitting and accessories, including:

- *ANSI/AWWA C 104/A 21.4, Cement-Mortar Lining for DIP*
- *ANSI/AWWA C 105/A 21.5, Polyethylene Encasement for DIP*
- *ANSI/AWWA C 110/A 21.10, Ductile Iron and Gray-Iron Fittings*
- *ANSI/AWWA C 111/A 21.11, Rubber-Gasket Joints for DIP*
- *ANSI/ AWWA C 115/A 21.15, Flanged Ductile Iron Pipe*
- *ANSI/AWWA C 150/A 21.50, Thickness Design of Ductile Iron Pipe*
- *ANSI/AWWA C 151/A 21.51, Standard for Ductile Iron Pipe Centrifugally Cast*
- *ANSI/AWWA C 153/A 21.53, Ductile Iron Compact Fittings*
- *ANSI/AWWA C 606, Grooved and Shouldered Joints*
- *ASTM A 716, Ductile Iron Culvert Pipe*
- *ASTM A 746, Ductile Iron Gravity Sewer Pipe*
- *MSS SP-60, Flange Joint between Tapping Sleeves and Valves*
- *MSS SP-111, Gray Iron and Ductile Iron Tapping Sleeves*
- *AWWA M 41, Manual of Water Supply Practices, Ductile Iron Pipe and Fittings*

Two installation guidelines deal directly with DIP: *ANSI/AWWA C 600, Installation of Ductile Iron Water Mains and Their Appurtenances*, and *Installation Guide for Ductile Iron Pipe* (DIPRA).

12.2.2 Dimensions and Pipe Wall Thickness

DIP is available from various manufacturers in diameters from 3 to 64 in. (75 to 1,600 mm), with standard pressure class ratings of 150 to 350 psi (1,033 to 2,411 kPa) in 50-psi (340-kPa) increments with nominal lengths of 18 to 20 ft (5.5 to 6 m). The "pressure class" refers to the pipe's maximum working pressure, assuming a 100-psi (690-kPa) surge pressure with a nominal safety factor of 2.0. Not all pipe sizes are available in lower pressure classes. For example, for 3- to 12-in. (75- to 305-mm) pipes, only pressure class 350 is available. Also, certain manufacturers do not make small and/or larger pipe sizes.

Pressures higher than 350 psi (2,411 kPa) are designed in consultation with the pipe manufacturer. Neither the DIP outside diameter (OD) nor the DIP inside diameter (ID) is the same as the nominal diameter. The actual OD of a 4-in. (100-mm) DIP, for example, is 4.80 in. (122 mm), and a 54-in. (1,400-mm) DIP has an actual OD of 57.56 in. (1,462 mm).

DIP has a constant OD with varying ID as a result of the thickness requirements of different pressure ratings, linings applied, etc. For most DIP sizes and classes, the ID is greater than nominal diameter. A fixed OD allows ready connection of DIP and cast iron pipes by different manufacturers. However, special couplings, gaskets, and/or designs may be required to connect DIP to other types of pipe, such as some PVC, HDPE, and steel pipes with different ODs. Several other pipe materials, such as *AWWA C 905* PVC and certain HDPE, are available in DIP ODs.

Readers should be aware that until 1991 DIP was made and identified with various special or thickness classes using thicker walls as standards. Now, pressure classes (e.g., 250, 300) are used, whereas the thickness class pipes (e.g., Class 50 to 56), although available, are considered special and nonstandard.

12.2.3 Types of Joints

Several types of DIP joints are available for different applications. Examples of such joints include:

- Push-on joint
- Restrained push-on joint
- Flanged joint
- Mechanical joint
- Grooved-end joint
- Shouldered end
- Threaded joint
- Ball joint

The term *restrained* used in reference to pipe joints means that the two pipe ends are locked together and cannot be pulled apart after

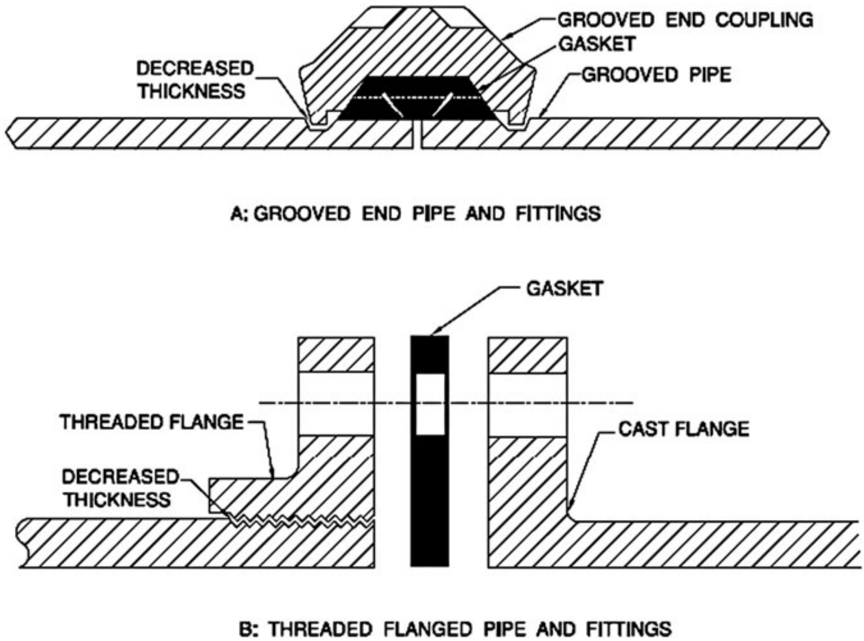

Figure 12-1. Grooved ends and threaded flanges for ductile iron pipes. Courtesy of the Watek Engineering Corporation.

engagement. Some of these joints, such as the mechanical joint, are not available in all sizes. Unrestrained joints, such as the mechanical or push-on joints, often require additional installation measures such as tie-rods, thrust blocks, or special gaskets for restraining. In certain cases, where the required pipe is threaded (such as threaded flanges) or grooved (for grooved end couplings), the standard minimum pressure class thickness pipe may not be adequate to support the special joints. Figure 12-1 shows examples of how the pipe thickness is locally decreased at these types of joints. Special thickness classes of pipe are available with thicker walls for these applications. These types of couplings and flanges are often used to connect to fittings and valves in vaults, manholes, and other structures.

12.2.4 Linings and Coatings

A variety of linings and coatings are available for DIP. The most common lining for water and non-acid-producing sanitary sewer service is Portland cement lining; other linings may be used for special applications. Cement-mortar linings prevent tuberculation (internal corrosion) by creating a high pH condition at the pipe wall and by providing a relative barrier between the pipe wall and the liquid. Additionally, cement-mortar linings create a smooth flow surface inside the pipe, which correlates to less friction and thus less head loss.

Special linings are available for applications where cement-mortar linings are not applicable, such as for septic sewers, acids, alkali wastes, and food processing. Some of the available special linings are calcium aluminate cement mortar, amine-cured epoxies, amine-cured coal-tar epoxy, amine-cured novalac epoxy, polyethylene, and polyurethane. Special linings for DIP are not covered by industry standards. Numerous sewer corrosion failures have occurred in concrete and ductile or cast iron sewer pipe when amide-cured epoxies were used as corrosion protection where sulfide existed in septic sewage. Calcium aluminate cements and mortars are only effective down to a pH of 3.0 or so, and will fail in some severe pH sewer environments that get as low as pH 0.5 on the exposed pipe crown. Pipe manufacturers should be consulted regarding the availability, application, and proper use of these linings. Readers are cautioned that disbondments and other problems have been reported with some of the special linings in certain applications. At the time of this publication, no uniform agreement exists among the manufactures and users on the ideal DIP lining for sewer and other corrosive services.

DIP is usually manufactured with a thin, asphaltic, shop-applied exterior coating. However, aggressive soil conditions require the use of external protection. In such environments, the industry recommends encasing pipe with loose polyethylene in accordance with *ANSI/AWWA C 105/A 21.5*, which is the most common method of external corrosion control for DIP today in the United States.

Installation of polyethylene encasement is relatively simple but requires diligence. Because it is applied at the job site, the potential for damage exists while the pipe is being installed. Because the wrap is not bonded to the pipe surface, repairs to damage are accomplished by taping over small holes or tears or by taping a cut piece of the film over the damaged area. Details and installation guides are presented in *ANSI/AWWA C 105/A 21.5*.

Other types of bonded protective coatings can be specified for DIP. However, they are relatively expensive and, for these types of coatings to be effective, they must be free of holidays (pinholes, defects, damage), provide electrical insulation, adhere to the total pipe surface, and resist deterioration. Experience has shown that few coatings possess all these characteristics.

12.3 A SAMPLE PROJECT TO DESCRIBE DUCTILE IRON PIPE INSTALLATION

12.3.1 Description of the Project

A two-phase DIP water transmission main project in Maryland is described here as an example because it contains various elements found in typical waterworks projects. Direct references to the sample project in which DIP was installed are interlaced within the following text to make the recommendations more realistic.

The project consisted of the following components:

- 20,000 ft (6,000 m) of 30-in. (750-mm) Class 250 DIP
- 2,000 ft (600 m) of 30-in. (750-mm) Class 300 DIP (for deeper segments)
- 2,500 ft (760 m) of 16-in. (400-mm) Class 250 DIP
- 500 ft (150 m) of 12-in. (305-mm) Class 250 CIP (for connection to existing water mains)
- 4 tapping valves and sleeves for end connections
- 10 air release valve (ARV) structures (at high points)
- 7 blow-off (BO) valve structures (at low points)
- 10 high-pressure 30-in. (750-mm) in-line butterfly valves
- 300 ft (90 m) of bored and jacked casing for three stream crossings
- 500 ft (152 m) of bored and jacked casing under a state highway

The project was built in two phases (i.e., by two independent constructors). Each phase had 270 days allocated for final completion after notice to proceed. The first phase was completed a few days ahead of schedule; the second phase, which involved more difficult traffic control and significant buried utilities, was completed 4 months ahead of schedule because of the utility contractor's extensive experience. Most of the pipe was installed using open trench, and the stream and highway crossing was installed in a bore/jack casing. Figure 12-2 shows a typical trench detail and provisions for sand backfilling the entire depth under state roads.

12.4 DELIVERING PIPE TO THE JOB SITE

12.4.1 Marking Each Piece

All pipe sections are marked and labeled according to *ANSI/AWWA C 151/A 21.51* standard requirements and, if applicable, to a pipe laying schedule prepared by the manufacturer for the specific project. This standard requires marking the weight, class or nominal thickness, and casting period on each pipe. Additionally, the manufacturer's mark, country where cast, year in which the pipe was produced, and the letters "DI" or "DUCTILE" are cast or stamped on the pipe. Pipes of similar joint, length, and class are often marked with the same number to provide storage and handling flexibility in the field.

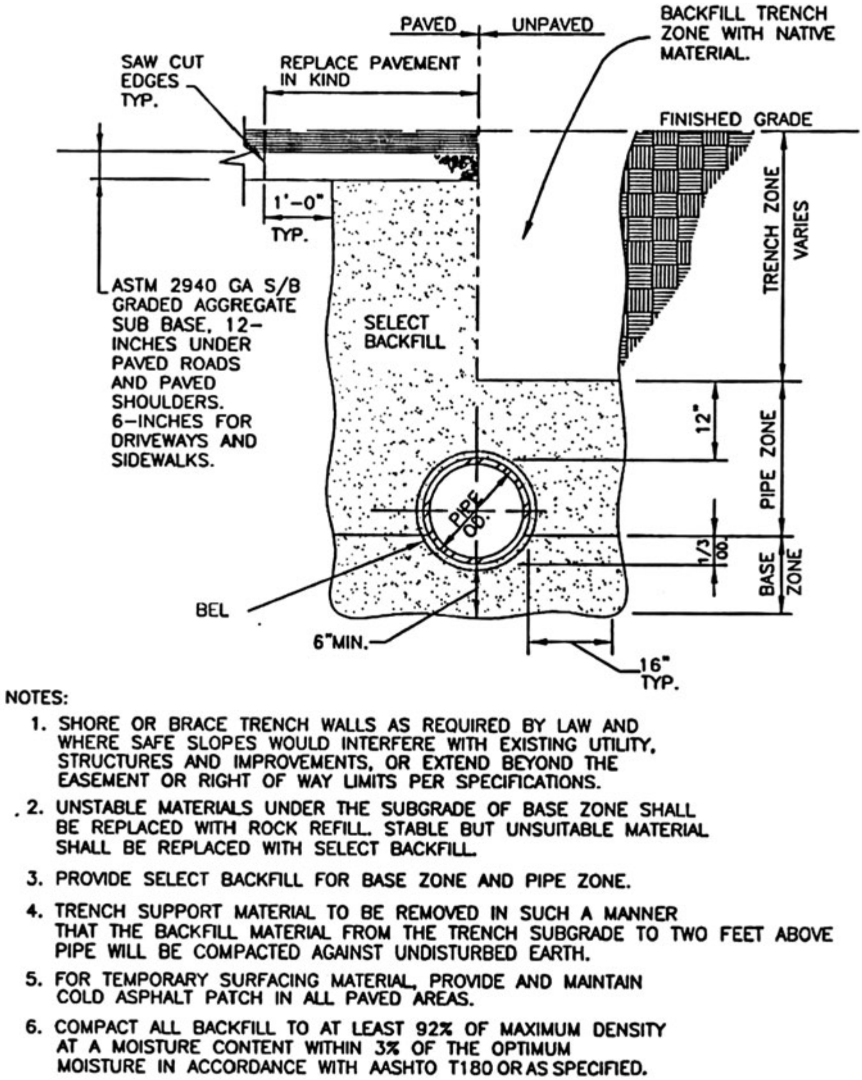

Figure 12-2. Trench detail for the sample project. Courtesy of the Watek Engineering Corporation.

12.4.2 Transporting Pipe Units

Pipes are normally shipped on a flatbed truck with spacers. On some large projects, pipe is shipped by rail car, if available. Pipe with special linings and/or coatings that are sensitive to UV or other damage are occasionally required to be shipped with end caps or other protection. Depending on the pipe size and number of tiers in a package, the bundles may be stacked in two or more high and secured to the truck bed by nylon straps. In making up tiers of pipe, every other pipe is usually turned so that at each end of the tier, the pipe is alternately bell and plain end. Loads on trucks or trailers are usually secured by nylon straps. Loads on rail cars are usually fastened to the car with steel strapping.

12.4.3 On-Site Inspection and Storage

The owner's representative can perform and witness various quality control tests of the piping at the pipe manufacturer's facility if required. Various inspections, such as coating and pipe thicknesses, and other testing to indicate specification conformance, can also be performed at the job site. In addition, the purchaser's representative should verify each shipment against shipping papers for any shortages or errors, which should also be recorded on the bill of lading by the carrier's agent. The purchaser may make tests specified in the applicable standard to ensure compliance. The manufacturer or contractor is responsible for replacing defective materials. All unusable defective material caused by manufacture or damage in shipment should be rejected and recorded on the bill of lading. Gaskets, polyethylene wrap, and nuts and bolts should be stored in a dry location out of direct weather and sunlight.

If the project site allows, the ideal case is for the pipe to be strung out along the work area. This method was generally used in the sample project, as shown in Fig. 12-3. Safety signs, pipe supports, etc. were used to prevent rolling and possible pedestrian or traffic hazards. Pipe storage along the edge of the travel-bed road was generally successful except in certain segments where right-of-way was fairly narrow. In those cases, accommodating vehicle traffic and pedestrians required storage at an off-site facility, and the pipe was brought to the site as needed.

Figure 12-3. Pipe storage on the job site. Courtesy of the Watek Engineering Corporation.

12.4.4 Unloading

Proper unloading of DIP is critical to prevent personnel injury and damage to the pipe or property. Pipe loads are often shipped with warning labels. The construction personnel must be familiar with and follow these procedures. Pipe should never be rolled off or dropped; a forklift or crane should be used for unloading. Before any length of pipe is lowered into the trench, it should be inspected for damage and the inside of the pipe should be inspected for loose dirt and foreign objects. If mud or trench water has been permitted to flow through the pipe, the inside should be scrubbed with a strong chlorine solution (for water mains) and flushed clean. This precaution will save time and expense when disinfecting the completed water main.

12.4.5 Stacking

DIP can be stacked if long-term storage is required. For safety and convenience, each pipe size is normally stacked separately. Refer to manufacturer's guidelines and DIPRA recommendations for maximum allowable stacking heights.

12.5 LAYING PIPE

12.5.1 Site Verification and Utility Conflicts

A sample of the plan and profile sheets used for the project is shown in Fig. 12-4.

An aerial survey with a 1-ft (0.3-m) contour accuracy was used during design of the sample project. The maps were digitized and various utilities and right-of-way information were shown on both plans and profiles based on available records. Data on critical crossings and connections were based on test pits. This degree of detail made the site verification and potential utility conflicts insignificant. Limited site investigations were conducted to minimize conflict with utilities and traffic impacts as well as to establish exact location and procedures for boring and jacking pits.

All curves and deflections were defined with coordinates during design. This procedure made it easy to set construction staking every 50 ft (15 m) and to control line and grade. The stakes were offset 10 ft (3 m) to minimize disturbing them.

All utilities were marked with different color paints by "Miss Utility" (the local One-Call service) prior to start of any work. During a boring and jacking operation, a group of telephone conduits and wires was cut despite the fact that the phone lines were located almost exactly where

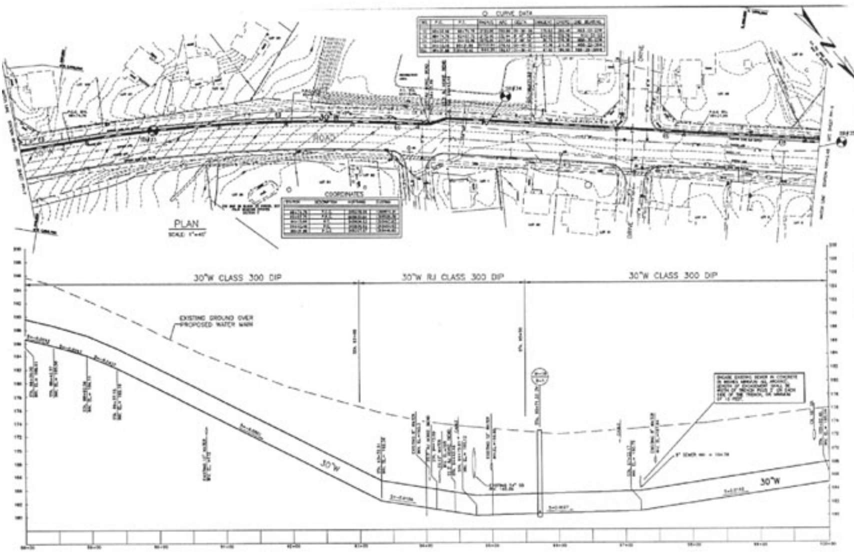

Figure 12-4. A typical plan and profile sheet for the sample project. Courtesy of the Watek Engineering Corporation.

they were marked. The main problem was lack of communication between various team members and the staff marking the utilities. A shallow storm drain immediately adjacent to phone cables had not been marked, and the cables were damaged because the constructor assumed the marks only showed the storm drain.

12.5.2 Details of Pipe Laying

Many of the general installation practices for DIP, such as trenching, dewatering, bedding, backfilling, and compaction, have been discussed in Chapters 3 through 8 of this manual. Other details can be obtained from the pipe manufacturer, DIPRA, and AWWA guidelines.

DIP should be lowered into the trench with slings or pipe tongs. Under no condition should it be pushed off the bank and allowed to fall into the trench. A variety of slings are available for handling DIP. Nylon slings are particularly well suited for lifting DIP and appurtenances. Several patented lifting tongs or clamp devices are available that release the pipe automatically whenever the hoist cable is slack. Care should be taken when using pipe tongs near trenches that have bracing protruding above ground. If the pipe contacts trench bracing or other similar components, the pipe tongs may release the pipe prematurely, which could result in personnel injury and pipe damage. When pipe is furnished with special exterior coatings, slings, tongs, or other handling devices should be padded to prevent damage to the coatings. Care should also be taken such that the steel hooks or chains used in lifting do not damage the interior lining of the pipes and fittings.

Although pipe is commonly laid with the bells facing the direction in which work is progressing, this practice is not mandatory. The direction of the bells is not functionally related to the direction of flow within the main. On larger diameters, the engineer or manufacturer may require that the bells face the direction of work to reduce loading on the spigot end. When pipe laying is not progressing, the open end of the pipe should be closed by a watertight plug or other approved methods. Depending on the pipe size and class, care must be taken to prevent pipe flotation if the trench floods while the pipe is plugged.

DIP joints should be assembled in accordance with *ANSI/AWWA C 600* and the manufacturer's recommendations. All spigots should be checked to ensure roundness prior to attempting joint assembly. The pipeline must often divert from a straight line when following the curvature of streets and roads. Push-on, mechanical, and many styles of restrained joints are well suited to applications where such joint deflection is required. On curves, the trench should be excavated wider than normal to allow for straight-line assembly before deflection. The deflection should not exceed that recommended by the pipe manufacturer.

DIP can be cut in the field using an abrasive cut-off saw, a rotary wheel cutter, a milling wheel saw, or any other device acceptable for cutting DIP. Cut ends and rough edges should be ground smooth. The cut end of push-on-type connections must be beveled slightly. The ANSI/AWWA standards for DIP require factory gauging of the spigot end of the pipe. Accordingly, pipe selected for cutting should be field-gauged. A mechanical joint gland inserted over the pipe barrel often serves as a convenient indicator for field gauging, although other procedures are available.

The following is a general sequence of DIP installation and is presented here only as a guide, not a procedure:

1. Excavate trench as required for the specified alignment, depth, and width. Provide trench support for safety as well as protection of the adjacent utilities, structures, and property, following the OSHA standards and project specifications. Provide temporary support of rails, tracks, power poles, etc. (if applicable) per agency requirements.
2. Remove and dispose of all rock, ashes, cinders, refuse, and organic or other unsuitable material to a minimum of 6 in. (150 mm) below pipe bottom.
3. If subgrade is unstable, provide a foundation for the pipe (e.g., large aggregate, concrete) as specified.

4. Excavate for bell holes at each joint, but not more than necessary to allow pipe to rest on its full length and not on the bells.
5. Dewater the trench and direct discharge away from the trench. Provide water quality and quantity control per specifications.
6. If the trench passes over or under other existing utilities, provide adequate clearances and compact the bottom of the trench as required to provide support equal to that of native soil.
7. Pipe is commonly laid with the bells facing the direction in which work is progressing. Check specifications for requirements.
8. Protect ends when pipe laying is not in progress. Foreign matter in the socket and spigot ends should be removed prior to gasket installation. The gasket should be wiped clean, flexed, and then placed in the socket. Looping the gasket generally will facilitate insertion.
9. Apply lubricant with a brush per manufacturer's recommendations.
10. The spigot should not be allowed to touch the ground or trench side after it is lubricated.
11. Joint assembly is performed by forcing the spigot end past the painted stripes. Refer to manufacturer's literature for paint mark descriptions and applying paint marks in the field for cut pipe sections.
12. When the pipe is deflected at the joints in a vertical and/or horizontal plane, comply with the maximum deflection allowances in the specifications.
13. DIP can be cut using an abrasive pipe saw, rotary wheel cutter, guillotine pipe saw, milling wheel saw, or a torch (if allowed by the manufacturer). Cut ends must be ground smooth and beveled. Follow manufacturer's recommendations for repairing and patching coating and lining. Note that some linings and coatings are heat-sensitive.
14. Backfill and compact the trench in accordance with the specifications.

DIP installation problems are often caused by the installer's lack of knowledge of the pipe joints and proper installation procedures. The larger a pipe is, the more difficult the installation. Careful consideration should be given to use trained installers with experience in the type of joint being installed.

Some linings and coatings are fragile and cannot tolerate abuse. Linings and coatings are subject to damage caused by methods of shipment, storage, handling at the site, installation, and welding (sometimes required for cathodic protection).

All the procedures recommended by the manufacturer must be reviewed and followed, and a trial run should be performed on a sample pipe to optimize the techniques before any pipe is installed. A manufacturer's representative and the design engineer can provide guidance during this practice procedure.

Figure 12-5. A typical pit for earth boring and pipe jacking. Courtesy of the Watek Engineering Corporation.

On the sample project, a trial run, including installation of the restrained joint pipe, welding a thermite weld wire, trench, and backfill was performed with the owner, inspector, and design engineer present. This procedure proved to be informative and useful.

A Komatsu PC300 LC backhoe with a 5-ft (1.5-m)-wide bucket was used for excavation, pipe installation, and backfill of the sample project. A 6-ft (1.8-m)-wide trench box was used except where the trench had to be sheeted and shored for boring and jacking pits, as shown in Fig. 12-5.

The sample project contract documents required backfilling the trenches daily and providing cold asphalt patch in the roadways because of neighborhood traffic and sediment control concerns. Therefore, dump trucks were loaded with excess soil excavated from the trench on a routine basis and taken off-site for disposal. This method of backfilling trenches and patching pavement daily greatly reduced sediment and traffic control impacts.

Pipe installation generally proceeded with minimal difficulties at a rate of about 200 ft (60 m) per day in nonpaved areas and 140 ft (42 m) per day in paved areas requiring traffic control and significant utility crossings.

Figure 12-6. Pipe-laying activity using a trench box. Courtesy of the Watek Engineering Corporation.

Soil boring logs were available about every 500 ft (150 m) and at each end of bored and jacked casings. Soil tests showed that the majority of the soils in the area were acceptable for the trench zone backfill. Figure 12-6 shows typical trench and pipe installation activity.

Minor problems occurred with installing the polyethylene encasement (poly-wrap) in difficult and wet areas. The encasement supplied was a bag type, which was difficult to pull over the pipe and fittings in certain areas. Flat sheets may have worked better in such areas. *AWWA C 105* procedures should be followed in installing poly-wrap.

12.6 TAPPING

12.6.1 Small Taps

Small service taps and house connections can easily be made either before or after pipe installation. All available pressure classes of DIP can be tapped for 0.75-in. (19-mm) service, and 1-in. (25-mm) taps can be made into 6-in. (150-mm) and larger pipe. Some utility companies and engineers prefer saddles instead of tapping, regardless of size. Two or more wraps of polyethylene adhesive tape is recommended around the pipe where the tapping machine and chain will be mounted (if polyethylene encasement is used). Double-wrap Teflon tape and/or sealant is used on the corporation threads(fittings with three-step plating).

When frost and freezing of service lines may be an issue, the tapping should be installed horizontally at the 3 o'clock or 9 o'clock position on the DIP to maximize available cover over this service line.

12.6.2 Large Connections

Larger connections to DIP can be made using tees, outlets, tapping sleeves, or tapping saddles with various types of outlets, such as flange and mechanical joints.

12.7 CONNECTIONS TO STRUCTURES

In the sample project, flanged and grooved end joints were used within the vaults and structures. Buried pipe was primarily unrestrained push-on joint, except where restrained joints were required on either side of valves and changes in direction. Length of the restrained sections depended on the type of soil, bedding/backfill conditions, internal pressure, and type of bend or fittings. All the details and types of joints were clearly indicated on the manufacturer-prepared layout drawing, which was completed in accordance with the project drawings and specifications.

12.8 INSTALLING IN TUNNELS AND CASINGS

Usually, a casing pipe must be installed under a highway, railroad, or stream crossing with the carrier pipe inside the casing. Casing pipe installation methods vary by pipe size, casing length, soil conditions, available machines, preferences, and so forth.

Carrier DIP may be pushed or pulled through the completed casing depending on the design of the annular space. Carrier-to-casing contact must be avoided by using wood chocks or manufactured skids. Certain types of joints, such as restrained joints, require pulling after the joint is made. Consult with the pipe manufacturer regarding pulling or pushing limitations as a function of carrier pipe length.

At several locations in the sample project, such as highway and stream crossings, the DIP was used as a carrier pipe in a concrete casing pipe (installed by boring and jacking operation). Conventional concrete cradles and modern casing spacers were reviewed during design based on construction safety, capital cost, future flexibility, and other factors. Casing

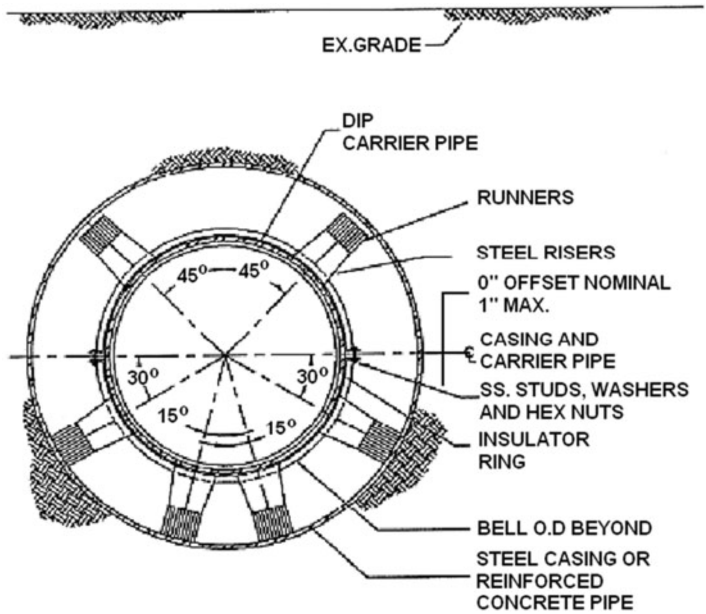

Figure 12-7. Casing and carrier pipe detail. Courtesy of the Watek Engineering Corporation.

spacers were used for all casing locations. Figure 12-7 shows a casing schematic. Casing spacers greatly enhanced construction efficiency and safety at essentially no additional cost because the casing pipe diameter was significantly less than conventional methods requiring workman entry.

12.9 RELATED TOPICS

12.9.1 Corrosion Protection

Soil samples from the sample project were sent to a laboratory for soil corrosivity analysis, including pH, oxidation reduction, sulfides, and resistivity tests. Results indicated that the soil was generally acceptable and noncorrosive. However, the design engineer included an 8-mil-thick polyethylene bag over the entire pipe length for long-term protection at low cost.

12.9.2 Environmental Considerations

Alternatives for stream crossings were investigated and reviewed with natural resource agencies during design. The design included boring and jacking under all the streams because of the environmental sensitivity of these streams and associated wetlands and the timing required for open-cut permits.

12.9.3 Restrained Joints

Pipes with restrained push-on joints were used at bends, fittings, valves, and changes in direction, and concrete thrust blocks were used where restrained joint pipe was not feasible. This design decision minimized installation time and reduced traffic concerns caused by open excavations required for curing of the concrete thrust blocks. The remaining buried pipe was unrestrained, push-on joint. Flanged and grooved-end joints were used in vaults and structures.

Unlike unrestrained push-on joints, restrained joint sections sometimes provide less flexibility in field adjustments, field cuts, and deflections. Some restrained joint styles have a factory-welded ring on the spigot end; such pieces must be ordered to exact lengths because field welding of DIP is generally either not allowed or not desired.

This limitation of restrained joints hinders achievement of exact stations for valves, structures, air release valves, etc. if special field restraining rings are not allowed. For the sample project, the design engineer had provided flexibility for the installer to make minor adjustments, up to 5 ft (1.5 m) horizontally, for location of various noncritical structures (subject to certain established criteria to prevent dips and high points). Routine communication between the inspector, the design engineer, and the constructor resulted in minimum field cuts or use of special restraining couplings. The constructor also carefully planned ahead (a few pipe sections before reaching the structures) to make the necessary adjustments to the vertical alignment. This planning was more critical in the restrained joint section because of limited allowable deflection.

Some restrained joints provided by different DIP manufacturers are not compatible. This problem was encountered at a tie-in location in the sample project. The bell of an existing restrained joint from another manufacturer had to be cut off, and special couplings and tie-rods were used to make a restrained connection. In retrospect, if restraining rings are used to join cut pipe sections, special "gauge full length" pipes should be specified and purchased so the manufacturer will provide an entire length of pipe having the same gauge, or wall thickness.

12.9.4 Public Relations

Because a segment of the sample project was adjacent to a middle school, the team members had concerns regarding schoolchildren and pedestrians because many of the sidewalks had to be closed. An evening meeting was requested in the school conference room with members of the school and neighborhood community. Certain hours-of-operation restrictions, such as no work on the day of a Halloween parade, were established. A flyer was sent to all parents and published in the school newspaper summarizing the nature of the project and some safety tips. This proactive approach produced excellent results, and no community or safety problems occurred.

12.9.5 Contaminated Soils

If the pipe being installed passes through soils contaminated with, for example, petroleum or organic solvents, the standard gaskets and packing glands may not be suitable or adequate. Consult with the design engineer and the manufacturers for the proper material.

12.10 TESTING AND ACCEPTANCE

12.10.1 Inspection

On the sample project, a full-time, experienced inspector visually inspected the operation, verified the alignment and profile, performed compaction testing, and gathered information and data for the record drawings. Contract specifications may require measurements of ring deflection of the pipe barrel.

12.10.2 Pressure Testing

DIP pressure testing is usually performed using water rather than air. Test pressure is generally specified as 1.25 to 1.5 times the working pressure for a 2- to 8-hour duration, depending on length, size, project requirements, and owner/design engineer's preferences. The specifications should specify the values.

Pipe is pressurized using pumps, and air is removed from the pipeline's high points. The pressurized system is often allowed to stabilize before the official test start. Pipeline, fittings, valves, etc. should be backfilled and secured, and the concrete thrust blocks should be allowed to cure before the test begins.

During the test period, makeup water is added with a displacement meter or pumping from a vessel of known volume to keep the pressure constant [normally within 5 psi (35 kPa)] at the test pressure. The measured volume should be less than the allowable for a satisfactory test. *AWWA C 600* contains a formula and a table for allowable leakage.

Elevation corrections should be performed to ensure that all pipe sections, including the high points, are being tested at the test pressure. Care should be taken not to exceed the valve and appurtenances pressure ratings and pipe pressure rating at the low points. The sample project had about 80 ft (24 m) of elevation difference end-to-end, so correct test pressure was a concern.

Because of the test pressure concern and because of the pipe length, the project was divided in four sections for pressure testing using bulkheads and valves. A test pressure of 180 psi (1,240 kPa) was held for a minimum of 8 hours. The contract allowed a small amount of makeup water based on the following equation:

$$L = \frac{H \times N \times D \times P^{1/2}}{C}$$

where

H = test period (hours)
L = allowable makeup water (gal)
N = number of rubber-gasketed joints
D = diameter of the pipe (in.)
P = test pressure (psi gauge)
C = 7,400

Makeup water volume is intended for trapped air, absorption by pipe wall, take-up of restraints, and temperature variations during testing. All visible leaks, such as those inside structures, are required to be corrected regardless of whether the results are within acceptable range.

Insignificant or no losses were observed in the first three segments. Because of a malfunctioning isolation valve in an air release structure, initial leakage in the fourth segment was significant and the test had to be stopped. Satisfactory results were obtained when the problems were corrected and the pipe was retested.

12.10.3 Conditional Acceptance

The contract documents of the sample project required walking the entire pipeline route when all tests were performed and restoration and pavement were completed. Representatives of the owner, operational staff, design engineer, inspection consultants, constructor, and major subcontractors were present at the walk-through. Visual inspection of pavement, curb and gutter, painting, valve boxes, interior of structures, and manholes and covers were conducted, and any deficiencies were noted on a punch list. All valves were turned for verification of operation. Most of the punch list items were restoration- and finish work-related, such as adjusting valve boxes, seeding, and uneven pavements, which were later completed and verified. A substantial completion conditional acceptance was issued to the constructor.

12.10.4 Performance Period

All pipes, valves, material, and workmanship were guaranteed for 1 year after conditional acceptance. During this period, the design engineer made quarterly visits to the site and provided a report of any deficiencies to the owner. After about 10 months, a final punch list was given to the constructor for implementation before the final walk-through. During the final walk-through, a few minor deficiencies were found, which were corrected in a week. Final acceptance was then issued to the constructor.

12.11 RECORD DRAWINGS

The contract required the constructor and the inspector to discuss and note all changes to the design drawings on a single set of prints at least once a week. All markups with backup (if applicable) were given to the design engineer. The inspector then spent a full day at the engineer's office, where the markups were permanently changed on the computer-drafted originals. All record drawings were then required to be stamped and accepted by the inspection consultant as being accurate.

CHAPTER 13

PRESTRESSED CONCRETE CYLINDER PIPE

13.1 GENERAL BACKGROUND AND DISCUSSION

13.1.1 Description

Prestressed concrete cylinder pipe (PCCP) is made as a composite of two materials, combining the advantages of concrete's compressive strength for resisting external loads with steel's ability to contain internal pressure. At initial manufacture, a cylinder of concrete (the pipe core) is cast with the specified inside diameter and wall thickness. A watertight barrier is provided throughout each pipe core by a continuous, thin steel cylinder which becomes either the outside of the concrete core or is fully embedded within it. Cylinders are welded to the steel pipe joint bands. After the concrete has cured, the outside of each core is wrapped (prestressed) by high-strength steel wire in a spiral pattern, which compresses the concrete to resist effects of external loading. Concrete compression is developed by a specified combination of wire tension and the spacing (pitch) between each wrap. Portland cement-mortar coating is then applied over all of the wrapped wire and any other exposed steel components to complete each pipe piece.

Only straight pipe units can be made in this manner. Bends and other special fittings are made from steel plate with matching pipe joints and are mortar-lined and -coated. These special fittings are not wire-wrapped.

Pipe joints are normally sealed by rubber O-ring gaskets, although mechanical joints may also be used.

Prestressed concrete noncylinder pipe is also manufactured. Installation procedures are similar to cylinder pipe.

13.1.2 Applications for Prestressed Concrete Cylinder Pipe

Prestressed concrete cylinder pipe is most often used for pressurized pipelines operating above 50 psi (340 kPa) in applications like these:

- Raw water and treated water transmission mains, especially 30 in. (762 mm) and larger
- Sanitary force mains or gravity sewers 30 in. (762 mm) and larger with appropriate lining
- Intake and outfall piping
- Cooling water or process pipelines for power plants and industrial applications

Selection of prestressed concrete cylinder pipe for specific conditions typically considers the following factors:

Backfill Economy: The combination of steel and concrete in prestressed concrete cylinder pipe results in a rigid pipe design, which allows the use of a wide range of backfill materials and simpler compaction techniques because the pipe wall is effectively self-supporting.

Overall Economy: PCCP becomes less costly as pipe diameters increase over 30 in. (762 mm). The concrete and steel combination is typically less expensive than plate steel for pressure and overburden design. PCCP uses project-specific design to better optimize use of pipe materials.

Weight: PCCP is relatively heavier than other pipe, and larger, more powerful machines may be required for handling. Shipping costs may also be higher, depending on distance and weight. Occasionally, PCCP may be manufactured specifically with extra concrete to prevent floating (when empty) in underwater applications.

Handling: Cement-mortar coating on PCCP requires careful handling to prevent mortar damage. Cracks and disbondment of the coating from the wire may allow corrosive agents access to prestressing wires and other steel components of the pipe. Particular attention must be paid when storing, transporting, lifting, and assembling the pipe to minimize all damage potentials.

Field Changes: PCCP is not field-cut to fit because the anchorages for the prestressing wires must be maintained. However, short steel pipe lengths and special fittings described above are used to make field adjustments. These fittings might include bevel adapters (short fittings with a small bend angle in them) and closure pieces (adjustable-length short fittings, which are either welded or bolted into position after adjustment).

13.2 PRODUCT INFORMATION

13.2.1 Trade Associations, Standards, and References

The American Water Works Association (AWWA) publishes the primary standards for PCCP:

- *AWWA C 301, Prestressed Concrete Cylinder Pipe, Steel-Cylinder Type*
- *AWWA C 304, Design of Prestressed Concrete Cylinder Pipe*

AWWA also publishes a related manual:

- *AWWA M 9, Concrete Pressure Pipe*

Other manuals discussing the selection, design, and installation of PCCP are available. Pipe manufacturers typically provide design and construction manuals.

A trade association concerned with the improvement of PCCP is the American Concrete Pressure Pipe Association (ACPPA). This organization manages a Compliance Audit and Certification Program to assist pipe manufacturers.

Contact information for AWWA and ACPPA is found in Appendix B.

Materials incorporated into PCCP must conform to the engineer's specifications or other controlling standards such as those listed above. Typical raw material verification and tests conducted at the manufacturing plant that the purchaser may request are as follows. A shop inspector should be aware of the details of these procedures.

- *Cylinder Steel:* Physical and chemical reports of steel used for cylinder, joint rings, prestressing wire.
- *Completed Steel Cylinder:* Hydrostatic pressure testing of the completed steel cylinder.
- *Pipe Core:* Concrete compression tests.
- *Finished Pipe:* Physical properties of rubber for gaskets; absorption tests of cement-mortar coating and an affidavit of compliance with *AWWA C 301*; hydrostatic tests of completed pipe, if required.
- *Test Equipment:* Calibration reports.

During manufacture, other inspections may be specified or recommended as listed below:

- *Steel Cylinder:* Inspect for dents, surface dirt, and corrosion.
- *Pipe Core before Prestressing:* Check for voids requiring repair, offsets, and bulges that cause bridging and gaps under the wire, damage or cracking in the core concrete, surface dirt.
- *Prestressed Pipe Core Prior to Coating:* Check slurry coverage, clearance between prestressing wires, position and number of

prestressing wires, surface dirt, wrapping load, procedures to correct wire breakage.

- *Completed Pipe:* Inspect for joint ring dimensions and roundness, mortar coating defects such as cracks, delaminations, spalls, insufficient coating thickness, soft areas, and foreign matter needing repair, marking, and identification.

13.2.2 Dimensions and Thickness

PCCP is commonly made with inside diameters from 16 to 48 in. (400 to 1,220 mm) for lined cylinder pipe and 36 to 144 in. (914 to 3,600 mm) for embedded cylinder pipe. The standard pipe length is 16 to 24 ft (4.8 to 7.3 m), depending on diameter and pipe supplier, and wall thicknesses vary from about 2 to 12 in. (50 to 305 mm), depending on diameter. PCCP is specifically designed for each project. The design calculation and manufacturing specifications given in *AWWA C 301* and *C 304* provide for a broad range of pressure and overburden capabilities. Regional variations and special manufacturer's options are common.

13.2.3 Manufacture

PCCP manufacture begins with fabrication of the steel cylinder, a thin-walled tube section with thickness based on the expected design conditions. For example, pipe intended to resist thrust loads may typically incorporate thickened cylinders. Steel joint rings, which form the joints for the completed pipe, are welded to the cylinder and the entire cylinder assembly is hydrostatically tested to ensure watertightness.

For lined cylinder pipe, a pipe core involves casting concrete inside the steel cylinder. For embedded cylinder pipe, the cylinder assembly is positioned vertically within a form and concrete is placed around both sides of the cylinder assembly. The concrete pipe cores are then usually cured by heat and moisture.

Next, high-strength steel wire is wrapped under tension around the completed concrete pipe core as Portland cement slurry is applied to the exterior of the core. The selected spacing of the wraps and the tension in the wire creates the required level of compression in the concrete pipe core. Additional cement slurry and mortar coating is then applied over the prestressing wires to provide corrosion protection. Finally, the cement-mortar coating is also cured with heat and moisture.

Figure 13-1 shows how steel prestressing wire is wrapped under tension around the concrete pipe core as cement slurry is applied.

13.2.4 Types of Joints

Standard joint rings for PCCP include steel bell and spigot ends welded to the cylinder or special fitting. An O-ring rubber gasket is used for

Figure 13-1. Wrapping a prestressed concrete pipe. Courtesy of Price Brothers Corporation.

sealing against leakage. Figure 13-2 illustrates a standard joint for prestressed concrete embedded cylinder pipe.

Restrained joints include locking devices designed to prevent the pipe from pulling apart after installation due to the effects of unbalanced thrust forces. Examples include interior locking rings or externally bolted harnessing clamps.

Other specialty joints are available where project conditions require:

- Ball joints (which allow deflection of up to about 15 degrees)
- Deep or extra-deep joints (which allow greater deflection than the standard joints)
- Subaqueous joints (which include a draw-bolt assembly to ease underwater installation)
- Testable joints (which have two gaskets and include a test hole for pressurizing the area between the gaskets and allowing verification of watertightness without pressurizing the entire pipe)
- Flanged ends, mechanical or welded joints, etc. as required to meet pipe made by others or other pipeline appurtenances

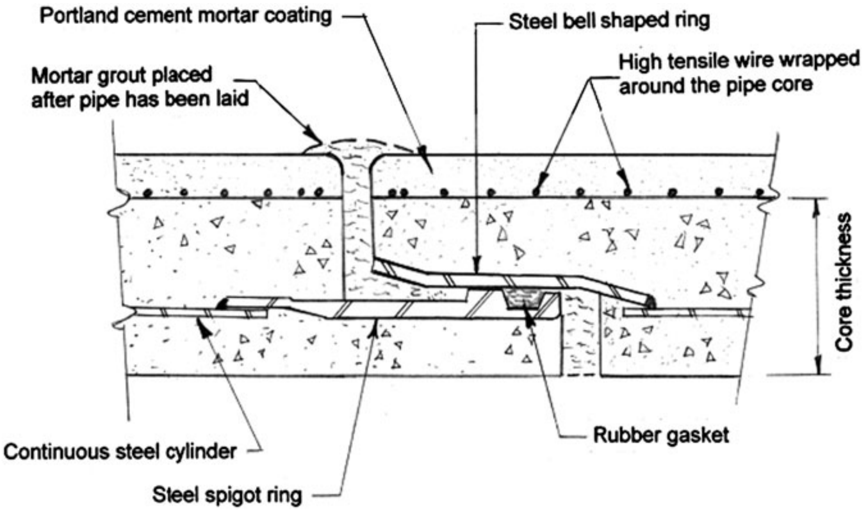

Figure 13-2. Standard joint for prestressed concrete embedded cylinder pipe. This is a rubber and steel slip-on joint. Courtesy of Price Brothers Corporation.

13.2.5 Special Fittings

Special fittings are available to make field adjustments simpler. These fittings include bevel adapters (short fittings with a small bend angle in them) and closure pieces (adjustable-length short fittings, which are either welded or bolted into position after field adjustment).

Fittings for PCCP are formed from steel plate, joint rings, and a mortar lining and coating. Because the fittings are not prestressed, the steel plate used for fittings is designed for the full service pressure and is much thicker than the steel used for the cylinder of the prestressed pipe lengths. The contract specifications may require these fittings to be hydrostatically tested.

13.3 LININGS AND COATINGS

The manufacture of PCCP pipe cores provides a bare concrete lining that meets water transmission requirements because most water will not degrade the concrete. For carrying sewage or other materials corrosive to concrete, additional lining systems may include epoxy, PVC, urethane, or coal-tar-based materials applied to the concrete, or special plastic liners anchored in the concrete. Adhesion between linings and the pipe core, as well as inertness between the lining and the fluid material, must be certified by both the pipe and lining manufacturers to minimize the risk of shortened service.

Cement-mortar coating on the pipe exterior may also have supplemental systems to protect the pipe against external corrosive environments. Some of these aggressive environments are corrosive soils or stray currents from cathodic protection systems used on other facilities. Passive coatings may include loose polyethylene encasements and painted- or sprayed-on coatings. All coatings, like the pipe itself, must be protected during shipment and handling to prevent damage, which may allow corrosive elements to reach the steel interior components of the pipe. Contrasting colors are sometimes specified for protective coating materials and allow visual verification that the coating is not damaged.

An effective supplemental protection for the prestressing wire is cathodic protection, which will include electrical bonding at each joint in the pipe and insulating the joints made with other pipe materials.

13.4 SHIPPING AND HANDLING

13.4.1 Markings and Layout Schedules

PCCP is manufactured to match the manufacturer's layout schedule. This schedule indicates where specific pieces of pipe are installed in relationship to the stationing and grade shown on the purchaser's contract documents. Each pipe is marked on its interior with a unique serial number, pressure rating, strength classification number, plus additional markings as necessary to define where the pipe fits into the layout schedule.

13.4.2 Transportation

PCCP is typically shipped while supported by wooden chocks or cradles on flatbed trucks. Rail or barge shipment may be feasible to job sites with suitable access.

As previously emphasized, the cement-mortar coating of PCCP requires care in handling to prevent damage. This pipe is typically shipped without internal bracing because the pipe walls are rigid enough to support themselves, and ends are typically left open if the pipe lining is fully cured at the manufacturer's plant. Plastic sheets over pipe ends are common if curing continues beyond the shipping period.

13.4.3 On-Site Inspection and Storage

Upon delivery, inspect the pipe before acceptance. Areas of interest include the overall condition of the lining and coating, the presence of the appropriate markings in conformance with the layout schedule, and any signs of distress to the joint rings. Rubber gaskets and similar materials should be checked for general condition, quantity, and size, and then stored in a shaded place, out of the sun and away from fuel oil, gasoline, and other materials that damage rubber.

Pipe should be stored in its installation sequence to minimize handling.

Pipe storage should keep the pipe interior free from debris; if necessary, close the pipe ends with plastic sheets. Pipes must not be stored on hard, sharp materials. Pipe in contact with the ground should rest only on loose sand, sandbags, or timbers. Pipes must not be stacked on top of each other unless specifically approved by the manufacturer and the specifications. If freezing conditions are expected, the pipe should be set on wooden timbers off the ground.

13.4.4 Handling

The delivery schedule should be well coordinated to avoid excessive pipe handling. Delivery of the pipe pieces can best be made as close to the trench as possible.

The crane or backhoe must be outfitted with a nylon sling or other approved device to handle pipe. Multiple slings may be used in handling large pipe and fittings. Space must be provided under the pipe, especially in the trench, to allow the sling device to be released in a manner that does not drag on or damage mortar coatings.

In Fig. 13-3, a pipe and bend combination is lowered into the trench. Note the end cap on the bend, the dual lifting points, the spotters, and the trench box and sheeting. A well point dewatering system is also shown.

13.5 INSTALLATION

13.5.1 Site Verification and Utility Conflicts

Before the final pipe production, field information shown on contract drawings should be confirmed to ensure that all pipe sent to the job site is dimensioned correctly. This requirement is of particular importance for large-diameter pipe because of its limited capability to accommodate field changes.

The constructor may be required to field-locate and measure underground utilities that the proposed pipeline crosses. The level of detail available during the design stages may not be adequate for construction because existing conditions are often based on inaccurate locations by utilities.

Finding the precise location of underground conflicts shown on the drawings or evident in the field is commonly referred to as *test pitting* or

Figure 13-3. Setting a pipe and pipe bend combination. Note the end cap on the bend, the dual lifting points, the spotters, and the trench box and trench sheeting. Source: Gannett Fleming, Inc. Used with permission.

potholing. With accurate test pit information and an accurate field survey, the pipe manufacturer can make a final pipeline layout schedule that follows the design drawings and accommodates any new information. Further adjustments to the vertical or horizontal alignment of the pipeline may be accomplished by small deflections at the pipe joints or by using beveled pipe adaptors.

13.5.2 Pipe Placement and Assembly

The amount of excavated trench left unfilled may be dictated by field conditions, safety requirements, convenience, or the contract documents. Typically, when a backhoe handles the pipe, excavation proceeds one to two pipe lengths in front of the pipe laying. The trench may be excavated longer or wider if a separate pipe-laying crane is used. When sheeting or a trench box is used, affected joints must be checked as sheets are pulled or the trench box is moved to make sure previously completed joints are not disturbed.

The pipe must rest on a prepared foundation in accordance with the contract documents. Also refer to Section 6.2.3 of this manual. If details are not provided, bedding may be used as shown in *AWWA M 9*. Pipe bedding is prepared to the depth indicated but just short of the pipe joint, which allows placement of the exterior mortar grout around the pipe joint.

Pipes are inspected again before lifting into the trench, checking for visible damage to the pipe coating. Damage must be corrected before the pipe is brought close to previously installed pipe.

Figure 13-4. A trench box in service. Courtesy of Price Brothers Corporation.

The grade of the pipe trench is checked against the pipe-laying schedule and design drawings using a transit, hand level, or laser device. Often, this work must be done inside a trench box (Fig. 13-4).

When pipes are made with exterior concrete belled ends, pipe laying requires that spigot ends are inserted into bell ends. For larger diameters, pipes without external bells are common and engagement of either end into the other is possible. The method that will best avoid displaced gaskets and provide the most reliable joint seals should be used. The spigot-into-bell installation usually is most reliable.

The steel bell and spigot rings at each joint must be manufactured to close tolerances. They must be absolutely clean of dirt and properly lubricated to slide together without damaging the gasket. The gasket groove in the spigot and the gasket are lubricated separately prior to placing the gasket on the pipe. The bell ring is lightly lubricated over its entire inner surface. (Use only lubricant provided by the supplier. Petroleum-based lubricants will damage the rubber gaskets). Be sure to keep all lubricants clean. Lubricant should be applied when the pipe has been lowered partly into the trench or just before. Lubricated gaskets are stretched around the spigot by a smooth rod (such as the shaft of a screwdriver) placed between

Figure 13-5. Engaging a field joint in a PCCP. With the pipe joints clean and lubricated, proper alignment of the spigot and bell allows easy engagement of the pipe ends. Courtesy of Price Brothers Corporation.

the gasket and the spigot ring and run completely around the joint, once in each direction. This process stretches the gasket evenly around the spigot and helps to ensure a good seal.

With the joints cleaned and lubricated, each pipe is aligned so the spigot end squarely enters the bell. A person positioned inside or outside the previously installed pipe guides the pipe from that end, preventing dirt from touching the lubricated surfaces. Never engage the joints at predominantly one point on the ring. Figure 13-5 shows how spacers are used to control the insertion of the spigot end of the pipe into the bell end when using an internal feeler gauge (discussed immediately below). Variable-thickness spacers may be used to create pipe deflections.

With the pipe squarely aligned with the previously installed section, engagement should occur smoothly. Assembly cannot be forced or uneven because damage to the gasket or the protective concrete surrounding the joint rings may occur. After engagement of each bell and spigot joint, the position of the rubber gasket is checked to confirm that it has remained inside the spigot groove. This test may use a metal feeler gauge or an ultrasonic instrument. The feeler gauge may be designed for internal or external use (Fig. 13-6). Check with the pipe manufacturer for instructions on using these gauges. Feeler gauges are used to check the final position

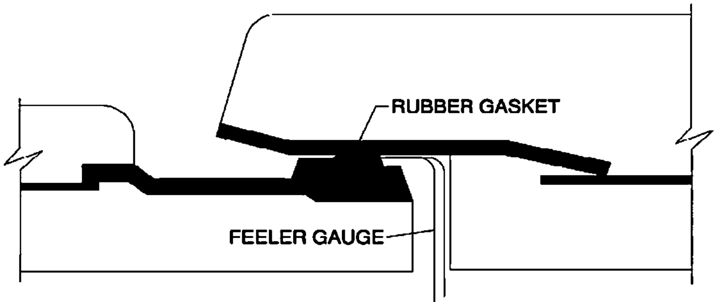

Figure 13-6. An internal feeler gauge. Courtesy of Price Brothers Corporation.

of the rubber gasket. If an inspector cannot "feel" the rubber with the feeler gauge, disassemble the pipe joint and inspect the condition of the gasket. If an ultrasonic instrument is used, the instrument supplier must provide instructions for use.

Once the joint is correctly made and the pipe is bedded, grade and alignment may be rechecked, especially if a small deflection has been used. Restrained-joint pipes held together by mechanical connections do not have as much capacity for deflection as do slip-on joints. Therefore, restrained-joint pipes must be checked carefully for proper restraint system engagement.

When the pipe is finally bedded, a Portland cement-mortar collar is poured to fill the outside joint groove using an outside grout band (diaper) as a form. These joints are normally filled a few joints away from the free end of the pipe to minimize length of open trench. Where longer open trench permits, more lag between placing the pipe and grouting joints may be taken. Free-flowing grout mix is poured initially into the joint at the 11 o'clock position to ensure complete filling of the void around the full circumference. Interior joints are also grouted inside the pipe or as otherwise required to protect the joint rings.

The contract documents usually will provide details for backfill procedures. In general, requirements for backfilling rigid concrete pipe will be less stringent than those for flexible conduits such as ductile iron, plastic, or steel pipe. Requirements under pavement or in sensitive areas may be more stringent.

At least 2 in. (50 mm) of cover is typically placed over the pipe before operating construction equipment over the pipe. Any loading applied by equipment operated over the pipe, or from other sources, must be approved by the engineer because this condition must never exceed the load strength of the pipe.

13.5.3 Thrust Restraint

Cylinder thickness and other design features vary in restrained-joint pipe areas. Field welding to make a restrained joint is common. In these areas, pipe must be placed strictly according to the layout schedule. Individual restrained joint construction varies depending on joint type. Refer to manufacturer's recommendations for individual restrained-joint types.

13.5.4 Closures

The follower ring closure for PCCP resembles the mechanical coupling or solid sleeve closure in ductile iron pipe. Its purpose is to join PCCP across short gaps to complete a pipe segment or make new connections simpler by adding joints and increasing flexibility. Closures are made from steel pipe and usually have two sliding bell or spigot ends. Some existing pipe segments may require adapters to fit.

13.5.5 Testing and Acceptance

The completed pipeline typically requires hydrostatic testing. Testing is commonly performed in pipe reaches between valves. Other options include using internal test bulkheads, internally welded in the PCCP steel cylinders and cut away from the pipe after testing. External test bulkheads may be specified. In each case, appropriate thrust restraint must be developed throughout the portion of the pipeline to be tested.

Alternatively, for low-pressure pipes, testable joints may be specified instead of a hydrostatic test. These joints have two gaskets so that pressurized air may be used to test each joint without pressurizing the pipe. The contract documents indicate the intended test pressure, length of time the pressure must be held, and allowable leakage amount during the test. Leakage amounts are typically a function of the length of pipe being tested, its diameter, and the test pressure.

Adequate time must be allowed for filling the pipe, and sufficient water must be available for filling. Air must be removed before pressure testing because trapped air will compress and affect the test results. Temporary air taps may need to be added if air release valves have not been provided at all high points.

Upon satisfactory completion of testing, the entire pipe alignment is visually inspected and final corrections or restoration items are addressed for repair.

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CHAPTER 14
REINFORCED CONCRETE PIPE

14.1 GENERAL BACKGROUND AND DISCUSSION

Compared to other pipes in this manual, installation of reinforced concrete pipe (RCP) is least influenced by the pipe material. This pipe is very rugged. Three of the most important construction procedures include providing equipment to handle the pipe, creating a firm but slightly yielding earth foundation under the barrel, and ensuring watertight joints. A sample project is included in Section 14.4 to describe these concepts and procedures.

Pipes made of Portland cement concrete are a direct result of developments in reinforced concrete technology. Concrete material has always been highly resistant to the corrosiveness of earth environments and, when used as a buried pipe, rigidly holds its circular shape, especially in comparison to other available materials. Techniques developed for reinforcing concrete with steel reinforcing, both conventional and prestressed, allow the design of concrete pipe with steel cylinders, which will resist earth loads from almost unlimited depths of earth cover and can resist internal pressures up to 173 psi (1,193 kPa).

Modern RCP is manufactured in diameters as small as 12 in. (305 mm) and as large as 21 ft (6.4 m). This size range is well adapted for permanent drainage facilities, such as sanitary sewers, storm drains, and culverts; for delivering water in municipal service; or even as pedestrian or vehicle tunnels. For all these functions, the main advantages are the pipe's great resistance to deformation, containment of varying pressures, and high resistance to abrasion.

Concrete pipe gravity sanitary sewers that are exposed to biogenic sulfuric acid due to the presence of sulfide in the sewage must be properly lined with a protective material such as PVC lining. Concrete pipe pressure sewers (force mains) will not corrode as long as there are no sections of the force main that are not completely full. Coatings that are sprayed or brushed on the cured concrete pipe for protection against biogenic acid exposure typically fail in 5 to 10 years. ASCE Manual 69, *Sulfide in Wastewater Collection and Treatment Systems*, addresses in detail the issue of sulfide-related concrete pipe corrosion.

Concrete pipe is practical but the dead weight of the product can be a challenge. Early pipe manufacturers were limited by the hoisting capacity of available cranes, especially at a construction site. Today, this aspect is of little concern because machines to handle concrete pipes are much more capable, efficient, and mobile. Pipe sections weighing 45 to 60 tons and more have been installed with no significant problems.

The most common industry specifications for design and manufacture of RCP are included in the following ASTM and AWWA standards:

- *ASTM C 76, Reinforced Concrete, Culvert, Storm Drain, and Sewer Pipe*
- *ASTM C 361, Reinforced Concrete, Low Head Pressure Pipe*
- *ASTM C 655, Concrete D-Load Culvert, Storm Drain, and Sewer Pipe*
- *AWWA C 302, Reinforced Concrete, Pressure Pipe, Non-Cylinder Type*
- *AWWA C 300, Reinforced Concrete, Pressure Pipe, Steel Cylinder Type*
- *ASCE 15–98, Standard Practice for Direct Design of Buried Precast Concrete Pipe Using Standard Installations (SIDD)*

Some concrete pipes are made without steel reinforcing for sewage and drainage work, which often does not subject them to internal pressure (*ASTM C 14* and *ASTM C 118*). Such pipes are usually 36-in. (915-mm) and smaller. Installation is similar to the reinforced pipe previously described. Breakage at the pipe joints is a concern.

14.2 DESCRIPTION OF REINFORCED CONCRETE PIPE

Installers of RCP can make better decisions during construction if they understand how this pipe is manufactured with varying strengths to meet the contract specifications and the approved pipe layout schedule. In pressure pipe applications, or in gravity pipe to be installed on curved alignments, each pipe piece may have a particular location at which it must be installed because of its unique design. Changing locations of pipe units must be approved by the pipe designers.

The RCP barrel represents a specialized concrete structure in which the pipe wall is designed to resist compression, shear and bending stresses caused by the earth loading, live loading, and (possibly) from internal pressure. Bending of the barrel from effects of earth loading is described in Chapter 2, especially in Fig. 2-4. The wall thickness of the barrel determines how much compression can be resisted. Tensile stresses, from earth loading or bursting ("hoop tension") from internal pressure, are resisted by the position of one or more separate coiled cages of reinforcing steel cast in the concrete. The size and spacing of the reinforcing varies according to the loading. If needed, stirrups are added to the circular reinforcing to resist shear stresses.

For economy, alternative designs may use a single cage of reinforcing. In some cases the steel must be formed into an elliptical shape, closest to the outside of the installed pipe at the springline and closest to the inside surface at the bottom (invert) and top (crown) of the pipe. Pipe produced with a single elliptical cage will locate the position of the field *top* on the pipe barrel, to ensure correct field placement. In the trench, this field top mark must lie within 5 degrees of the truly vertical position to avoid failure of the pipe barrel because the tension-resisting steel was not installed in the proper location.

Manufacturers have standardized ordinary pipe wall thicknesses. The pipe wall thickness is referenced in the relevant ASTM standards, usually identified as A, B, or C wall. Thicker pipe walls (C wall and thicker) have been used for unusually high earth loadings, and thin-walled pipes of about ID/16 have been used for other services. B wall pipe, the most commonly used, will have a wall thickness of the diameter in feet plus one inch, or ID/12 + 1. Reinforcement design will be based on these standard thicknesses.

Generally, gravity sewer, storm drain, and culvert pipe will be specified to conform to D-Load test strength in accordance with *ASTM C 497*. The D-Load represents the maximum force that will bear down on the RCP once it has been put in place and backfilled. The load includes the dead load (weight of the fill over it) and the live loads (weight of the largest vehicle expected to pass over the RCP). The pipe barrel is designed by the pipe manufacturer to pass loading tests made on production pieces of completed pipe.

For testing, an empty pipe is held horizontally in special equipment and squeezed between two beams which apply vertical loads at top and bottom of the barrel cross section. Normally, 2% (1 out of every 50 pieces) of a given lot of pipe are tested at the pipe plant for quality control. There are two load limits to this test. The first is the vertical load to produce a 0.01-in. (0.25-mm)-wide crack not more than 12 in. (305 mm) long on the inside of the barrel, known as the "0.01-inch crack D-Load strength." The second is the load at which the pipe resistance to deformation, or failure, is reached, referred to as the "ultimate D-Load strength." For reasons of economics, most production pipe tests are made to the 0.01-in. D-Load strength only, and not to the ultimate D-Load, because the ultimate test destroys the pipe. Special short pipe test sections are sometimes taken to the 0.01-in. load and the ultimate load to verify the pipe design. The test results are recorded and the applied loads are divided by the diameter in feet and then by the length of pipe being tested, also in feet. This is a proof test that shows how the manufacturer's designs, for example, will resist the required D-Load, expressed in pounds per foot of pipe of pipe diameter per foot of pipe. Expression is given as an 800D design, 1250D, 2000D, etc. A 36-in. (914-mm) diameter by 8-ft (2.5-m)-long 1000D pipe section must withstand a load of 24,000 pounds before developing a 0.01-in. crack. In recent years, computerized analysis of pipes has been developed to directly design concrete pipe. Such designs may be in accordance with the ASCE SIDD design (*ASCE 15–98*), *ASTM C 655*, or a similar design specification.

14.2.1 Pipe Weight

The weight of concrete pipe may be estimated by the following equation (all dimensions in inches and pounds), assuming 150 lb/ft^3 (2,402 kg/m^3) concrete:

$$\text{Wt/ft of pipe} = 3.27 \times (\text{wall thickness}) \times (\text{wall thickness} + \text{inside diameter}) \text{ pounds per foot}$$

14.2.2 Pipe Manufacture

A pipe manufacturing plant produces highly technical concrete products. Special mixers are used to manufacture concrete with very low slumps and high compressive strengths. Normal production results in 4,000- to 6,000-psi (28,000- to 41,000-kPa) or higher strengths. Any suitable admixture may be added to this concrete.

Vertically cast pipe (VCP) is typically cast in smooth and accurately dimensioned vertical steel forms in which high-frequency vibrators consolidate the stiffest mixes. Bell ends are cast square on the bottom and beveled ends are made by tipping the top, or spigot end form, up to a maximum bevel angle of 5 degrees. The pipe still in the forms may be cured in place or moved to a curing area. Production rates for pipe are controlled by the equipment and manufacturing process; the number of forms available; and, in some cases, the breaking strength of the concrete test cylinders. The forms are typically removed when tests show the concrete has reached 2,000 psi (14,000 kPa), or in about 20 to 40 hours. The cast pipes may then be further cured by water, fog spray, or in a steam curing chamber until the remaining design strength is achieved.

Pipes are also manufactured by a centrifugally spun process in a rotating horizontal form, developing high G forces that compact the concrete and are cured in the form. Such pipe is referred to as *spun pipe*.

A process becoming more common is the *dry cast immediate strip process*. The concrete mix is negative or dry of zero slump; high-amplitude vibration is applied; and the pipe is moved to the curing process on the lower end ring form but with no inner or outer form. A fiberglass temporary top end form is left in place during curing. Some of these machines, fully automated, produce multiple pipe sections at one time.

If specified, plasticized PVC or PE plastic liners for corrosion protection of concrete pipes are easily installed on the inside forms prior to casting.

Pipes remain in a vertical position until after curing. The heaviest pipes require special lifting equipment for tipping the pipe because, if the end of the cylinder is allowed to rest on part of a bottom edge, high forces will concentrate on a small area and likely break the pipe end.

Pipe units may be marked with layout numbers to coincide with the manufacturer's layout drawings.

14.2.3 Cylinder Pipe and Noncylinder Pipe

All pressure pipe swells slightly under the effect of internal pressure, due to the circumferential hoop tension or hoop stress. Internal pressures are restrained by the circular steel reinforcing cages, which act as barrel hoops. Experience shows that pipe reinforced only with mild steel wire or rod reinforcement (40,000 to 80,000 psi yield strength) can be designed to remain reasonably leaktight up to an internal pressure of 54.19 psi (373 kPa). Below this pressure, pipe reinforced only with steel rods (noncylinder pipe) is adequate. When design pressure exceeds 125 ft (38 m), the inside reinforcing rods are replaced by a continuous cylinder of sheet steel, which acts as a watertight membrane and provides an inside layer of concrete reinforcement. This latter design is referred to as *concrete cylinder pipe*.

14.2.4 Joining Pipe Ends

Manufacturers typically cast pipe in laying lengths from 8 to 24 ft (2.5 to 7 m), which implies that many field joints must be made. Each joint functions to prevent sideways displacement of pipe ends, because one end encases the other (spigot inside the bell or tongue inside the groove). The terminology used is that *a spigot end inserts into an adjoining bell end*. A spigot pipe end used on the sample project is shown in Fig. 14-1. Concrete pipes are usually laid by inserting spigots into bells, but the reverse is also possible. Generally, the bell end of the pipe is installed facing upstream, which requires that the installation starts at the lower end of

Figure 14-1. Spigot end of reinforced concrete pipe used on the sample project.

the line and proceeds upstream. This is identified on the layout sheets as the *lay direction*.

A watertight joint is usually required to prevent exfiltration and resulting pollution of adjacent soils and groundwater, and to prevent infiltration of groundwater into the pipe. Discussion in this chapter only considers watertight joints, which are sealed by O-ring or other types of gaskets. These gaskets are held in a pocket or groove near the end of the pipe spigot. The rubber is highly compressed between the spigot and bell surfaces during pipe engagement, which results in the joint seal. These seals are very efficient and have been successfully tested up to pressures far higher than usually needed.

Gasket containments for noncylinder pipes are formed by grooves cast into the concrete spigot ends. These ends must be protected from breakage or the joint will leak. Steel joint rings cast into the pipe have also been used. For cylinder pipes and some noncylinder pipes, the gasket is contained in a specially rolled steel shape, called a *Carnegie shape*.

During joint engagement, concrete pipes are sufficiently rigid that the rubber gasket is easily compressed. Usually, a strong longitudinal force is needed to force the two ends together. Some part of the gasket rubber may be caught and pinched by the sliding movements, resulting in an improper seal. A test is often specified to ensure that the joint gasket is properly positioned. A trained inspector can touch the side of the rubber by inserting a thin, hard steel strip (a feeler gauge) into the ungrouted joint openings to detect an improperly positioned gasket. Improperly positioned seals require removing the pipe unit, installing a new gasket, and relaying the pipe. This test depends on the skill of the inspector and is not 100% reliable. However, it is an inexpensive alternative to waiting for a final leak test to find the leaky joints, at which time the pipe is probably completely backfilled and very expensive to repair.

An alternative design for testing every pipe joint at the time the pipe is laid is to provide a double-gasketed spigot with a small connection between the two gasket grooves and the inside of the pipe for low-pressure air or water testing of each joint. This test is described in the discussion of the sample project in Section 14.4 (see Fig. 14-1). A number of portable joint testers are available which test only the joint itself from the inside of the pipe, with air or water.

At pipe joints for cylinder pipe, steel bell and spigot rings must be welded to the inside steel cylinders to complete the membrane seal if rubber O-ring gaskets are used. In some cases, the spigots might be welded to the bells. In this case, the rubber gasket is not installed.

For noncylinder pipes without exposed steel, joints are made between concrete and rubber and are not subject to underground corrosion. For this case, the joint space need not be filled. For cylinder pipe, the joint is sealed against steel surfaces, which must be protected against corrosion. All joints with steel exposed in the open spaces of the pipe ends are filled with cement mortar after assembly. Inside joints in pipes less than 24-in. (610-mm)-diameter are filled (buttered) with wet mortar before joint engagement. An inside swabbing tool is drawn through the pipe to smooth these joints soon after the pipe is laid. In larger pipes, a laborer will manually fill the joint space. Outside joint spaces are filled by wrapping a heavy paper form around the pipe ends and filling the open space with poured thin mortar. For this process, the filling should begin on only one side at the 1 o'clock position, which allows the air or water in the joint to be forced out during filling.

In some cases, the thickness of the bell ends must be equal to or greater than the normal one-half the thickness of the barrel. This increases the outside diameter of the pipe at each bell end. Small excavations must be made under each bell so both the pipe barrel and the bells have uniform contact with the bottom of the trench. Otherwise, the intermittent bells would become hard supports, forcing unusual loadings on the remainder of the pipe barrel to act as a bridge. On pipe diameters of larger than 54 in. (1,371 mm), the normal pipe wall thickness may be sufficient to allow eliminating belled ends without an increase in outside diameter. This pipe is sometimes referred to as *flush bell* pipe. Flush bell pipe has the advantage of eliminating the requirement to dig bell holes in the trench bottom.

14.2.5 The Installed Pipe

When backfilled, all RCP must resist external loads from a number of directions, including the weight of the column of earth lying over the pipe, the weight of the pipe barrel, the pressure of the inside fluid, and the weight of any overhead vehicles. As in any concrete structure, this load is resisted without visible deformation or deflection from the designed conditions. This rigidity is a result of the pipe stiffness, described in Chapter 2, and is usually a function of both the diameter/wall thickness ratio and the elastic modulus of the pipe material. For concrete pipe, stiffness calculates at enormous values compared with the stiffness of competitive flexible pipe materials. Measurement of barrel deflections in buried concrete pipe is only made for research purposes.

Analysis and extensive experience shows that vertical loads are passed through the pipe barrel and are resisted by the earth bedding under the pipe. The arc subtended under the pipe or the pipe bedding angle is usually shown on the drawings as 60 to 120 degrees. In rare cases, this bedding is prepared (shaped with a template screed) as a pipe cradle.

Should the pipe bedding fail or settle in a localized area, shearing forces will occur at pipe joints, possibly resulting in leakage, and increased pipe wall stresses may result in pipe failure. Foundation failure over a longer reach of pipe may mean the pipe's profile length will increase, opening up the joints on the bottom of the pipe. Either action is an invitation to failure or major leakage. This possibility emphasizes the need for completing all bedding and backfill work exactly as required by job specifications.

14.3 A SAMPLE PROJECT TO ILLUSTRATE ACTUAL INSTALLATION WORK

To make this text more meaningful, the following discussions will relate to a sample hypothetical project, which will illustrate an average field installation using the best practices and will show how a constructor may develop alternative actions.

The sample project involves installing reinforced concrete pressure pipe as a siphon to connect two reaches of irrigation canal. This siphon, which replaces an old flume across a deep ravine, is 2,725 ft (830 m) long and includes two parallel barrels of 72-in. (1,828-mm)-ID RCP. A simplified profile and typical cross section are shown in Fig. 14-2. This drawing shows the earthwork dimensions, pipe bedding, internal pressures, and other conditions related to the remainder of this chapter.

Some of the sample project features may be summarized as follows:

- ID = 72 in. (1,830 mm)
- Wall thickness = 7 in. (175 mm)
- Barrel OD = 86 in. (2,180 mm)
- Bell OD = 98 in. (2,490 mm)
- Maximum earth cover = 21 ft (6.4 m)
- Maximum internal pressure = 53.3 psi (368 kPa)

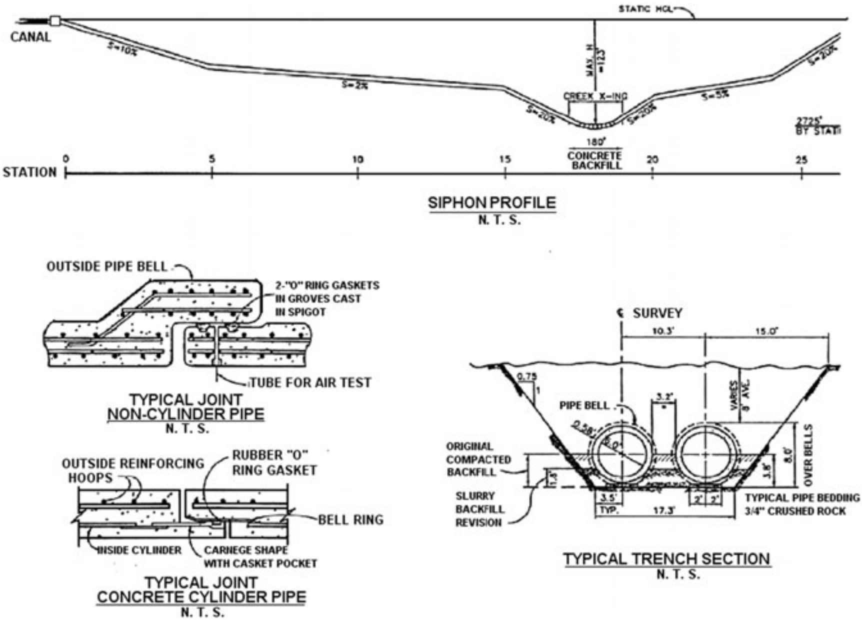

Figure 14-2. A plan and profile view of the sample project.

- Pipe is noncylinder and uses double rubber gaskets on concrete spigots
- Manholes installed at 500-ft (150-m) centers
- Design is according to ASCE standard SIDD design (*ASCE 15–98*), type III
- Installation determined by existing soil, which is lean silt, class ML
- Properties:
  - Laying length = 16 ft (4.8 m); weight/ft = 1,810 lb (8.0 kN)
  - Laying weight of each unit = 29,000 lb (129 kN)
  - Total number of laying units = 354 each pipe
- Manufactured under *ASTM C 361* in a plant 300 miles (480 km) from job site
- Lead time for first pipe delivery is 4 months
- Delivery will be by truck, two pipes per load, three loads delivered per day

14.3.1 An Appraisal of the Sample Project

The sample project requires:

- Clearing and grubbing of trees along the route.
- Making the trench excavation. This also includes crossing an actively flowing stream while minimizing pollution from mud and debris.

- Obtaining and installing more than 5,500 ft (1,680 m) of concrete pipe.
- Backfilling all excavations.
- Construction of new canal transitions.
- Removal of the old flume.

More specific planning for this job considered the following characteristics:

- Steep sections are wooded; about 50 trees must be cleared of stumps and grubbed.
- Flat sections are on farmed land and will require saving topsoil.
- Right-of-way is reasonably clear; working space is adequate.
- New pipes will cross no buried pipes, under only two overhead power lines.
- Excavation is in lean ML soil, apparently without significant rock on the flats, but some rippable rock occurs on slopes.
- Average excavation volume for the entire cross section is 15 yd^3/ft (38 m^3/m).
- The bottom is suitable for excavation by wheeled tractor and elevating scrapers (paddle loaders), assisted by a bulldozer. Finer grading will use a motor grader and hand work.
- Side-slopes are probably stable at depths encountered.
- Scraper excavation will require some larger areas for spoil storage, especially at bottoms of slopes.
- Stream diversion and excavation in the creek bed will be slow and expensive work while holding mud pollution in the creek to a minimum.

14.3.2 Subcontracting for Pipe Delivery

The constructor's first need is to subcontract for the delivery of the pipe units. The pipe manufacturer, or supplier, is a subcontractor to the constructor and assumes major responsibilities as described in Chapter 4. *The Concrete Pipe Handbook*, published by the American Concrete Pipe Association, contains descriptions and definitions relevant to subcontracting.

A manufacturing plant inspector's duties include:

- Verify use of correct materials and reinforcement size and placement.
- Witness D-Load strength, hydrostatic, or other QC tests required by the specifications.

- Verify correct cylinder breaking strength of concrete used for pipe barrels.
- Verify use of manufacturer's approved curing process.
- Identify need for and final inspect repairable production flaws.

14.3.3 Hauling and Handling Pipes

On the sample project, the weight of the individual concrete pipe units required a plan to minimize the number of pipe lifts, or picks. A crane is often needed for this job because backhoes may not have lifting or reach capacity at all positions to safely handle pipe sections. This reduced capability is especially true at trench-side, where the hoisting machine must be very steady, never deflecting in a harmonic or bouncing manner while moving a pipe section into joint engagement.

Transport to the job site is most commonly accomplished by trucks, which are subject to gross vehicle weight and highway load width limitations. Exceptions by hauling permits are common. An average maximum pay load would be about 45,000 net pounds (200 kN) on a semi-trailer truck and would include a maximum load width of 12 ft (3.6 m). Sometimes, pipe units 8 ft (2.4 m) long are transported sideways on the truck.

Off-loading pipe from trucks at the work site may require a separate crane. Slings under the pipe barrel are the common device for lifting. On nonpressure pipes, small holes are used through which a toggle bolt is inserted during lifting, and then the bolt is easily removed when the pipe is set in place. Holes are patched after installation.

An efficient method for field unloading is to drive the transporting truck directly to the trench-side, where the pipe-laying backhoe or crane may pick pipe units directly from the truck and set them in the trench. This process obviously depends on direct access to the trench-side.

When low-bed trailers are used, the pipe may be rolled off onto a low dock built for this purpose. This dock is located adjacent to an area of smooth, soft ground (sand), where the pipe units may be rolled to any storage position. Another method involves lifting pipe pieces with a remodeled front-end loader equipped with a single finger-like bracket. Some of these machines were originally designed for lifting timber logs and often have a capacity to handle pipes as large as 10 ft (3 m) in diameter. On the sample project, such a device was used to move pipe units from trucks to a special trailer pulled by a bulldozer, and was then used to haul units up the 20% slopes directly to the pipe-laying crane at trench-side.

A unique use of equipment originally intended for the timber industry and adapted for pipe handling is shown in Fig. 14-3.

Figure 14-3. Special equipment to handle a large concrete pipe.

14.3.4 Excavating the Trench

Excavation is the slowest part of the project and usually depends on the productivity of a backhoe or other excavating machine. The typical excavated section for the sample work is shown in Fig. 14-2.

In the sample project, scrapers completed the trench excavation much more quickly than a backhoe would have. A cycle of scraper operation was established to dig, haul, and dump soil. Equipment operated downhill on the steep slopes, but the scrapers actually required extra space for equipment operation and spoil storage, especially at the bottom of the sloped reaches, where a major spoil pile was developed.

Because two pipe barrels were installed in the same trench, use of a trench box or other slope support was impractical, and the contract drawings showed flattened trench side-slopes. However, a trench box was necessary for worker safety at the creek crossing because the excavation had to be held to the narrowest width possible.

Good surveying control was needed, especially in curved, tortuous pipe alignments. Because all pipe units were custom-made to follow a certain alignment, an appropriate layout had to be accurately made in the trench invert. For the operations described, final invert elevations were measured up or down from the projected level plane established by a laser level. Fine-grading of the trench bottom was performed using a small motor grader supported by a small wheel loader and some hand shoveling. For alignment control of each pipe, a wooden hub was set to line and grade in the trench, 2 ft (0.6 m) from the bell end of all pipes.

Preparing uniform bedding was a critical part of installation for this rigid pipe because all the vertical loads were concentrated at this level. Bedding material specified was 0.75-in. (22-mm) crushed rock, which was easily distributed. Compaction was not specified because the crushed rock was only 3 in. (80 mm) thick. Bell holes were also cut into the trench bottom. These excavations were finished by the small wheeled backhoe loader in conjunction with the fine-grading operation.

To facilitate operations at the creek crossing, the contractor requested a design change to widen the centerline alignment of the pipes and lay each pipe in a separate trench. This design allowed smaller volume of the creek to be held in a dewatered condition and made a trench box practical to protect the workers under unstable earth conditions. After the first pipe was encased in concrete, the second pipe installation could be made separately. This change was approved.

14.3.5 Laying and Jointing the Pipe

Installing all the pipe units required setting the pipes in their designed position as well as completing all the field joints in an acceptable manner. A large crane was used to lift and set the pipe units on the prepared bedding. This machine worked from one side of the trench. Laying rate was 12 joints per day on the flat and 8 joints per day on the slopes. Pipe was laid uphill on the slopes, spigots into bells. Pipe could not be laid every day because of the need to use the crane to place the compacted bedding material.

On steeper-sloped reaches, level pads for the crane operation were cut at 50-ft (15-m) intervals, and three pipe units were laid from each site before moving to the next uphill pad. Pipe units were delivered to the crane on a special trailer pulled uphill by the bulldozer. A modified sling lifted pipes in a sloping position so they could engage the joint at the slope of the previously laid pipe. A steady, unyielding lifting machine was needed (as previously discussed) because the pipe ends could never be bumped or hard-touched during pipe joint assembly. The mass of the pipes was so great that even a small impact had sufficient energy to break the spigot ends or crack bells. Three cases of minor damage occurred, which were repaired using epoxy mixes.

In addition, on steeper slopes the pipe tended to slip downhill. Whenever possible, pipe should always be laid in the uphill direction. Pipe joints were held apart on the slopes by wooden spacer wedges in the joint grooves, and then backfilling to springline had to be completed within 100 ft (30 m) of the pipe laying. Ultimately, the upper pipe ends were encased in concrete at the new canal transitions. When working on gentler slopes during the pipe-laying period, backfill could not be placed, and many pipes were rested on the bedding without any sideways restraint. To prevent misalignment, pipes were specified to be braced by at least eight sandbags—two on each side of the pipe at each end.

Pipe joint testing was greatly improved by using the double-gasketed system, in which every joint is ready for test immediately after making the joint. A connecting 0.25-in. (6-mm) tube was cast into the space between gasket grooves on every spigot so that after engagement, a low-pressure air test could be performed by connecting into a threaded pipe

Figure 14-4. Equipment handling large concrete pipe.

Figure 14-5. Installing large-diameter concrete pipe.

fitting. In this manner, if the joint would not hold a small air pressure, the gasket seals were assumed to be faulty and the pipe could be immediately disengaged for gasket correction. Feeler gauges were not needed. Using this device, only two faulty gasket seals were found and replaced.

The heavily lubricated rubber gaskets were only installed immediately prior to pipe laying because the gasket soap is easily contaminated by foreign solids, which would make sealing unlikely.

Examples of the many variations in equipment used for installing large-diameter concrete pipes are shown in Figs. 14-4 and 14-5 (this work was done on an irrigation project and was not related to the sample project). The equipment used in Fig. 14-4 is a front-end loader with special attachment and the equipment used in Fig. 14-5 is an excavator with special attachment for pipe handling.

14.3.6 Backfilling the Pipe

After pipe laying, compacted selected earth material was specified to be placed above the bedding material and up to the pipe springline to complete the pipe support system. This backfill represented an average volume of 3 yd^3/ft (7.5 m^3/m) of trench and was to be compacted to 90% of modified Proctor density (Proctor compaction testing is discussed in Chapter 2).

Compacting backfill under the haunch of the pipe proved difficult because limited space available around the pipes severely constrained the type of equipment used to compact backfill. This zone could most effectively be densified by shovels or hand tampers—very slow work. Above the lowest haunch zones, high-powered tamping or vibrating equipment could complete the work. In addition, only part of the material excavated from the trench could be readily densified by smaller compactors. During trench excavations, whenever suitable sandy materials were found they were segregated by a bulldozer into piles near the station of the excavation. However, for about one-third of the pipeline stations, the constructor had to load and haul suitable material from borrow sites to provide compactable materials.

For economy, the constructor developed an alternative procedure for the haunch. He had access to inexpensive granular material that was slightly larger than specified. The constructor requested, and the engineer approved, placement of a mixture of this granular material as a slurry concrete to one-half the depth of compacted haunch material. A mix using 1.5 sacks of Portland cement per cubic yard was delivered to the trench side in mixer trucks and was placed by dropping the material through a steel chute to the placement site. This alternative produced the additional advantage of negating the requirement to place sandbags at each pipe.

The above description emphasizes why free water cannot be tolerated in the trench bottom or in the bedding zone. This important work cannot be done properly under wet or saturated conditions in the trench area.

Remaining backfill above the pipe springline was finished to the surface by random fill densified to 80% of the maximum Proctor density by vibrating plate compactors. The engineer determined that scraper-like wheeled equipment could not operate if the fill was less than 3 ft (1 m) over the pipes without causing damage to the pipe. Thus, most of this backfill earth was delivered for placement by small-wheeled tractors, pushing earth in a wave-like manner over the pipes.

Overfills on the ground surface resulting from surplus earth material were finished to avoid unsightly depressions where water could collect. Topsoil was replaced over the farmland with a 1-ft (0.3-m) surcharge to allow for soil settlement. At the road crossings, compaction was specified to meet 90% of the modified Proctor density up to the subgrade of the road.

14.3.7 Final Completion

For the sample project, a final hydrostatic leak test was performed on the completed pipes. Both barrels were filled with water from the canal and adequate soaking time was allowed for saturating the dry concrete pipes. No leakage was detected, largely due to the leak tests made of the rubber gaskets as the pipe was laid. The owners accepted the work.

All as-built drawings and a final report of the construction work were submitted at that time.

CHAPTER 15
BAR-WRAPPED CONCRETE CYLINDER PIPE

15.1 GENERAL BACKGROUND AND DISCUSSION

15.1.1 Description

Bar-wrapped concrete cylinder pipe (BCCP) is produced in the western and southwestern regions of the United States and in Canada. This durable, semi-rigid pressure pipe is designed as a composite structure, combining the best properties of steel and concrete. The composite structure includes a steel cylinder, lined with cement mortar, helically wrapped with moderately tensioned round steel bar, and overcoated with a dense cement-mortar exterior. This pipe is normally produced in sizes from 10- to 72-in. (250- to 1,830-mm) diameter for pressures up to 400 psi (2,750 kPa). Laying lengths for standard pipe installed in straight alignments vary from 32 to 40 ft (9.75 to 12.20 m), depending upon the pipe size and manufacturer.

Pipe-laying operations for a smaller-diameter BCCP is shown in Fig. 15-1. This photograph illustrates the typical appearance of this product as a thin-walled concrete pipe and emphasizes the relatively long laying lengths.

15.1.2 Applications

BCCP is used primarily in municipal, industrial, and irrigation water transmission and distribution pipelines, plant piping systems, sewage force mains, and seawater cooling systems.

Figure 15-1. Installing a typical reach of bar-wrapped concrete cylinder pipe. Copyright © Boyle Engineering Corporation. Used with permission.

15.2 PRODUCT INFORMATION

15.2.1 Trade Associations, Standards

BCCP is designed and manufactured in accordance with the following standards and specifications:

- American Water Works Association (AWWA) *C 303, Standard for Concrete Pressure Pipe, Bar-Wrapped, Steel-Cylinder Type*
- *AWWA M 9, Concrete Pressure Pipe Manual*

15.2.2 Fabrication

BCCP effectively combines a welded steel cylinder with steel joint ring, a protective mortar lining on the inside, helically wrapped mild-steel round bar, and a dense cement-mortar coating. The steel cylinder provides the watertight membrane, resists a portion of the tensile hoop stresses, and provides longitudinal tensile strength. Steel cylinders are usually fabricated to a constant outside diameter. The cement-mortar lining contributes to the pipe's rigidity, protects the inside of the steel cylinder from corrosion, and provides a smooth surface with low resistance to flow.

The continuous mild-steel bar wrap is applied at a tensile stress of 8,000 to 10,000 psi (55,000 to 69,000 kPa) to provide the balance of steel required to resist tensile hoop stresses and to reinforce the mortar coating. The bars are locked tightly against the steel cylinder so the cylinder, bar, and coating will act as a composite structure. Wrapping the steel bar under tension produces compressive stresses in both the steel cylinder and the cement-mortar lining to increase the rigidity of the pipe and reduce the effects of drying shrinkage. Also, varying the pitch of rod spacing allows use of an optimum area of hoop reinforcement per unit length of pipe.

15.2.3 Pipe Properties

The total pipe wall thickness includes the steel cylinder, cement-mortar interior lining, bar reinforcing, and an exterior cement-mortar coating. Steel cylinders are lined with cement mortar to create a constant internal diameter.

Steel cylinders are formed by helically welding hot-rolled carbon steel sheets, usually in standard thicknesses varying from 0.060 to 0.375 in. (1.5 to 9.5 mm), depending on the pipe size and internal pressure. Specially shaped steel bell and matching spigot rings are welded to the ends of the cylinder as required for the O-ring joints. Before lining, each steel cylinder with attached rings is hydrostatically tested to ensure watertightness. Any leaks are welded closed.

The steel reinforcement is plain round bar, normally ranging from 0.219 to 0.625 in. (5.5 to 16 mm) in diameter, which is wrapped around the steel cylinder under moderate tension at a controlled pitch or spacing, producing compressive stresses in the steel cylinder and cement-mortar lining.

15.2.4 Joints

Pipe sections are field-joined with self-centering steel bell and spigot joints sealed with a confined O-ring rubber gasket. The rubber gasket is compressed between the bell and spigot rings, completely filling the spigot groove and forming a watertight seal between adjacent pipe sections.

This pipe joint permits a small relative movement between assembled pipe sections, within prescribed limits, without affecting watertightness of the joint. The interior and exterior joint spaces must be filled with cement mortar to complete the joint and prevent corrosion of the steel joint rings. Figure 15-2 illustrates this type of joint.

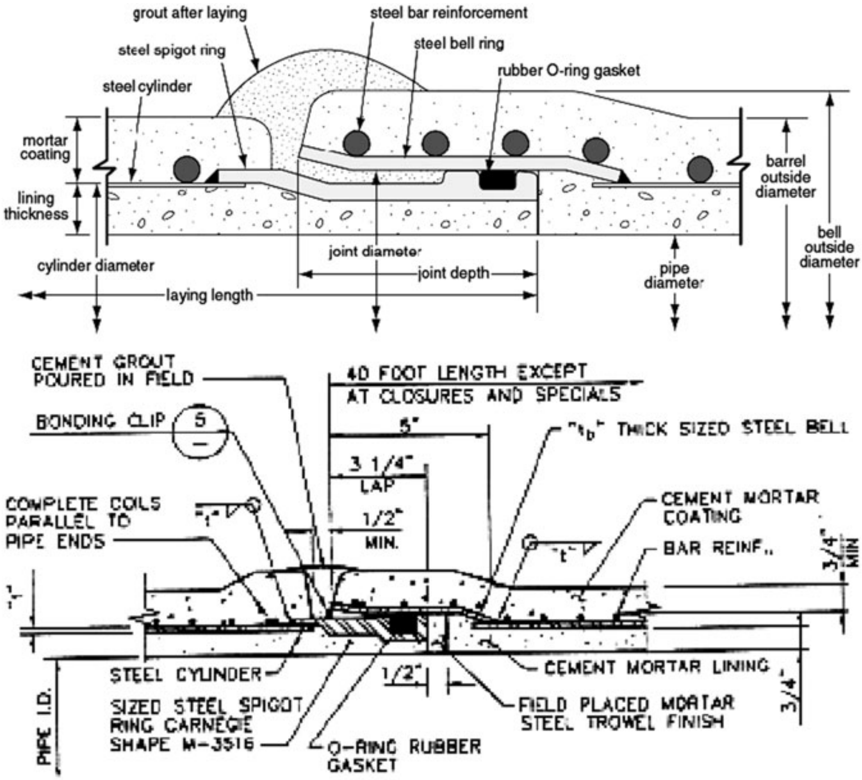

Figure 15-2. Bar-wrapped concrete cylinder pipe, typical field joint. Copyright © Boyle Engineering Corporation. Used with permission.

To transmit thrust forces, pipe joints are either field-welded or mechanically restrained. Figure 15-3 shows two types of field-welded joints for BCCP. The type used depends upon the pipe size and steel cylinder thickness and will be specified on the construction plans.

15.2.5 Pipe "Specials"

Short lengths for bends, elbows, or other fittings used with BCCP are made as steel cylinders and without bar wrapping. Pipe joints will match the design details. All these pieces are mortar-lined and -coated.

15.2.6 Linings and Coatings

Cement mortar inside the steel cylinder serves as the lining and protects the steel cylinder from corrosion. The lining thickness is normally

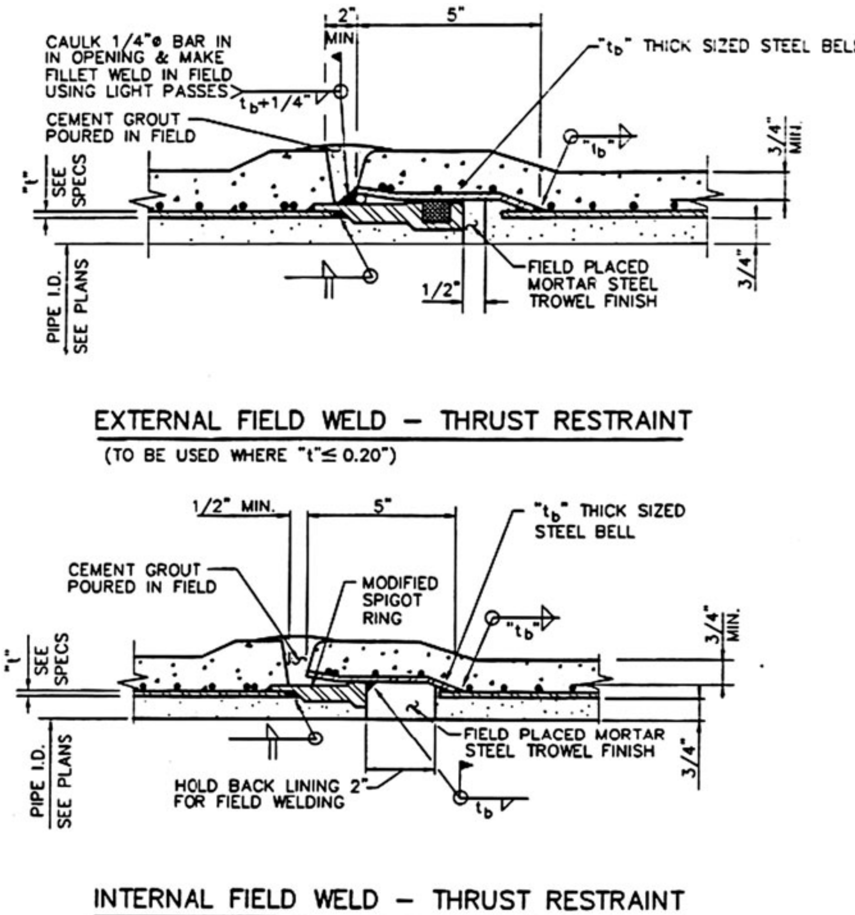

Figure 15-3. Thrust restraint details for bar-wrapped concrete cylinder pipe. Copyright © Boyle Engineering Corporation. Used with permission.

from 0.5 to 0.75 in. (12 to 19 mm). Cement-mortar linings and coatings are manufactured from fine aggregates and Portland cement. Mortar for the lining and coating consists of about one part cement to not more than three parts of fine aggregate by weight.

The mortar coating on the pipe exterior protects against physical damage and corrosion. This coating is normally 1 to 1.5 in. (25.5 to 38.1 mm) thick. If the soil surrounding the pipe is particularly corrosive, an additional coating, such as coal-tar epoxy, is applied over the mortar coating.

The exposed steel surfaces of the steel bell and spigot joint rings are normally coated at the factory to protect against corrosion during transportation and installation. Care must be taken to prevent damage of the mortar. Any damaged mortar must be repaired according to AWWA standards.

15.3 SHIPPING AND HANDLING

15.3.1 Marking

BCCP is custom-designed for each project. Prior to pipe manufacturing, a line layout is prepared to establish stationing and fabrication details for each pipe section. Each pipe section and fitting is numbered to identify its position in the pipeline and then marked with the respective number upon manufacture. The marking includes the pipe number corresponding with the line layout schedule, design pressure, and coating date. Beveled pipes are also marked, with the degree of bevel, the point of maximum pipe length, and the field top centerline.

15.3.2 Transportation

Of prime importance in shipping and handling is protection of the lining and coating from damage. Pipe must be transported to the job site on padded bunks with tie-down straps or padded banding to protect the pipe. Pipe ends are particularly vulnerable to damage from impact. Care must be taken to avoid any dents or flat spots in the steel bell and spigot rings that would interfere with the watertightness of the joint when completed in the field.

Pipe ends may be fitted with plastic caps or formed disks at the factory to prevent excessive drying of the mortar lining. These plastic caps must remain in place during handling and storage of the pipe and must be replaced if removed to spray water inside the pipe for the purpose of keeping the pipe and liner moist.

15.3.3 On-Site Inspection

Pipe shipments should be inspected for damage upon arrival at the project site. Damaged pipe should be reported immediately. Particular attention should be paid to the condition of the cement-mortar lining and coating to check for significant cracking. The presence of end caps should be noted and, if damaged, they should be replaced and the mortar lining moistened by spraying with water, if required.

15.3.4 Handling

Pipe must be handled with equipment designed to prevent crushing or cracking damage to any pipe surface. Pipes larger than 24 in. (610 mm) should be lifted with handling beams or "strong-backs," and at least two lifting points must be provided to protect the coating. Pipes should not be lifted by single cable steel chokers and must never be pushed or dragged along the ground.

Internal bracing is usually required in 30-in. (750-mm)-diameter and larger pipes to limit circumferential deflection. These braces are usually 4-in. by 4-in. (100-mm by 100-mm) wooden posts installed as a cross with one leg vertical. Bracing that remains in place until backfilling is complete is passed out through manholes.

Internal bracing is used to control pipe barrel deflections that could crack the cement-mortar lining and coating. Any changes in the specified bracing system should be approved by the engineer.

15.4 INSTALLATION

15.4.1 Site Verification and Utility Conflicts

The drawings for the project will provide a map of the area through which the pipeline is to be constructed and will present an alignment and profile of the pipeline with the necessary stationing and elevations. In addition to topographic features, the drawings should also include all existing utility locations in both the plan and profile views from record or field exploratory information.

Prior to construction activities, the site must be surveyed in the field to confirm the presence and condition of all existing surface features, such as roadway improvements, structures, and visible utility appurtenances. This inspection should be performed with representatives of the constructor and the owner. Underground utilities must be properly marked on the surface for location and depth. In many areas of the country, a One-Call service is available to constructors for this purpose.

15.4.2 Pipe Placement and Assembly

General excavation of the trench and related earthwork elements are discussed in Chapters 3 through 8.

Using BCCP, the trench is normally excavated to about 6 in. (150 mm) below the pipe subgrade and then backfilled with the specified bedding material and compacted to bring the trench bottom up to grade. Because the design relies on side support from the surrounding soil, the trench wall must be maintained within the pipe zone [from the pipe subgrade to 12 in. (305 mm) above the top of the pipe] to provide the required lateral support. Depressions are usually cut in the bedding material to accommodate the pipe bells and external joint filler forms, and spaces are formed to permit removal of the pipe handling slings.

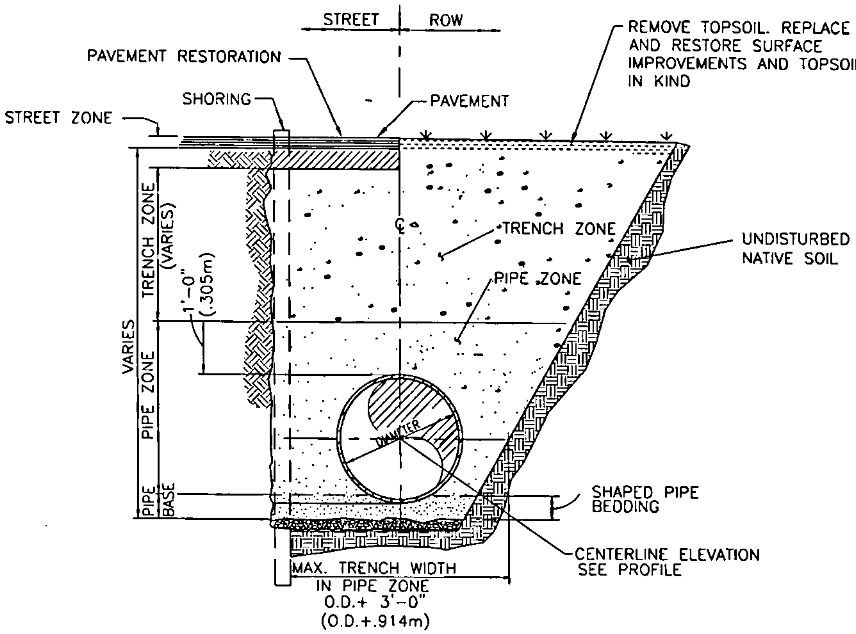

Figure 15-4. Typical trench and bedding detail for bar-wrapped concrete cylinder pipe. Copyright © Boyle Engineering Corporation. Used with permission.

Each section of pipe is laid in the order and position shown on the pipe-laying diagrams prepared by the pipe manufacturer. The pipe is lowered onto the bedding and installed to line and grade to provide firm bearing along its full length except at the bell and sling locations, where a depression should have been cut in the bedding material (Fig. 15-4).

Pipe joints are prepared by cleaning the pipe ends of foreign material and applying a lubricant to the gasket. The spigot end of the pipe being laid is inserted into the bell end of the pipe in the trench. The necessary longitudinal force to engage the pipe ends is provided by a come-along or pipe jacks.

A normal inside joint space between pipe ends is from 0.25 to 0.50 in. (6 to 12 mm) for pipe in a straight alignment. This joint space is checked to maintain the station of each pipe joint according to the pipeline-laying diagrams. This stationing is especially important in curved portions of the pipeline to ensure that the pipe will fit in the excavated trench.

Each joint should be checked by feeler gauge to confirm proper gasket seating. If the rubber gasket is out of position, the pipe must be pulled apart and a new gasket must be installed.

The exposed steel surfaces of the steel joint rings are protected on the interior by filling the joint space (pointing) with cement mortar. On larger pipes, this filling is done with a hand trowel. On smaller pipes, it is accomplished by applying cement mortar to the back face of the bell just before inserting the spigot and running a swab through the assembled pipe to wipe off the excess mortar.

Grouting of the joint exterior is accomplished using a diaper, a fabric form that is placed around the joint and secured with steel straps. Grout is poured from one side at the top until it is visible on the opposite side. Any air or water in the joint space must be forced out and replaced by mortar grout.

Other operations incidental to joint completion may include (1) installing metallic jumper bonding cable for electrical continuity if the pipe is to be cathodically protected, and (2) field-welding of the joints for thrust restraint.

15.4.3 Tapping

All connections and outlets for BCCP should be included during the original pipe fabrication. However, an experienced constructor can tap existing pipes for a new connection if necessary. Smaller taps up to 2 in. (50 mm) in diameter can be made with a tapping saddle. The saddle is held by straps around the pipe and is fitted with a corporation stop. A drill inserted through the corporation stop is used to drill through the steel cylinder and cement-mortar pipe wall. The drill is retracted and the corporation stop is closed to form the completed tapped outlet.

Larger taps are made with a slightly different tapping saddle that incorporates a flanged outlet. A gate valve is bolted to the flanged outlet and the opening is drilled through the gate valve, similar to the method for smaller sizes.

15.4.4 Connections to Structures

Pipe within structures is usually mortar-lined steel pipe connected with flanges or grooved-end and plain-end flexible couplings. Differential settlement could take place between the structure and the connecting pipe. The design engineer's drawings should provide for flexible joints near the structure to allow for this differential settlement.

15.4.5 Installations in Tunnels and Casings

Where the pipeline crosses other large utilities or busy intersections, BCCP can be installed inside a tunnel or jacked casing. In these cases, the carrier tunnel is constructed first and the BCCP carrier pipe is then installed inside the casing. The pipe will normally be joined in the entrance pit and then moved into the casing on skids. The annular space between the BCCP and casing or tunnel is then filled with a lean (light) grout or blown sand. Occasionally, the annular space remains unfilled, but some measure to prevent flotation must be implemented.

Several methods can be used to place the grout in the annular space. Grout fittings may be fabricated through the wall of the BCCP when the pipe is manufactured. The grout can then be pumped through these grout fittings to fill the annular space. Another method is to use a long pipe or slick line placed above the BCCP. Grout is pumped through the slick line, which in turn is retracted as the grout fills the annular space. The slick line is a length of rigid pipe that is embedded in the grout face and attached to the end of the flexible grout hose. Another method is to bulkhead each end of the casing and pump grout in from the lower end of the casing until it fills the entire annular space up to the higher end. The air is forced out the higher end as it is displaced with the grout.

15.4.6 Thrust Resistance

Thrust resistance is an important element in the integrity of the overall pipeline system. Unbalanced thrust forces result from changes in direction of water flow or changes in the area of the wetted cross section occurring at the pipe joints of diameter reducers, elbows, and curves. Joint thrusts are resisted by friction of the dead weight of the pipe and water on the surrounding soil, or by the use of thrust blocks. The design drawings should show how these forces are resisted.

At small joint deflections, the dead weight of the pipe, water, and surrounding soil may be sufficient to restrain the pipe. At smaller-radius curves, however, where shorter pipe lengths are required, or at pipe specials or fittings, the joints may need to be restrained or tied together for a distance on each side of the fitting or curve. Joint restraint for BCCP can be accomplished by field-welding the joints or mechanical restraints. Field-welded joints are illustrated in Fig. 15-3. The pipe may be manufactured with additional cylinder thicknesses to accommodate this case.

Thrust blocks can also be used at fittings to resist thrust forces by bearing on undisturbed soil. An earth coating of gunite or mortar is often used to save the soil in an undisturbed condition.

15.4.7 Corrosion Protection

The cement-mortar linings and coatings applied to this BCCP are the main factors that protect all the steel components from corrosion. Therefore, these elements must not be cracked or damaged during transportation, handling, and pipe installation. In addition, proper sealing of both internal and external joint recesses after pipe installation is necessary to protect the bell and spigot steel joint rings; the recesses must be completely filled to be effective. In especially aggressive soil conditions, all of the exterior mortar coating on the pipe may receive an additional protective overcoating of dielectric materials, such as epoxy products.

Electrical potential and current flow between the pipe steel and the chemicals in the soil are the causes of corrosion problems. Pipelines installed in aggressive soils with high chlorides or low resistivity should be monitored throughout the life of the pipeline.

Damaging electrical currents may also originate from nearby pipelines that are also cathodically protected, electric railways, or other sources of direct current—all of which may initiate or accelerate steel corrosion. A detailed corrosion investigation will be performed during the design period to investigate areas where the pipeline approaches other such pipelines or stray current sources. This work will likely recommend electrical bonding of the field joints to provide electrical continuity along the pipeline, which will allow monitoring of the electrical potentials between the soil and the pipeline steel. Coating the pipe exterior with a high-built coal-tar epoxy is another way to reduce collection and discharge of electric currents. In the most corrosive situation, installation of a cathodic protection system for the pipeline will be specified, incorporating galvanic anodes or impressed current rectifiers. Bonding of the pipe at field joints is required for this protection.

Effective monitoring procedures use electric bonds between pipes to provide electrical continuity throughout the affected reaches of the pipeline. Heavy steel or copper bonding connectors are welded or fused to the small, welded steel bonding clips or bonding bars (Fig. 15-5). One connector end may be shop-welded and the other field-welded. Two bonds per joint are used, located symmetrically from the top of the pipe. This type of bonding is not required at field-welded joints because the

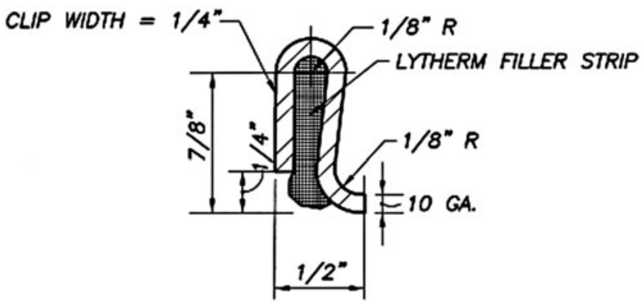

Figure 15-5. Bonding connector for electrical continuity in a corrosion protection system. Copyright © Boyle Engineering Corporation. Used with permission.

electrical connection is more than adequate. Test stations should be installed at regular intervals to provide direct connections to the pipe for monitoring.

15.5 TESTING AND ACCEPTANCE

15.5.1 Inspection

Field inspection of a BCCP installation must occur continuously from the arrival of the pipe at the site, through backfill and compaction of the trench, to pipeline system testing. As noted earlier, BCCP is a semi-rigid pipe that depends upon the surrounding soil for most of its loading-carrying capacity.

Daily inspection is extremely important to confirm that the important installation procedures are followed. Inspection should coincide with pipe placement, joining, and backfilling.

Inspection must include writing clear, concise daily construction reports. Daily progress, other utilities crossed, installation and backfill procedures, and testing with results should be recorded. The actual installed location of appurtenances such as valves, outlets, air release valves, etc. must be recorded for future reference and location.

The semi-rigid nature of this pipe requires measurement of pipe barrel deflections of buried pipe to control backfilling procedures and to check whether the pipe is being deformed beyond the specified amount (refer to Chapter 6).

15.5.2 Testing

BCCP is usually required to be hydrostatically tested. The test pressure is usually between 1.25 and 1.5 times the working pipeline pressure. Test duration can vary from 4 to 24 hours, depending upon the pipe size. The hydrostatic test is usually performed after backfilling. The portions where restrained joints are used to develop the weight of the soil for thrust resistance must be backfilled and compacted prior to testing. Concrete encasements and thrust blocks must also be allowed to cure prior to testing. Testing the pipeline in segments will require installation of special test bulkhead sections.

Following is the general hydrostatic test procedure for BCCP:

1. After the pipeline has been cleaned and flushed, the line is filled at a slow rate to avoid the entrapment of air and left at a low pressure for a period of at least 24 hours to saturate the cement-mortar lining.

2. The test pressure is developed using a positive displacement pump and maintained for the specified period of time. During the test period, the makeup water is added by pumping, and the volume is metered when the pressure drops by more than 5 psi (34.5 kPa).
3. The volume of water used to maintain the test pressure during the test period is the leakage. The leakage must be less than that required by the project specifications. Any visual leaks at valves, appurtenances, and structures must be repaired.

15.6 CONDITIONAL ACCEPTANCE

Most construction contracts provide a guarantee period, such as 1 year, within which the constructor must repair any damaged or noncompliant construction. This period starts after the final punch list items have been successfully completed and the owner has acknowledged conditional acceptance.

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CHAPTER 16

VITRIFIED CLAY PIPE

16.1 GENERAL BACKGROUND AND DISCUSSION

16.1.1 Description

Vitrified clay pipe (VCP) is made from specially selected clays and shales. The pipe is extruded, dried, and fired in kilns to temperatures of about 2,000 °F (1,093 °C), which produces a homogeneous, dense product that is abrasion- and corrosion-resistant. Vitrified clay is very strong in load-bearing capacity but is less resistant to impact. VCP is relatively tough and durable, and has a proven useful life of more than 100 years.

The strength of VCP is carefully monitored throughout the production process. Project specifications usually require certification at the beginning of construction that the pipe meets the project specifications. On some projects the specifications may require that the engineer or an owner representative observe testing in lieu of certification.

16.1.2 Applications

VCP is used primarily for gravity-flow sanitary sewer applications and may also be used for low-head, inverted siphons.

16.1.3 Product Information, Standards, Trade Associations

VCP is available in sizes 4-in. through 48-in. (100- to 1,220-mm) nominal inside diameter. It is produced in accordance with *ASTM C 700, VCP, Extra Strength, Standard Strength and Perforated*, which specifies available limits for dimensional variation.

All VCP joints are produced to meet the requirements of *ASTM C 425, Compression Joints for VCP and Fittings*, which requires a shear test, deflection test (deviation from straight), and a pressure test. Although *ASTM C 425* requires a shear test, the inspector should be aware that the main purpose of the joint is to seal adjacent pieces of pipe. The shear strength of the joint maintains line and grade of adjacent pieces of pipe during the process of bedding, initial backfill, and compaction. Specified line and grade of the sewer must be attained by providing full support along and around the pipe barrel.

Companion specifications include:

- *ASTM C 12, Installing VCP Lines*
- *ASTM C 301, Standard Test Methods for VCP*
- *ASTM C 828, Low-Pressure Air Test of VCP Lines*
- *ASTM C 896, Standard Definitions of Terms Relating to Clay Products*
- *ASTM C 1091, Hydrostatic Infiltration Testing of VCP Lines*

The trade association for VCP is the National Clay Pipe Institute (NCPI); contact information for NCPI is found in Appendix B. For additional information about installation of VCP, refer to the *Clay Pipe Engineering Manual* and the *Clay Pipe Installation Handbook*, both published by NCPI.

16.2 SHIPPING AND HANDLING

16.2.1 Marking

Each length of pipe shall bear the initials or name of the manufacturer and the location of the plant. The words “Extra Strength” or the symbol “ES” shall be included, when applicable, to identify the class of the pipe. The markings shall be plainly legible for identification.

16.2.2 Delivery

Pipe sizes 4 in. through 12 in. (100 through 305 mm) are usually palletized for delivery. Larger sizes are secured on delivery trucks on timbers (raggle boards), which have notches cut to match the outside diameter of the pipe. The pipe supplier or the constructor may unload the pipe (depending upon the agreement between the two parties) from the delivery trucks at the job site. In any event, VCP can be safely handled with a lift truck or a crane, using a J hook, canvas sling, or wire cable sling with a choker to prevent the pipe from slipping. In the manufacturing plant, the forks on front-end loaders used to move pipe are covered with rubber, polyurethane, or other soft material to prevent damage to the pipe during transport. The inspector is advised that the forks on front-end loaders used to unload or move pipe on the job site should also be padded to prevent damage to the pipe.

16.2.3 On-Site Inspection and Storage

An inspector must constantly check the condition of pipe delivered. Occasionally, pipe is bumped and nicked during loading, shipping, and unloading. The inspector should examine delivered pipe to ensure that pipe damaged during delivery, handling, and storing is not installed.

When pipe is stored along the trench, adequate set-back must be provided between the pipe and the edge of the trench. Set-back must comply with all federal, state, and local requirements. Usually, 2 ft (0.6 m) is adequate, but deep trenches and unstable trench walls that could collapse may require greater set-back.

When pipe is stored at the job site or temporarily stored at the edge of the trench, the spigot end of bell and spigot pipe, or the coupling of plain end pipe, should be elevated on a piece of timber (raggle board) or a small, temporary earth mound to prevent the joint material from contacting the ground and carrying the weight of the pipe. Also, the pipe should be lifted carefully when moved so the joint material is not dragged along the ground and thereby damaged.

16.3 INSTALLATION

16.3.1 Pipe Support

The ability of VCP to carry trench load depends on pipe strength, bedding, trench width and depth, soil weight, and soil type. The design engineer's specifications for providing uniform support of the pipe barrel on a firm foundation must be followed.

The pipe may be laid on a flat trench bottom of suitable undisturbed native material or, in the case of overexcavating, on a restored flat bedding base. In either case, the bottom of the entire pipe barrel shall have continuous and uniform support.

When a bedding material is used, the bottom of the trench must be overexcavated. The proper amount of bedding material is then placed and compacted, if required, to achieve specified grade. The inspector must verify that the bedding material and compaction meet the requirements specified. The depth of the bedding material must be at least one-eighth of the pipe outside diameter (OD), but in no case less than 4 in. (100 mm) unless modified by the specifications.

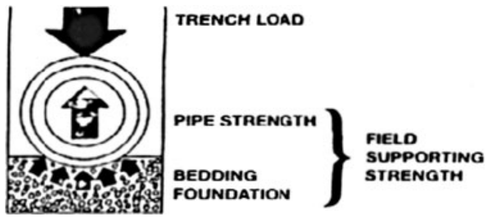

Figure 16-1. Pipe field support strength. Courtesy the National Clay Pipe Institute.

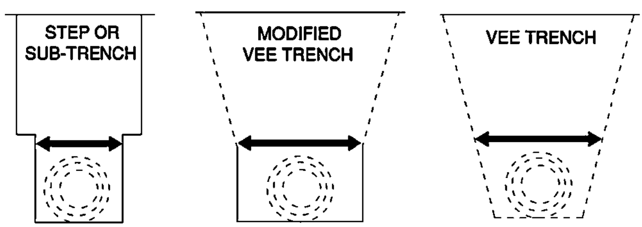

Figure 16–2. Trench shapes. Courtesy the National Clay Pipe Institute.

Bell or coupling holes must be dug so that the load is equally supported by the pipe entire barrel, and never only by the pipe bell or coupling. Bell holes must be no larger than necessary to ensure that the pipe barrel is resting firmly and evenly on the trench bottom or bedding material.

The engineering specifications and/or contract drawings will indicate the type of bedding detail for installing the pipe in the trench. The design engineer uses a bedding factor based on the specified bedding to compute the load-bearing capacity of the pipe. The field supporting strength of the pipe consists of the pipe's bearing strength increased by the support of the bedding specified (Fig. 16-1).

The design engineer has given careful consideration to the selection of a bedding factor to support the calculated trench load. Therefore, the inspector must verify that the constructor does not exceed the design trench width and that the constructor places the bedding material according to the project specifications.

The inspector should note that the trench shape—step or subtrench, vee or modified vee—does not determine imposed load (Fig. 16-2). The load on VCP, as with any rigid pipe, depends on trench width at the top of the pipe. The inspector must physically measure the trench width at the top of the pipe frequently, rather than "eye-balling" or guessing the width. In the event the trench width is wider than specified, the inspector must promptly inform the design engineer.

16.3.2 Case History

Because trench width is critical, a case history is offered for review.

A sewer project called for 24-in. (610-mm) VCP to be installed with 20 ft (6 m) of cover, trench width 48 in. (1,220 mm), Class B bedding, and sand and gravel backfill with a weight of 130 lb/ft^3 (2,082 kg/m^3). A bridge would later be constructed above the sewer. The load on the pipe was calculated to be 5,188 pounds per linear foot (7,720 kg per liner meter). The projected safety factor was 1.76. However, the constructor installed the pipe in a 60-in. (1,525-mm)-wide trench, which reduced the safety factor to 1.24.

The bridge contractor moved in to build the bridge. He deposited another 24 ft (7 m) of soil upon which to pour the concrete for the bridge, over the just-installed sewer. The resulting cover was 44 ft (13.5 m). The safety factor was further reduced to less than 1.0 and the pipe was in an overload condition. Had the original installation been placed in the specified 48-in. (1,220-mm)-wide trench, the safety factor, taking into account the added load, would have been 1.45.

16.3.3 Pipe Joining

The manufacturer's recommendations for pipe assembly must be closely followed. The inspector should note that debris on the mating surfaces of the joint may result in improper assembly.

With couplings or factory-applied flexible compression joints, care must be taken to wipe the mating surfaces clean before lubricating and joining. For bell and spigot pipe, lubricate both joint surfaces with lubricant provided by the pipe supplier, line up the socket and spigot, and push the pipe together with a steady pressure. For small-diameter pipe, this assembly can be done by hand (Fig. 16-3).

When using a bar to push the pipe together, care must be taken not to damage the lip of the socket or coupling. A wood block may be used to

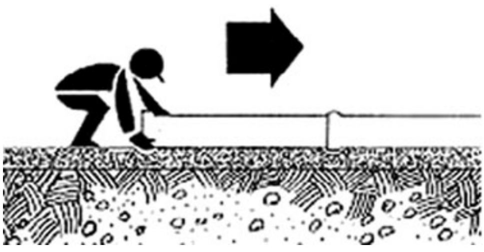

Figure 16-3. Pipe joint assembly by hand. Courtesy the National Clay Pipe Institute.

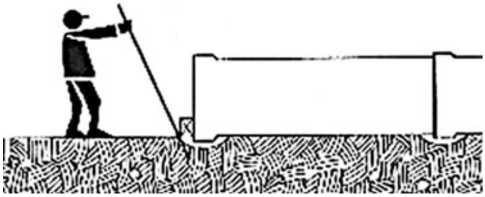

Figure 16-4. Pipe joint assembly using bar and wood-block cushion. Courtesy the National Clay Pipe Institute.

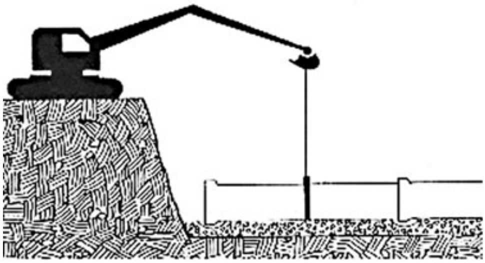

Figure 16-5. Pipe joint assembly using a sling. Courtesy the National Clay Pipe Institute.

cushion the bar pressure (Fig. 16-4). As an alternate to barring the pipe home, a come-along may be used to pull the joint together.

For large-diameter pipe, a sling or other approved device can be used to lower the pipe and aid in assembly (Fig. 16-5).

16.3.4 Bedding and Initial Backfill

After laying the pipe, additional bedding material, if required, is placed to the height shown in the contract details. The initial backfill material is then carefully placed to a minimum height of 12 in. (305 mm) above the top of the pipe.

The bedding (or initial backfill material, depending upon bedding detail) must be sliced into the haunch area of the pipe to fill the voids and consolidate the material in this area. Proper consolidation of the material ensures uniform support of the pipe haunch, which will produce the required bedding factor. To be effective, slicing must be done when the bedding or initial backfill material is no higher than about one-fourth of the pipe OD (Fig. 16-6). Initial backfill should be free of lumps or stones larger than 1 in. (25 mm).

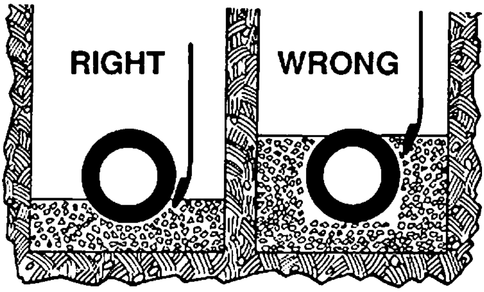

Figure 16-6. Slicing backfill into the haunch. Courtesy the National Clay Pipe Institute.

16.3.5 Fittings

The basic principles for constructing and inspecting mainline sewers should also be applied to the laying of the service lines to each property (building sewers and house connections). They should be considered as a part of the overall sewage system and constructed with the same care as mainline sewers. Fittings should be positioned and supported by carefully tamping the bedding around and into the haunch area of the fitting. Special attention should be given to provide uniform support under both the mainline barrel of the fitting and the spur.

16.3.6 Final Backfilling

Final backfilling is normally done in layers and should be done to meet the specification requirements. Often, a front-end loader or a bulldozer is used to push the backfill material into the trench at an angle to minimize impact on the pipe. No clump or stone larger than 6 in. (150 mm) should be allowed in the backfill within 5 ft (1.5 m) of the top of the pipe.

16.3.7 Compaction

The engineering specifications may call for compaction of the backfill material. The degree and method will be specified to minimize settlement of the pavement subgrade. Any method of compaction used to achieve the specified density should be done under the direction of the design engineer. Suitable compaction equipment must be selected with care.

A minimum of 5 ft (1.5 m) of cover over the top of VCP is usually required before any heavy-duty mechanical compaction equipment is employed. This cover will reduce dangerous impact loads on the pipeline. A pavement-breaking type of falling weight "stomper," or drop hammer, must never be used for compacting backfill, even with a substantial cover over the pipe.

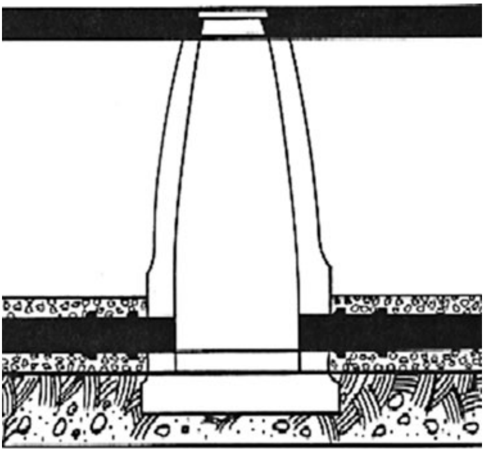

Figure 16-7. Short pipe stubs at a manhole. Courtesy the National Clay Pipe Institute.

16.3.8 Manholes

The inspector must become familiar with the specified details for manhole construction. Manholes should be installed on an unyielding foundation. Settlement of the manhole can cause shearing of the adjacent pipe. Short stubs with flexible compression joints or flexible rubber seals should be used at the manhole walls to allow minor differential settlement to occur without developing shear forces (Fig. 16-7).

16.4 FINAL TESTING

Final testing is normally required to prove proper workmanship. The inspector must become familiar with the particular testing outlined in the design engineer's project specifications. Line and grade of the pipe must be checked. Testing may be done by one of three methods: low-pressure air, hydrostatic infiltration, or hydrostatic exfiltration. The testing procedures specified must be carefully read and followed. If careful attention has been given to specifications and construction details, the commonly specified test procedures will present few difficulties.

Flexible compression joints or flexible rubber seals should be used at the manhole walls to allow minor differential settlement to occur without excessive shear forces in the pipe.

Careful engineering design and quality pipe are not enough to ensure a successful pipeline. Attention to detail in the pipe installation by the constructor and inspector is essential to provide a trouble-free, permanent sewer line.

CHAPTER 17

POLYVINYL CHLORIDE PIPE

17.1 GENERAL BACKGROUND AND DISCUSSION

17.1.1 Applications

Polyvinyl chloride (PVC) is a popular pipe material for many pressure and nonpressure applications because of its desirable combination of characteristics, including chemical resistance, long-term strength, and high stiffness. The use and availability of PVC pipe has grown steadily. This chapter is devoted to the discussion of gasketed PVC pipe within the major markets of pressure and nonpressure sanitary sewer and water distribution.

More recent technological advancements have allowed the PVC pipe industry to expand production to include larger pipe diameters. As a result, PVC pipe has been successfully introduced to several other buried pipe applications, including gravity storm sewers, highway drainage, agricultural drainage, and larger-diameter pressure transmission pipe.

17.1.2 Product Information, Trade Associations, Standards

Many standard specifications relate to PVC pipe. The standards listed below pertain to product specifications for gasketed PVC pipe and fittings in major markets. The national consensus standards groups that authored these standards are the American Association of State Highway and Transportation Officials (AASHTO), ASTM (formerly the American Society for Testing and Materials), and the American Water Works Association (AWWA). The Uni-Bell PVC Pipe Association, formed in 1971, funds PVC pipe research and development, provides technical service and support, develops recommended standards, and promotes proper use of PVC pipe with gasketed joints.

Contact information for all these organizations is found in Appendix B.

AASHTO Gasketed PVC Pipe and Fittings Standards:
- *AASHTO M 278, Class PS-46 Polyvinyl Chloride (PVC) Piping Systems for Subsurface Drainage of Transportation Facilities*
- *AASHTO M 304, Polyvinyl Chloride (PVC) Profile Wall Drain Pipe and Fittings Based On Controlled Inside Diameter*

ASTM Gasketed PVC Pipe and Fittings Standards (Nonpressure):
- *ASTM D 3034, Standard Specification for Type PSM Poly (Vinyl Chloride) (PVC) Sewer Pipe and Fittings*
- *ASTM F 679, Standard Specification for Poly (Vinyl Chloride) (PVC) Large-Diameter Plastic Gravity Sewer Pipe and Fittings*
- *ASTM F 794, Standard Specification for Poly(Vinyl Chloride) (PVC) Profile Gravity Sewer Pipe and Fittings Based on Controlled Inside Diameter*
- *ASTM F 789, Standard Specification for Type PS-46 and Type PS-115 Poly (Vinyl Chloride) (PVC) Plastic Gravity Flow Sewer Pipe and Fittings*
- *ASTM F 949, Standard Specification for Poly (Vinyl Chloride) (PVC) Corrugated Sewer Pipe With a Smooth Interior and Fittings*
- *ASTM F 1803, Standard Specification for Poly (Vinyl Chloride) (PVC) Closed Profile Gravity Sewer Pipe and Fittings Based on Controlled Inside Diameter*

ASTM Gasketed PVC Pipe Standards (Pressure):
- *ASTM D 2241, Standard Specification for Poly (Vinyl Chloride) PVC Pressure-Rated Pipe (SDR Series)*
- *ASTM F 1483, Standard Specification for Oriented Poly (Vinyl Chloride) PVCO Pressure Pipe*

AWWA Gasketed PVC Pipe and Fittings Standards:
- *ANSI/AWWA C 900, Polyvinyl Chloride (PVC) Pressure Pipe and Fabricated Fittings, 4- through 12-inch (100- through 300- mm) for Water Transmission and Distribution*
- *ANSI/AWWA C 905, Polyvinyl Chloride (PVC) Pressure Pipe and Fabricated Fittings, 14- through 48-inch (350- through 1,200-mm) for Water Transmission and Distribution*
- *ANSI/AWWA C 907, Polyvinyl Chloride (PVC) Pressure Fittings for Water, 4- through 12-inch (100- through 300-mm)*
- *ANSI/AWWA C 909, Molecularly Oriented Polyvinyl Chloride (PVCO) Pressure Pipe, 4- through 24-inch (100- through 600-mm) for Water Distribution*
- *AWWA M 23, PVC Pipe Design and Installation*

Installation Standards for PVC Pipe:

- *ASTM D 2321, Standard Practice for Underground Installation of Thermoplastic Pipe for Sewers and Other Gravity-Flow Applications*
- *AWWA C 605, Underground Installation of Polyvinyl Chloride (PVC) Pressure Pipe and Fittings for Water*

17.2 RECEIVING, STORAGE, AND HANDLING

17.2.1 Receiving Inspection

When receiving the PVC pipe shipment at the job site, the constructor or purchaser should exercise established precautions. The following procedures are suggested as common practices to prevent problems. Each pipe shipment should be inventoried and inspected with care upon arrival. The pipe was inspected and loaded with care at the factory using methods acceptable to the carrier. The carrier is responsible for delivering the shipment in good condition. The recipient is responsible for ensuring that no loss or damage has occurred.

The records accompanying each shipment provide a complete list of all items shipped. Items should be checked against the records. Report any errors to the carrier immediately and make proper notation on the delivery receipt.

The following procedures for acceptance of delivery are recommended:

- Examine the overall condition of the load. If the load is intact, ordinary inspection while unloading should be sufficient to ensure that the pipe has arrived in good condition.
- If the load has shifted, has broken packaging, or shows rough treatment, carefully inspect each piece for damage.
- Check total quantities of each item against shipping records (pipe gaskets, fittings, lubricant, etc.).
- Note damaged or missing items on the delivery receipt, notify the carrier immediately, and make claims in accordance with their instructions.
- Do not dispose of damaged material; follow the carrier's instructions regarding handling of such material.
- Shortages and damaged materials are normally not reshipped without request and authorization. If replacement material is needed, reorder from the manufacturer's distributor or representative.

17.2.2 Storage

The constructor should identify storage sites prior to ordering material. Piping products often sustain damage during storage. The following procedures and practices are recommended to prevent damage to PVC pipe:

- If possible, store pipe at the job site in unit packages provided by the manufacturer. Avoid compression, damage, or deformation to bell ends of the pipe. Note that PVC pipe in unit packages often has bell ends arranged alternately with pipe spigots.
- When stacking unit packages of PVC pipe, ensure that the weight of upper units does not deform pipe in lower units and that the height of the stack does not result in instability, which could cause stack collapse, pipe damage, or personnel injury.
- Support PVC pipe unit packages using racks or dunnage (support racks from the shipping carrier) to prevent damage to the bottom during storage. Space supports to prevent pipe bending.
- When exposure to direct sunlight for more than 2 years is unavoidable, cover PVC pipe with an opaque material that will permit adequate air circulation above and around the pipe as required to prevent excessive heat accumulation.
- Do not store PVC pipe adjacent to heat sources or hot objects such as heaters, boilers, steam lines, engine exhaust, etc.
- Keep the interior and all sealing surfaces of pipe, fittings, and other accessories free from dirt and foreign matter.
- Protect gaskets from excessive exposure to heat, direct sunlight, ozone, oil, and grease. Store solvent cement in tightly sealed containers away from excessive heat.

17.2.3 Handling

The recipient is responsible for determining the means by which PVC pipe is unloaded in the field. The preferred method involves unloading in package units using mechanical equipment; however, the pipe can be unloaded individually by hand. When unloading package units, follow these instructions carefully:

- Remove restraints from the top unit loads.
- Remove boards across the top and down the sides of the load that are not part of pipe packaging.
- Using a forklift or front-end loader equipped with thin chisel forks, extend forks to remove each top unit (one at a time) from the truck. Remove rear units first. To prevent damage to adjacent units, do not run the forks too far under the units. Ensure that the forks are fully engaged.
- If a forklift is not available, use a spreader bar with fabric straps capable of handling the load [with straps spaced about 8 ft (2.5 m)

apart and looped under the load]. Cables may also be used if cushioned with rubber hose sleeves or other material to prevent abrasion.
- Pipe units must never strike anything. Severe impact could cause damage (particularly during cold weather).

Cautions:
- Do not handle units with individual chains or single cables, even if padded.
- Do not attach cables to unit frames or banding for lifting.
- Place and store pipe package units on level ground.
- Do not stack package units more than 8 ft (2.5 m) high. Protect units with dunnage in the same way they were protected while loaded on the truck.
- Unload lower units using the unloading process described above.

If unloading equipment is not available, unload pipe by removing individual pieces. Standard procedures for preventing damage to PVC pipe during handling are as follows:

- When handling PVC pipe, avoid severe impacts, abrasion damage, and gouging or cutting by metal surfaces or rocks. Avoid stressing bell joints and damaging bevel ends.
- Always lower the pipe from trucks and into trenches. Never drop pipe from trucks and into trenches.
- In preparation for pipe installation, place (string) pipe as close to the trench as practical and on the opposite side from excavated earth. Point bell ends in the direction of work progress.
- Impact damage is more likely to occur in subfreezing temperatures. Handling techniques considered acceptable at warm temperatures may cause damage at very cold temperatures. When handling PVC pipe in cold weather, consider the variation in the pipe's impact strength. The impact strength of PVC pipe at 0 °F (–18 °C) equals and sometimes exceeds the impact strength of most other pipe products; however, unlike some other materials, PVC pipe's impact strength at 0 °F (–18 °C) is lower than its impact strength at 73 °F (23 °C).

17.3 INSTALLATION

17.3.1 Pipe Joint Assembly

Gaskets may be supplied separately or may come with the pipe; refer to the manufacturer's literature for more information. When gaskets are

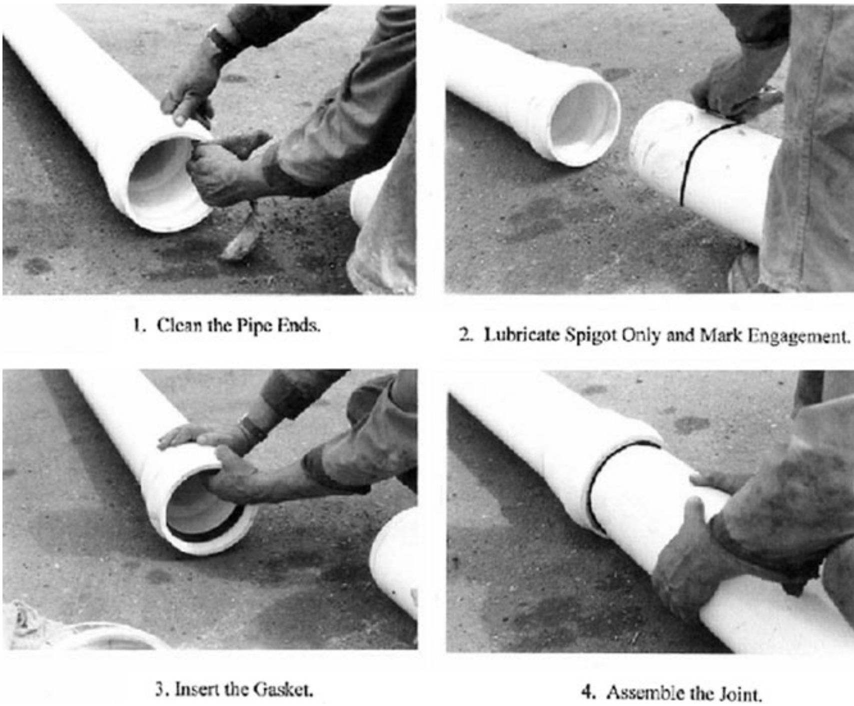

Figure 17-1. Joint assembly procedures. Courtesy of the Uni-Bell PVC Pipe Association.

supplied separately, ensure they are clean and dry before insertion into each bell groove. Wipe each gasket groove and spigot clean and dry before assembly. When gaskets are already installed in the pipe, wipe the gaskets, the groove area behind the gasket, and the pipe spigot ends clean. Check each gasket to allow uniform insertion into the race. Do not remove the gaskets from the race for cleaning.

Apply lubricant to the spigot bevel and about mid-way back to the insertion line. Do not apply lubricant inside the bell. Use only lubricants supplied or recommended by the manufacturer (Fig. 17-1).

If joint assembly proves difficult, disassemble and examine the gasket. Be sure the gasket is properly seated and both pipe lengths are aligned. Repeat assembly steps. Correct assembly is achieved when the insertion line on the spigot is even with the lip of the bell.

The bar and block method shown in Fig. 17-2 is recommended because the worker can feel the amount of force being used and whether the joint goes together smoothly. Larger pipe may require mechanical assistance to apply sufficient assembly force. Ensure that the spigot is not overinserted and that previously assembled pipe joints are also not disturbed

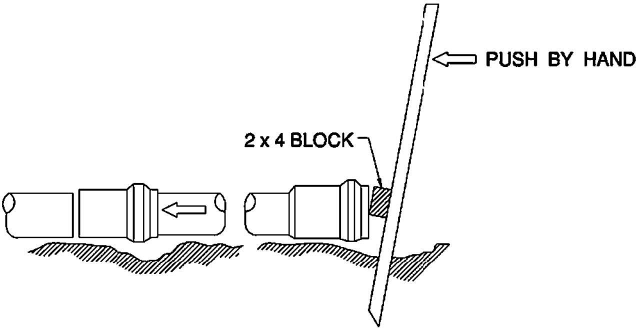

Figure 17-2. Bar and block joint assembly method. Courtesy of the Uni-Bell PVC Pipe Association.

and pushed-in beyond the marks on the other spigot ends. In all cases, good alignment of the pipe is essential for proper assembly. Pipe misalignment, overinsertion, or excessive assembly force can cause rolled gaskets, split bells, acceptance testing failure, and damage to previously assembled joints.

17.3.2 Trench Construction and Pipe Placement

Detailed installation guidelines are available from the manufacturer, Uni-Bell literature, or from national consensus standards. Pressure pipe guidelines are available in *AWWA C 605*; gravity sewer pipe recommendations are available in *ASTM D 2321*. The following information is only a guide and is given as a summary.

Trench Excavation: Excavate trench as required for the specified alignment, depth, and width. Protect workers with sheeting and trench boxes in hazardous areas and slope walls in dry soils. When moving sheeting or trench boxes, ensure the pipe is not moved and the side support material is not disturbed.

Stockpiling Excavated Material: Clean trenches save time and money. Do not let excavated material block sidewalks, drives, or utility outlets. Follow all safety rules and regulations.

Dewatering: Keep the trench as dry as possible until pipe has been installed and enough backfill has been placed to prevent pipe from floating. PVC pipe will float if not filled with water or weighted. The height of loose backfill material required to prevent empty pipe flotation equals 1.5 times the pipe diameter. Provide water quality and quantity control per specifications.

Preparation of Trench Bottom: Construct the trench bottom so as to provide a firm, stable, uniform support for the full length of the pipe.

Provide bell holes at each joint to permit proper joint assembly and pipe support. When an unstable subgrade condition is encountered (one that will not provide adequate pipe support), excavate additional trench depth and backfill with suitable foundation material per specifications. Remove ledge rock, boulders, and large stones to provide 4 in. (100 mm) of soil cushion on all sides of the pipe and accessories.

Pipe Laying: Pipe is usually laid with bells facing the direction in which work is progressing; however, this practice is not mandatory. For example, when laying pipe on a slope, pipe is frequently laid with the bells facing uphill for ease of installation. When pipe laying is not in progress, close open ends of installed pipe to prevent trench water, dirt, debris, and animals from entering the pipe.

Field Cutting: PVC pipe can be easily field-cut with (depending on pipe diameter) a hacksaw, hand saw, or a power hand saw with a steel blade or abrasive disc. Proper joint assembly requires a square field cut; therefore, pipe should be marked around its entire circumference prior to cutting. Use a factory-finished beveled end as a guide for proper bevel angle and depth. Bevel the pipe end with a wood rasp, pipe beveling tool, portable sander, or abrasive disc saw. Round off sharp edges on the leading edge of the bevel with a pocket knife or a file. Re-mark the insertion line using a factory marked pipe of the same size and class as a guide.

Changes in Direction: Changes in direction do not always require elbows, sweeps, or other fittings. Changes in direction may be accomplished through deflection at the joint or by longitudinally bending the pipe. Either method may be used but not both on the same length of pipe.

- *Joint deflection:* Allowable joint deflection depends on the pipe size and joint design. The pipe manufacturer can supply joint deflection limits.
- *Allowable bending:* PVC pipe can accommodate controlled bending within acceptable limits. A general rule of thumb for the minimum bending radius (Rb) is Rb = 300 OD. Tighter bending radii may be achieved for certain products. Consult the manufacturer for specific recommendations. In most cases, bending can and should be accomplished manually.

Trench Terms: Common terms used in pipe installation are illustrated in the trench cross section shown in Fig. 17-3. These may be contrasted with those in Fig. 6–2 in Chapter 6.

Pipe Embedment: Install PVC pipe so as to provide uniform longitudinal support under the pipe. Work embedment material under the sides of the pipe to provide satisfactory haunching. Place initial backfill a sufficient height over the top of the pipe for impact protection during

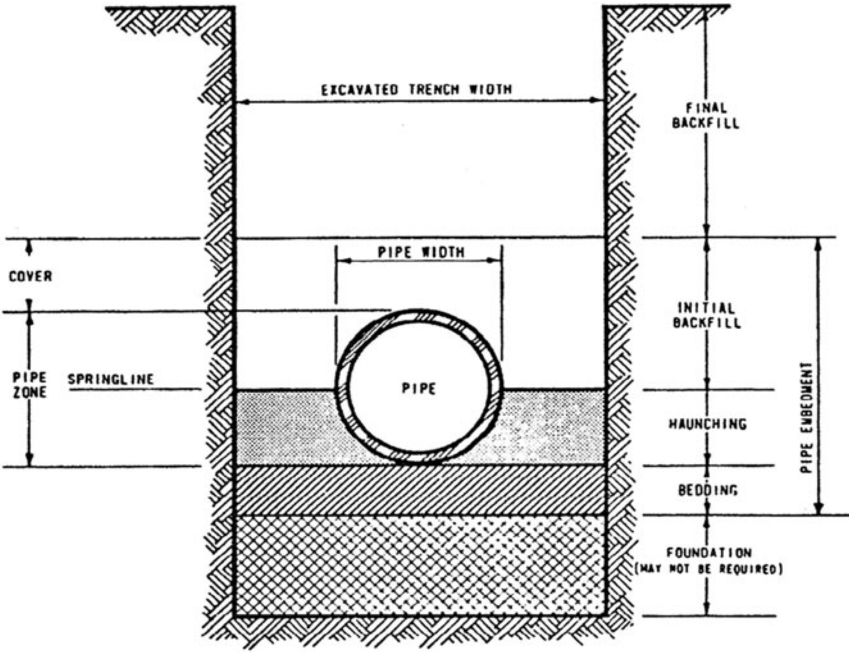

Figure 17-3. Trench cross section. Courtesy of the Uni-Bell PVC Pipe Association.

final backfill. Select, place, and compact embedment materials per the specifications.

Final Backfill: Avoid using large rocks [larger than 4 in. (100 mm)], clumps of frozen soil, rubble, and other such material in the final backfill. The originally excavated material generally can be used and should be compacted as specified by the engineer.

17.3.3 Specific Considerations for Pressure Pipe

Joint Restraint or Thrust Blocking: Provide concrete reaction, thrust blocking, or mechanical thrust restraint devices at each hydrant, valve, bend, tee, plug, dead-end, and at reducers or fittings where changes occur in pipe diameter or direction. Joint restraint devices, if specified, should meet the requirements of *ASTM F 1674*. Inspect each joint restraint device before backfilling.

Service Connections: Service connections vary in size from small services supplying individual homes to large outlets for industrial users. Service connections to PVC water mains are accomplished in the field using the following methods:

- *Direct tapping:* PVC municipal water mains manufactured in accordance with *AWWA C 900* in nominal sizes 6-in. through 12-in. (150-mm to 305-mm), DR14 and DR18; service connections of 1 in. (25 mm) or smaller may be tapped using direct tapping.
- *Tapping through service clamps/saddles:* All PVC pipe sizes and classes may be tapped using service clamps or saddles. Maximum outlet size with a service clamp or saddle is 2 in. (50 mm).
- *Tapping with large service connection through tapping sleeves and valves:* Tapping sleeves and valves are used when service connections larger than 2 in. (50 mm) (and up to size-on-size) are made in a PVC water main.

Tapping PVC pressure pipe is simple and safe when using the appropriate tools and procedures. The references listed below detail recommended tools and procedures for tapping PVC pipe.

- Uni-Bell tapping video, *Tapping of PVC Pressure Pipe*. English, French, Spanish; available from Uni-Bell PVC Pipe Association.
- *UNI-PUB-8, Tapping Guide for PVC Pressure Pipe*, available from Uni-Bell PVC Pipe Association.
- *UNI-B-8, Recommended Practice for the Direct Tapping of Polyvinyl Chloride (PVC) Pressure Pipe*, available from Uni-Bell PVC Pipe Association.
- *Handbook of PVC Pipe: Design and Construction*, available from Uni-Bell PVC Pipe Association.
- *AWWA C 605, Underground Installation of Polyvinyl Chloride (PVC) Pressure Pipe and Fittings for Water*, Section 6.4, "Service Connections."

17.3.4 Specific Considerations for Nonpressure Pipe

Manhole Connection: Proper manhole connections are essential to good system performance. The following precautions are recommended:

- Prepare a stable foundation and place bedding for each manhole and connecting pipe to prevent shifting, which could damage the connection.
- Use a waterstop gasket produced from elastomeric material, which prevents leakage while allowing longitudinal pipe movement.
- Use a nonshrinking or expansive type grout for connecting pipe and waterstop to manhole walls.

Deep Risers: Proper installation of deep risers will minimize vertical forces applied to the main line sewer caused by soil settlement

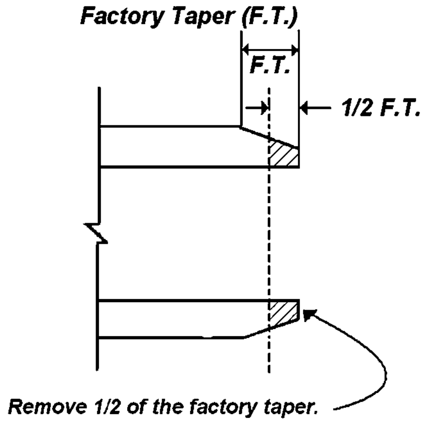

Figure 17-4. Creating a blunt taper for risers. Courtesy of the Uni-Bell PVC Pipe Association.

around the riser stack. The following installation procedures are recommended:

- Do not drop the riser straight into the top of the main line. Rather, install the riser against the trench wall, using an elbow to reach the mainline tee or wye.
- Prepare uniform support at the riser pipe connection by providing uniform bedding with good compaction all around and up the pipe.
- Achieve good compaction in the haunching from the base to the springline of the fitting and sewer line, using select material if necessary.
- Use blunt tapers where possible to help prevent riser settlement into the fittings. A blunt taper is shown in Fig. 17-4.

Soil Migration: Take into consideration the prevention of soil migration where conditions are such that running or standing water occurs in the trench or where substantial seasonal water table changes are expected. Materials used for underdrains, bedding, or haunching should be of proper gradation and thickness to prevent migration of material between the underdrain, pipe embedment, and native soils in the trench and at the sides of the pipe.

Overexcavation: Maintaining the specified pipe grade or profile is essential to good system performance. Where overexcavation does occur, the elevation must be raised at least over entire pipe lengths to ensure proper pipe support and to prevent sagging between joints.

17.4 INSPECTION AND TESTING

17.4.1 Inspection and Testing for Pressure Pipe

Good practice dictates pressure testing portions of a line as they are completed in advance of entire system completion. Before testing, backfill and brace the pipeline sufficiently to prevent movement under pressure. Three parts of the line should be considered when testing:

- The pipe to be tested must be sufficiently backfilled to prevent movement while under test pressure.
  - Joint restraint at fittings should be permanent and constructed to withstand test pressure. If using concrete thrust blocks, allow sufficient time before testing to permit the concrete to cure. Cure time of 7 days is recommended when Type I Portland cement is used; 3 days is recommended when Type III high-early-strength Portland cement is used.
- Restrain test ends to withstand the appreciable thrusts developed under test pressure.

Filling the Pipeline: Fill slowly from any available source of potable water. The water may be introduced from lines in service through valved connections, temporary connections to hydrants, taps made in the new line, or at the connection in the line cap. The use of existing lines as a source of water to fill the line requires a backflow prevention device downstream from the valve or tap. Make all such connections at the lowest point in the line if possible. Where testing a portion of a line that has not yet been tied to the final course, some other source of water must be provided. Flow velocity during line filling should not exceed 1 ft/s (0.3 m/sec).

Expelling Air from Pipeline: Expel all air from the pipeline during filling and again before making either pressure or leakage tests. Automatic air release valves are recommended. Compressed, entrapped air can greatly amplify any surges and pumping pressures. Furthermore, entrapped air may cause erroneous pressure test results.

Pressure Testing: A pressure test is intended to locate defects in materials or workmanship and permit proper repair. In a properly designed line, automatic relief valves, slow closing and opening of valves, slow pump starting, and other controls will minimize pressure surges. Test pressure and other testing recommendations are available in installation standard *AWWA C 605*. Do not build up pressures greater than specified by reading pressure at a gauge located at a high point in the line. In such cases, actual pressure at low points will be greater. Pressures greater than those specified may damage equipment and/or move thrust blocks. Maintain specified test pressure for the specified test time while monitoring for pressure loss. Air pressure testing of installed pressure pipe can result in catastrophic failure and should not be performed.

Leakage Testing: The purpose of the leakage test is to establish that the section of line tested, including all joints, fittings, and other appurtenances, will not leak or that leakage is within the limits of the applicable allowance.

Normal operating pressure is usually applied for leakage tests. Maintain pressure at a constant level throughout the test. Measurement of the amount of additional water pumped in during the test provides a measurement of the amount of leakage, if any.

Air trapped in the line during the test will affect results. The project engineer generally establishes leakage allowance and test methods and procedure. If not, Table 17-1 may be used to determine maximum leakage allowable.

Table 17-1. Allowable Leakage for Polyvinyl Chloride Pipe with Elastomeric Joints[a]

Nominal Pipe Size (in.)	Average Test Pressure in Line (psi) 50	100	150	200	250
	Allowable Leakage Per 1,000 ft (305 m) or 50 Joints [U.S. gal/h (L/h)]				
4	0.19 (0.72)	0.27 (1.02)	0.33 (1.25)	0.38 (1.44)	0.43 (1.63)
6	0.29 (1.10)	0.41 (1.55)	0.50 (1.89)	0.57 (2.16)	0.64 (2.42)
8	0.38 (1.44)	0.54 (2.04)	0.66 (2.50)	0.76 (2.88)	0.85 (3.22)
10	0.48 (1.82)	0.68 (2.57)	0.83 (3.14)	0.96 (3.63)	1.07 (4.05)
12	0.57 (2.16)	0.81 (3.07)	0.99 (3.75)	1.15 (4.35)	1.28 (4.84)
14	0.67 (2.54)	0.95 (3.60)	1.16 (4.39)	1.34 (5.07)	1.50 (5.68)
16	0.76 (2.88)	1.08 (4.09)	1.32 (5.00)	1.53 (5.79)	1.71 (6.47)
18	0.86 (3.26)	1.22 (4.62)	1.49 (5.64)	1.72 (6.51)	1.92 (7.27)
20	0.96 (3.63)	1.35 (5.11)	1.66 (6.28)	1.91 (7.23)	2.14 (8.10)
24	1.15 (4.35)	1.62 (6.13)	1.99 (7.53)	2.29 (8.67)	2.56 (9.69)
30	1.43 (5.41)	2.03 (7.68)	2.48 (9.39)	2.87 (10.86)	3.20 (12.11)
36	1.72 (6.51)	2.43 (9.20)	2.98 (11.28)	3.44 (13.02)	3.85 (14.57)
42	2.01 (7.61)	2.84 (10.75)	3.48 (13.17)	4.01 (15.18)	4.49 (17.00)
48	2.29 (8.67)	3.24 (12.26)	3.97 (15.03)	4.59 (17.38)	5.13 (19.42)

[a] PVC pipe with elastomeric joints, when installed in accordance with National Fire Protection Association (NFPA) instructions, complies with the leakage requirements for private fire service mains as specified by the NPFA.

Source: Uni-Bell PVC Pipe Association, *Handbook of PVC Pipe*, 4th ed., 2004. Used with permission.

A properly installed line will normally show little or no leakage using the methods described. A gross leak can usually be traced to a major problem (e.g., missing or dislodged gasket, broken pipe, loose mechanical joint bolts, and inadequate thrust block). These problems normally are readily detectible and quickly repairable. A minor leak greater than allowable limit can be hard to find and repair and may require use of dye in the system. This problem is best prevented during installation by following these procedures:

- Vent all high points; use a corporation stop if air release valves are not required.
- Double- and triple-check all mechanical joint bolted connections.
- Adequately cure thrust blocks before testing.
- Exercise care to clean out gasket grooves if gaskets are not factory-installed. Rain and dust often leave deposits that must be removed from exposed gasket grooves. Ensure that exposed gasket grooves are properly cleaned before inserting gaskets.
- When inserting pipe into a mechanical joint or gasket joint, check that the spigot end is squarely cut and beveled properly for that hub.
- Test the mainline prior to installing services to ensure integrity of the mainline.

Leakage is immediately apparent when installing in backfilled service lines and assemblies under pressure. The following procedure will determine if air is entrapped in a pipeline:

1. Pressurize with water to desired test pressure.
2. Allow pressure to drop to a predetermined level.
3. Measure makeup water required to establish test pressure.
4. Repeat second and third steps.

If the makeup water required filling the line the second time is significantly less than required for the first filling, the line contains air. No significant difference indicates a probable leak.

17.4.2 Inspection and Testing for Nonpressure Pipe

All projects should be tested upon completion and must meet all local and state government requirements. The engineer will designate the locations of tests and extent of the system to be tested, optional methods of testing leakage, alignment, and deflection, and the requirements for recording test results. Sections of sewer pipe that fail to pass tests should have the defects located and repaired or replaced, and should be retested until within specified allowances. Local or state government regulations may require specific methods to achieve repairs.

Precleaning: Prior to other tests, clean all sewer lines by flushing with an appropriately sized sewer-pipe cleaning ball. Precleaning by high-velocity jet or other method may be necessary.

Visual Test: Inspect all sewer lines visually to verify accuracy of alignment and freedom from debris and obstructions. The full diameter of the pipe should be visible when viewed between consecutive manholes. The method of test can be photography, closed-circuit television, or visual lamping with mirrors and lights.

Leakage Test: Test methods suitable for various conditions are low-pressure air exfiltration, water infiltration, or water exfiltration. Low-pressure air exfiltration is recommended. Plugs or caps on branch connections must be secured against blow-off during leakage tests.

Air Testing: The minimum duration permitted for the prescribed low-pressure exfiltration pressure drop between two consecutive manholes should not be less than that specified by the design engineer or required by state or local regulations. Refer to *ASTM F 1417* for more testing details and recommendations.

Infiltration Testing: Infiltration testing is an acceptable method of leakage testing only when the groundwater level is above the top of the pipe throughout the length being tested. The allowable infiltration for any portion of sewer system should be measured by a weir or current meter placed in the appropriate manhole and should not exceed 25 gal/in. of internal pipe diameter per mile per day (4.6 L/mm/km/day), including manholes.

Exfiltration Testing: Exfiltration testing is an acceptable method of testing only in dry areas, or when the line is sufficiently deep and the groundwater level above the pipe is suitably low enough to develop test pressures that exceed the external pressure generated by the level of groundwater above the pipe. The allowable water exfiltration for any length of sewer pipe between manholes should not exceed 25 gal/in. of internal pipe diameter per mile per day (4.6 L/mm/km/day). During exfiltration testing, the maximum internal pipe pressure at the lowest end should not exceed 10.84 psi (74.74 kPa), and the water level inside the manhole should be 2 ft (0.6 m) higher than the top of the pipe or 2 ft (0.6 m) higher than groundwater level, whichever is greater.

Deflection Testing: Deflection testing may be required even when using proper construction practices and inspection during pipe installation and when using embedment material that has been properly selected, placed, and compacted. Locations with excessive deflection should be repaired by rebedding or pipe replacement. The most common deflection testing device is a go/no-go mandrel. A properly sized go/no-go deflection mandrel must meet the project specifications. Accurate testing requires thoroughly cleaned pipe and testing performed 30 days after the trench has been backfilled.

Deflection testing procedures outlined in this manual were first standardized by ASTM in 1981 with the publication of *ASTM D 3034–81, Standard Specification for Poly (Vinyl Chloride) (PVC) Sewer Pipe and Fittings*.

CHAPTER 18

POLYETHYLENE PIPE

18.1 GENERAL BACKGROUND AND DISCUSSION

18.1.1 Description

Polyethylene (PE) pipe was first produced in 1948 and has since become widely used for many types of pipe conveyance, including water, sewage, and natural gas. These applications require carefully engineered design and manufacturing, because, whether pressurized or not, piping systems must endure long-term stresses without failure. Proper installation practices will also contribute to this endurance.

The raw material for PE pipe is commonly plastic, either medium-density polyethylene (MDPE) or high-density polyethylene (HDPE). Key physical characteristics of both these materials include toughness, ductility at low temperatures, fatigue resistance, and bending flexibility. The specification for the raw material formulation is given in *ASTM Standard D 3350*, *Standard Specification for Polyethylene Plastic Pipe and Fittings Materials*. This specification describes properties of the various plastic resin materials that provide the required properties and are identified by the term *cell classification*.

Cell classification for resins is described by classification symbols. For example, MDPE might be identified as a 234343E resin, and HDPE might use 345464C. Each digit or letter in the cell classification represents a range of physical property values that resin must exhibit during actual testing. The classification series of numbers and letters refers to material properties in the following order: (1) density, (2) melt index, (3) flexural modulus, (4) tensile strength at yield, (5) environmental stress crack resistance, (6) hydrostatic design basis, and (7) color and ultraviolet (UV) stabilizer additives used. These properties are all important in the engineering design of PE pipes.

Low concentrations of carbon black are added to PE material to provide UV resistance. For specific applications, manufacturers may differentiate intended services by either producing pipe material in different colors or by including colored stripes on the pipe. For example, blue denotes water pipe; green denotes sewer pipe; red is for fire mains or special conduits; and yellow for natural gas. Drainage pipes often have only the basic black color.

18.1.2 Manufacturing Methods

Two methods are used to manufacture PE pipe, depending on whether the product will be conventionally extruded pipe or profile-type pipe. The extruded pipe has a smooth interior and a solid exterior pipe wall. Profile pipe is smooth inside but has a ribbed or corrugated-like exterior.

Conventionally extruded PE pipe is manufactured using a continuous extrusion process, which controls the outside diameter. PE resin pellets are mixed, melted, and slowly pushed through the extruder by a mixing screw. Molten PE then enters the extrusion dies that form the pipe, followed by expansion of the material against a sizing sleeve by the action of a vacuum pressure applied on the outside of the pipe. As the tube is pulled through the vacuum tank, cooling water is gradually applied to the pipe while maintaining its cylindrical shape. The pipe is imprinted with its appropriate identification or print line and is either coiled or cut to length, depending on customer specification. In this process, the outer diameter (OD) of the pipe is controlled by the sizing sleeves (Fig. 18-1). The inner diameter (ID) varies depending on the specified pipe wall thickness.

In the manufacturing process for profile-type PE pipe, the inside diameter is controlled by a profile extrusion that is continuously wound upon a mandrel. The wall construction allowed by this method produces a geometrically efficient hollow rib design to minimize pipe weight and maximize ring stiffness. Profile-wall pipe can also be produced with a solid wall and may be used for manhole design (Fig. 18-2).

18.1.3 Standards, Trade Associations

PE pipe is manufactured and tested to a variety of well-known standards published by ASTM and AWWA; contact information for these organizations is found in Appendix B. Additional standards may also be used. PE pipe for water distribution and service is manufactured according to:

Figure 18-1. Controlled-outside-diameter HDPE pipes. Reprinted with permission from Performance Pipe, Plano, TX.

- *AWWA C 901, Polyethylene (PE) Pressure Pipe and Tubing, ½ through 3 inches (13 through 76 mm) for Water Service*
- *AWWA C 906, Polyethylene (PE) Pressure Pipe and Fittings <4 through 63 inches for Water Distribution and Transmission*

and meets *National Sanitation Foundation* (NSF) *Standard 6.1*.

Sewer pipes are typically manufactured to meet the requirements of:

- *ASTM F 714, Standard Specification for Polyethylene (PE) Pipe (SDR-PR) Based on Outside Diameter*, or
- *ASTM D 3035, Standard Large Diameter Profile Wall Sewer and Drain Pipe*, and
- *ASTM F 1759, Standard Practice for Design of High-Density Polyethylene (HDPE) Manholes and Subsurface Applications*

18.1.4 Applications

PE pipe, fittings, and custom fabrications are widely used for municipal water, sanitary sewers, and storm sewers. Other applications beyond the

Figure 18-2. HDPE pipe with ASTM F 894 *profile walls, bell-and-spigot jointed. Reprinted with permission from Performance Pipe, Plano, TX.*

scope of this manual include oil and gas gathering, landfill leachate collection, industrial process lines, mining, chemical and hazardous waste lines, as well as electrical and communications conduit. Since the 1960s, PE pipe has been used for municipal underground gas distribution, where it must meet U.S. Department of Transportation (USDOT) standards for fused joint integrity and pipe toughness. PE pipe has found success in the sewer and water markets partly because PE does not rust or corrode and is resistant to the sulfuric acid that commonly occurs in municipal sanitary sewers.

Both conventionally extruded pipe and profile-wall pipe are commonly used for pipeline rehabilitation and new gravity-flow sewer applications. The smooth inside diameter maintains high rates of fluid flow because of its resistance to scale or biological buildup; it has a Hazen-Williams C factor of 150. The use of fused pipe joints eliminates the need for thrust blocking because the joint can carry all end thrust. PE pipe also has a high strain allowance and can withstand the freezing of water inside the pipe. For short-term pressurization, PE pipe has some limited reserve pressure capacities beyond its normal rated pressure, which is helpful during final acceptance testing of pressure piping. This reserve capacity also gives PE pipe the ability to handle higher-than-rated surge pressures.

18.1.5 Product Information

Dimensions and Thickness for Solid Wall Pipe: Solid-wall MDPE and HDPE pipe is available in diameters from 0.5 through 63 in. (12.7 through 1,600 mm) in Iron Pipe Size (IPS) outside diameters. In addition, HDPE pipe is available in Ductile Iron Pipe Sizes (DIPS) outside diameters ranging from 4 to 48 in. (100 to 1,220 mm). Dimensions for solid-wall pipes are given in *ASTM F 714* and *ASTM D 3035*.

Pipe is classified by dimension ratio (DR), which is determined in this manner:

$$\text{DR} = \frac{\text{Outside Diameter (OD)}}{\text{Minimum pipe Wall Thickness}}$$

The DR of solid-wall PE pipe is most important because it controls the internal pressure ratings of solid-wall pipe. Pressure rating is given in standardized tables furnished by each manufacturer of this pipe. For example, DR 9 pipe will contain pressures of 200 psi (1379 kPa); DR 17 pipe will contain a pressure of 100 psi (690 kPa). At 73.4 °F (23 °C), PE pipe can handle an overpressurization due to surge up to 50% of its rated pressure for recurrent surges, and up to 100% of its rated pressure for occasional surges. The DR values may also affect resistance to external loads caused by earth backfills or applied wheel loads.

Dimensions and Thickness Profile Wall Pipe: HDPE profile-wall pipe has a smooth inside diameter and is manufactured to nominal inside diameters from 18 to 120 in. (455 to 3,050 mm). This pipe is commonly used for nonpressure applications using gravity flow, such as sanitary sewers, or low-pressure applications if all pipe joints are welded. Profile-wall pipes are classified by the ring stiffness constant (RSC) (refer to *ASTM F 894*), which is dimensionally equivalent to the inverse of the flexibility factor (FF) and is a measure of stiffness.

RSC should not be confused with the *ASTM D 2412* pipe stiffness. The actual *ASTM D 2412* pipe stiffness may be obtained from Table X1.1 in Appendix X of the HDPE profile-wall pipe specification *ASTM F 894*. The *ASTM D 2412* pipe stiffness can also be determined by dividing the RSC or “Class” by 0.17 times the pipe inside diameter. For example, a Class 40 90-in.-diameter HDPE pipe will have an *ASTM D 2412* pipe stiffness of 40/(0.17 × 90), or 40/12.24, which gives 2.6 psi (18 kPa).

Refer to Section 2.8 in Chapter 2 regarding some of the issues involved when ultra-low-stiffness pipes are installed in stiff beddings such as crushed rock or dense soils.

The expression for ring stiffness constant, RSC, is:

$$\text{RSC} = 6.44\frac{EI}{D_{\text{mean}}}$$

where

E = flexural modulus of the pipe material
I = moment of inertia of the pipe wall
D_{mean} = inside diameter plus two times the wall centroid dimension.

The importance of RSC is, in general, that as the external load on a pipe increases, the value of this factor must also increase. Profile pipes are furnished in RSC classes 40, 63, 100, and 160, and even special classes.

18.1.6 Types of Joints

Several types of PE pipe joints are available for different applications. Conventionally extruded or smooth-wall PE piping products are connected using heat fusion, electrofusion, extrusion welding, and mechanical methods such as flanges, metal or plastic compression couplings, and mechanical joints. Profile-wall pipe may be jointed with gasketed bell and spigot joints for gravity flow applications, or with extrusion-welded or butt-fused joints for low-pressure applications. These methods vary depending on system pressure, construction requirements, installation limitations, leaktightness, thrust load capacity, and, of course, the type of product used. Flanged stub end connectors and mechanical connectors such as mechanical joint adaptors can also be used to join PE to other piping materials such as ductile iron and cast iron.

Heat fusion jointing is made by three common methods: butt fusion, socket fusion, and saddle fusion (Fig. 18-3).

In *butt-fusion joining*, PE pipe ends are cleaned, faced, melted, and then pressed together by a mechanical device that maintains constant contact

Figure 18-3. Joining HDPE pipe by heat fusion. Reprinted with permission from Performance Pipe, Plano, TX.

pressure until the joint has cooled. Proper fusion requires the use of special fusion machines and heaters, which control the temperature and pressure during butt fusion. Information regarding the proper temperature and pressure settings may be obtained from the equipment or pipe manufacturer. The Plastic Pipe Institute publishes a generic fusion procedure that most manufacturers follow. When correctly performed, the fusion joint has an equal or a higher tensile strength than the pipe.

Socket fusion is used primarily for connecting tubing or small pipes to fittings, especially for small branch or service connections. One end fitting is a female socket end that accepts the other pipe end. Both ends are melted and the pipe is pushed into the socket.

Saddle fusion is mainly used to fuse service saddles, branch saddles, or tapping tees onto a main line.

Extrusion welding is typically used to field join profile-wall pipes and to manufacture large structures for low-pressure or nonpressure service, such as PE manholes, tanks, large-diameter pipe fittings, dual containment systems, and odor control structures. This jointing method uses a small, hand-held extruder that feeds molten PE onto a preheated PE pipe that has been cleaned and scraped to remove oxidation. The extrusion gun preheats the surfaces and then feeds a molten PE bead into the prepared joint area.

Electrofusion is a field or shop heat fusion process in which a coupling or saddle fitting is furnished to contain an integral heat source, usually molded inside electrical resistance heat coils. After surface preparation, the fitting is installed on the pipe and the electrical resistance coil is energized. During heating, the fitting and the pipe materials melt, expand, and fuse together. During the electrofusion process, heating and cooling cycles are automatically controlled. Electrofusion does not require any longitudinal movement of the joint surfaces and is frequently used for repairs on tie-in joints in the trench, where both ends are reinstated.

18.2 SHIPPING AND HANDLING POLYETHYLENE PIPE

18.2.1 Marking

All PE pipes will be marked with manufacturing details: manufacturer's name, nominal diameter size and actual OD, the standard to which it is manufactured, pressure classification, dimension ratio, and tests made. Certain standard specifications will require more specific descriptive data, such as the date of manufacture and equipment used to make the pipe.

18.2.2 Transportation

Depending on size, PE pipe is produced in straight lengths of 40 or 50 ft (12 or 15 m) for conventionally extruded (butt-fused) pipe, and 20 ft

(6 m) for profile-wall pipe using bell and spigot joints. Straight lengths are bundled together in bulk packs or loaded on a truck or trailer in strip loads. Transportation restrictions on length, height, and width usually govern allowable load configurations. Stacking heights should be restricted by the producer or as specified in the following section. Small-diameter pipes [6 in. (150 mm) and smaller] may be available in coils containing several hundred feet of continuous pipe.

18.2.3 On-Site Inspection and Unloading

Manufacturer's instructions must be followed closely when off-loading or handling pipe in any way. Handling hazards occur when pipes roll, fall, or otherwise strike workers. Deflected or coiled pipes can whip around when released from restraints and cause serious injury or loss of life.

Upon delivery of every shipment of PE pipe, the purchaser's inspector should check markings on all pipe, fittings, or prefabricated structures to verify that they have the correct size and dimensioning and are correctly identified by product type or class to meet the specified standards and order specifications. Close inspection is also vital so that damaged pipes will be rejected and sent back to their source. Material that has cuts, deep gouges (10% or more of the wall thickness required for the pipeline's operating pressure), kinks, or fractures should never be accepted. Minor scuffs and scratches will normally not affect the performance of PE pipe, but an experienced inspector or engineer must make this decision.

Improper off-loading from the transporting vehicle may be dangerous if pipes are allowed to roll out of control. PE pipe shipments generally come with warning labels describing the safe way to off-load the pipe and the dangers involved. All warnings must be observed. Unnecessary personnel should stay away from the loading/unloading area.

Pipe, fittings, and structures must never be rolled or pushed off the truck. This practice will damage the pipe and place nearby workers at serious risk. Heavy pipes, profile-wall pipes, and large structures (which are often shipped individually) as well as any coiled pipes must be unloaded with the use of a wide web fabric sling or a spreader bar for lengths of pipe greater than 20 ft (6 m). Wire rope slings and chains can damage the pipe and should never be used. Forklifts can be used to unload shipments, but care must be taken to avoid damaging or gouging the pipe with the forks. Even when the pipe bundles are safely on the ground, the pipes may roll free when the banding is cut.

18.2.4 Storage

The size and complexity of the project and components will determine how to best provide practical storage location for pipe supply. General

Table 18-1. Stacking Height For Different Sizes of Pipe

Pipe Size (in.)	Stacking Height (Rows)	
	DR Above 17	DR 17 and Below
4	15	12
5	12	10
6	10	8
8	8	6
10	6	5
12	5	4
14	5	4
16	4	3
18	4	3
20	3	3
22	3	2
24	3	2
26	3	2
28	2	2
28	2	2
30	2	2
32	2	2
36[a]	2	1

DR, dimension ratio.
[a] Do not stack pipe larger than 36 in.

storage site requirements include adequate area to accommodate the pipe units, room to allow handling equipment to maneuver, and a smooth, flat surface free of any material that may damage the pipe.

Individual pipe may be stacked in rows (Table 18-1). Pipe should be laid parallel, not crossing over or entangled with each other. The base row must be blocked to prevent sideways movement or shifting.

18.3 INSTALLATION OF POLYETHYLENE PIPE

18.3.1 General

All of Chapter 6 is generally applicable to PE pipe. PE pipe is installed aboveground, underground, supported above grade, floated in water, or submerged under water. Most PE pipe is installed in buried installations, which generally involve trench excavation, backfilling around the pipe, and placing earth up to the required finished grade. Factors affecting

Figure 18-4. Installation of ASTM F 894 *pipe for conveyance of foul air. This excavation is in a rock-hard, caliche-type soil. Reprinted with permission from Performance Pipe, Plano, TX.*

installation include pipe service requirements, size, type of pipe (solid-wall or profile-wall), soil conditions, backfill soil quality, burial depth, and joining requirements. For underground installation of PE pressure pipe, refer to *ASTM D 2774*; for gravity pipe, refer to *ASTM D 2321* (see Figure 18-4).

Larger jobs will include an engineer's installation specifications in the construction contract. Without these directions, installation recommendations obtained from the manufacturer may suffice. Installation guidelines are given in the *Plastic Pipe Institute Handbook of Polyethylene Pipe*, which is available from the Plastic Pipe Institute (refer to Appendix B).

A large amount of PE pipe is installed by trenchless construction methods, but this special type of installation is outside the scope of this manual. Examples of this work are pipe bursting, sliplining, and horizontal directional drilling.

18.3.1.1 Trench Placement and Assembly Solid-wall PE pipe may be joined in the field by heat fusions performed either inside or outside the trench. Profile-wall PE pipe should be installed one section at a time inside the trench, which permits the use of a trench shield. Gaskets should be installed, lubricated, and stress-relieved prior to joining the bell and spigot joints, according to the manufacturer's recommendations. Struts are often placed inside 42-in. (1,065-mm) and larger profile-wall pipes to increase the vertical diameter slightly and thus offset anticipated earth load deflection.

18.3.2 Trenching

Terminology applicable to trenching for flexible pipes is given in Fig. 6-2 in Chapter 6. The trench must be wide enough to place and compact backfill soils in the haunch areas below the springline (horizontal centerline) of the pipe. Refer to Chapter 6, which defines actions when trench side wall stability and trench depth are construction problems. Sloping side walls and use of trench shields are the usual solutions to trench excavation problems. When a trench shield is used to support the trench walls, care must be taken not to disturb the embedment material placed beside the pipe when the shield is removed. One solution is to place the trench shield on a side shelf in the excavation, resting no lower than about one-quarter of a pipe diameter under the pipe crown. This arrangement allows the most important backfill to be placed and remain undisturbed when the shield is raised (Fig. 6-3 in Chapter 6). Another workable method is to lift the trench shield from the trench bottom in stages as the elevation of the top of the backfill rises. In any case, the pipe zone trench down to foundation grade should be excavated within the protection of a trench shield. Minimum trench width can be determined with Table 18-2.

18.3.3 Embedment Material and Compaction

Suitable materials for pipe embedment and their required compaction levels are described in *ASTM D 2774* for pressure pipe and in *ASTM D 2321* for gravity-flow pipe. Soils are divided into classes, with the lower classes generally providing better pipe support. Class I and II soils are granular and tend to provide maximum embedment support. Class I is generally manufactured aggregate such as crushed stone. Class II

Table 18-2. Minimum Trench Width

Nominal Pipe OD (in.)	Minimum Trench Width, B_d (in.)	Parallel Pipe Clearance (in.)
<3	12	4
3 to 16	Pipe OD +12	6
18 to 33	Pipe OD +18	9
36 to 63	Pipe OD +24	12
72 to 96	Pipe OD +36	18

OD, outside diameter.

Table 18-3. Maximum Embedment Particle Size

Normal Pipe Size (in.)	Maximum Particle Size (in.)
2 to 4	½
6 to 8	¾
10 to 16	1
≥18	1½

materials consist of clean sands and gravels and are more likely naturally occurring soils, such as river deposits. Maximum aggregate size when used next to pipe should not exceed values given in Table 18-3.

When using granular embedment, consideration must be given to migration of native fine-grained soils into the embedment with a resulting loss in side support. This concern exists when the native soil is erodible and a significant groundwater flow gradient exists through the embedment. Where this potential exists, use granular embedment containing a mixture of gravel and sand. Granular materials containing up to 12% fines may still be considered Class II. Granular materials with more than 12% and up to 50% fines are considered Class III. Class IVa materials are fine-grained soils and, although they can be used as embedment material, they typically require more effort to obtain proper density for side support. These soils must be installed at the proper moisture content. Class IVa materials are generally only used as embedment, when the depth of cover is shallow and no live loads are expected.

18.3.4 Embedment Placement

The correct placement of embedment materials is very important in PE pipe installations. The zones of embedment materials are foundation, bedding, haunching, primary initial backfill, and secondary initial backfill (refer to Fig. 6-2 in Chapter 6).

A *foundation* is required when soil in the trench bottom is unstable, such as muck, saturated clays, or loose material. Bedding brings the trench bottom to the required grade, levels out irregularities to provide uniform support to the pipe, and protects the pipe from rock. *Haunching* is the backfill that is placed under the haunches of the pipe to provide support. *Primary initial backfill* provides the primary support against lateral pipe deflection. This zone should extend from the bedding up to at least 75% of the pipe diameter. *Secondary initial backfill* distributes overhead loads and isolates the pipe from the final backfill.

The *final backfill* is not an embedment material, but the nature and quality of compaction may directly influence a PE pipe installation because increased backfill density promotes arching. The final backfill should be free of large rocks, stumps, and debris. The material and compaction requirements for the final backfill should satisfy local ordinances and other applicable regulations.

When using PE solid-wall pipe, all rocks, cobbles, and boulders must be removed from the bottom of the trench [cobbles are any hard materials larger than 3 in. (75 mm)]. Smooth undulations are permissible, but any irregularities (ridges, hollows, and lumps) that may interrupt continuous pipe support must be leveled. Uniform trench bottoms where the in situ soil is free of rocks or other hard material may not require the use of foundation or bedding.

For PE profile-wall pipe, pipe grade is determined by the trench bottom. By installing foundation and bedding, the trench bottom can be constructed to the required grade. Once again, if the trench bottom is relatively uniform and the soil is stable and free of rock, foundation or bedding may not be required.

The trench should be free of any excess water before laying the pipe. During the dewatering process, care should be taken not to remove or displace the foundation or bedding soil material. Unstable trench bottoms (mucky or sandy soils) require excavation below the pipe bottom grade and installation of a foundation and bedding or a bedding of compacted Class I or Class II materials. The minimum bedding thickness is 6 in. (150 mm). All materials used for bedding, haunching, and primary and secondary backfill should be compacted to at least 90% standard Proctor density, or as specified by the engineer. Chapters 2 and 14 discuss determination of Proctor density.

18.3.5 Pipe Placement in Trench

Smaller solid-wall PE pipe can often be placed in the trench manually, but all pipes and structures require appropriate handling equipment to lift, move, and lower the pipe into the trench. To prevent damage to the pipe and injury to workers, the pipe must never be dumped, dropped, pushed, or rolled into the trench.

Branch connections may be made with equal outlet and reduced tees, which may be installed in the line during construction. When main sizes are 16 in. (400 mm) and larger, it is suggested that the two or three connections are flanged. The tee is usually heat-fused to the end of the pipe run, then set in position. The mating run and branch pipes are then coupled to the fitting flanges.

Field bending involves the excavation of the trench to a desired bend radius, then sweeping or pulling the pipe into the required bend (Fig. 18-5). With a cold bend radius of 20 to 30 times its outside diameter, solid-wall PE pipe in coils and long strings may be cold-bent safely; refer to

Figure 18-5. Flexibility of HDPE pipe eases installation. Reprinted with permission from Performance Pipe, Plano, TX.

Table 18-4. Cold Bending Radius

Pipe Dimension (*DR*)	Allowable Cold Bending Radius (*R*)
<9	20 × (pipe diameter)
9 to 13.5	25 × (pipe diameter)
>13.5 to 21	27 × (pipe diameter)
>21 to 26	34 × (pipe diameter)
>26 to 32.5	42 × (pipe diameter)
Fitting or flange present in bend	100 × (pipe diameter)

DR, dimension ratio.

Table 18-4. The pipe may be temporarily restrained to maintain the bend while the initial backfill is installed, but the restraints must be removed before the final backfill is installed. Coiled and bent pipes may have stored energy and may spring back forcibly when banding or restraints are cut.

18.3.6 Backfilling

Refer to *ASTM D 2774* for information on pipe embedment. Once the pipe has been laid, the haunch must be filled. Voids at this location are unacceptable in almost all specifications. The backfill material should be shovel-sliced into the haunches or mechanically compacted to fill this space. After this haunching work, primary and secondary initial backfill materials can be placed in layers and compacted with hand tamping tools, gasoline-driven impact tampers, or vibratory plates. When mechanical tampers are used, take care not to touch the pipe and damage it. Backfilling materials must be placed to an elevation over the bare pipe at least 18 in. (450 mm) or one pipe diameter (whichever is greater) before construction vehicles can be driven over the pipe. Most specifications require at least 3 ft (1 m) of cover, especially if earthmovers will pass over it.

Generally, embedment is compacted to at least 90% of standard Proctor density. Under roadways, a higher degree of compaction is usually required by the operating utility to reduce or prevent road surface settlement.

Profile-wall pipes are often installed within trenches supported by sheeting or a trench box. Backfill compaction must remain undisturbed while supports are lifted out as each layer is compacted. If a trench box is not lifted while compacting, voids will likely occur when the trench box is removed.

The final backfill may be placed in the trench by machines. When at least 3 ft (1 m) of compacted material covers the pipe, the final backfill may be compacted with self-powered compactors. The final backfill should be free of objects that may damage the pipe.

18.3.7 Tapping

When a service line is to be connected to the main at system pressure, a *tapping tee* is recommended for the hot tap. A tapping tee is saddle-fused onto the main, and a cutter within the tapping tee penetrates the main to allow for the service line flow. Saddle fusion is generally used to connect service laterals up to12 in. (305 mm) in diameter to the main, via service saddles and tapping tees. During the saddle fusion process, the surfaces of the pipe and the saddle, or tee, are cleaned, heated until a sufficient fusion bead is formed, and then pressed together until the surfaces have cooled and bonded. Tapping tees and service saddles may also be attached by electrofusion.

Mechanical service saddles are another means of tapping a pipe joint. Using mechanical saddles with sufficiently wide clamping straps or castings will increase the distribution of the clamping force, thereby decreasing the tendency of the material to creep away from the clamp. The saddle manufacturer will recommend the proper installation procedure.

Strap-on saddles are also used when tapping the main. Instead of heat fusion, these saddles rely on straps to securely hold them in place. Service saddles must be secured with wide band straps, and double-strap designs are preferred. U-bolt saddle connections are not recommended. Service saddles may also be used for connections to gauges, vacuum breakers, and air release valves. Mechanical hot tapping is also available for mains.

Service connections to nonpressure or gravity-flow solid-wall and profile-wall pipes are usually used for sanitary sewers and slipliners. These connections typically involve an Inserta-Tee® branch outlet, which secures in a gasketed hole in the main, or a strap-on saddle. Inserta-Tee® hole saws and installation equipment are available from the manufacturer.

18.3.8 Connections to Other Piping Materials by Mechanical Connectors

PE pipes can be joined to other pipe materials or to other PE pipe using flange adapters with backup rings, mechanica1 joint (MJ) adapters, or using other mechanical connectors (Fig. 18-6). A metal sleeve, referred to as an *internal stiffener*, should be inserted into the end of PE pipe so that it will be under the MJ. The insert stiffener prevents the PE pipe from cold flowing away from the gasket and any restraining device. Stiffeners are generally obtained from an MJ supplier. The stiffener OD must be properly sized to account for the ID tolerance of the pipe; otherwise, the stiffener may not insert into the pipe or may fit too loosely.

Mechanical couplings and joint fittings offer little resistance to axial movement. Even with the use of a stiffener, pressurized pipes will move out of the mechanical fittings when no external restraint devices are used. When PE pipe is pressurized, a slight ring expansion occurs, which causes the pipe to shorten slightly. This relationship is called the *Poisson effect*; it can be seen when a rubber band is stretched and the width of the band

Figure 18-6. Mechanical connection of HDPE pipe to a valve. Reprinted with permission from Performance Pipe, Plano, TX.

narrows. In a pressurized PE pipeline, the cumulative shortening caused by the Poisson effect may cause a disjoining of unrestrained mechanical joints that are in line with the pipe. Movement caused by shortening may extend past the PE pipe and cause pipes down the line from the PE pipe to disjoin. Disjoining can be prevented by installing external joint restraints or in-line anchors at the mechanical connections. Restraining may also be required where pipes are subjected to pull-out caused by thermal expansion and contraction. PE butt-fusion joints, MJ adapters, and flange connections are restrained. No external restraints or thrust blocks are normally required.

Restraint may also be provided by external mechanical restraining devices or by a PE MJ adapter, which transitions from PE pipe to a standard ductile iron MJ bell.

Some joint restraints are designed as add-ons to existing push-on fittings; others replace the gland and become a part of the fitting. Add-on devices may consist of external circumferential clamps and tie-rods across the joint. In-line anchoring may be used in addition to external MJ restraint. To restrain the pipe, a pipe wall anchor/in-line restraint is installed near the end of the pipeline and encased in concrete. External MJ restraint and in-line anchoring may be used individually or together in a system.

18.3.9 Connections to Structures for Gravity-Flow Applications

The best connection between a pipe and a manhole consists of a PE pipe connected to a PE manhole designed in accordance with *ASTM F 1759*. This connection provides the tightest seal available for profile-wall PE pipe as well, which can be either a bell-and-spigot or a field closure joint. Profile-wall pipe can also connect to both precast and poured-in-place concrete manholes through several different options. As with all connections of dissimilar materials, the integrity of the connection depends upon proper installation.

Two options are available when connecting profile-wall PE pipes to precast concrete manhole bases. The first option uses A-Lok connector pipe that is pushed into an A-Lok gasket that has been cast into the manhole base. The second option involves a Frenco or Kor-N-Seal boot or equivalent cast or fastened into the manhole outlet wall. A smooth-wall connector pipe is pushed into the boot and clamped into place.

Two options are available when connecting profile-wall PE pipe to poured-in-place manhole bases. The first connection option involves the use of hydrophilic gaskets placed inside each of the grooves on a Tomahawk connector before concrete is poured over the connection. The second option can be used for lighter groundwater applications or where some infiltration can be tolerated. A bitumastic compound is heavily applied to the area to be cast in concrete to the center 6 in. (150 mm) of

Figure 18-7. Pull-back installation of HDPE pipe. Reprinted with permission from Performance Pipe, Plano, TX.

the connection, and then concrete is poured over the connection. The concrete should be thoroughly vibrated to eliminate all voids.

18.3.10 Installation in Tunnels and Casings

Profile-wall PE pipe is often installed within tunnels or casings (Fig. 18-7). However, the annular space between the pipe and the casing must be filled with lightweight cementitious grout. A pipe class must be selected that can safely withstand the applied pressure during grouting, groundwater pressure, and any other service load after installation. To assist in counteracting the buoyancy effect of the grout and to resist excessive deflection, the pipe may require strutting, and the encased section of pipe may need to be filled with water. Refer to the pipe manufacturer's recommendations for grout encasement.

18.4 TESTING AND ACCEPTANCE

Buried Pipe: Gravity-flow sewer pipe should be inspected to verify that any deflection requirements specified by the engineer are met. Where pipe can be accessed, inspection may be as simple as taking diameter measurements. For smaller pipe, a deflection measuring device, or mandrel, may also be pulled through the pipe. Typically, to allow for soil to settle and stabilize, acceptance deflection is measured 30 days or more after the pipe has been installed. Typically, the 30-day deflection is limited to 5% of the pipe's base inside diameter.

Fusion Joints: Consult the manufacturer for recommended fusion procedures. Visual inspection of butt-fusion and joints and observation of the fusion procedure is recommended as a reliable, nondestructive joint evaluation procedure for all pipe sizes. A data logger device is available for monitoring and recording the fusion process.

Visual inspection of the size and shape of the butt-fusion beads helps determine whether a proper joint has been made. Consult the manufacturer's literature for recommended bead heights. Typically, the double bead width should be two to two and one-half times the height from the pipe surface; both heads should be uniform in size and shape all around the joint; and the depth of the V-shaped groove between the beads must not be more than half the bead height.

During construction fusion joining, some manufacturers recommend the first butt fusion for each size and dimension ratio of pipe shall be destructively tested to confirm fusion joint integrity, operator procedure, and fusion machine setup for the prevailing conditions on-site. The *bent strap test* is commonly used as a destructive test. A bent strap test specimen is prepared after a sample butt fusion is made. A strap that is at least 6 in. (150 mm) or 15 wall thicknesses long on each side of the fusion, and about 1 to 1.5 wall thicknesses wide, is cut from the sample fusion pipe. The strap is bent back so the ends touch. Disbondment at the fusion is unacceptable and indicates poor fusion quality. All of this testing should conform to the manufacturer's literature on pipe fusion.

18.4.1 Pressure Testing

Pressure testing can be dangerous. Internal pressure testing may cause the pipeline, joints, or components to fail by leaking or breaking. Breakage may occur suddenly and explosively, and may result in the forcible, uncontrolled movement of the system piping, components, or parts of components. During testing, keep personnel a safe a distance away from the section under test.

Gravity-flow sewer pipe should be tested per *ASTM F 1417*. Pressure pipes should be hydrostatically tested. *Avoid the use of high-pressure air for testing pressure pipes*. Explosive failures may occur, subjecting personnel to great danger.

18.4.2 Hydrostatic Test Procedures

Clean water is the preferred testing medium, but other liquids may be suitable. The section of pipe to be tested should be completely filled with liquid and bled of all trapped air. The section may require venting while it is filled with liquid, which can be done by loosening flanges or by using equipment vents.

The *monitored makeup water test* consists of initial expansion and test phases. During the initial expansion stage, the test section is pressurized to the test pressure, and enough makeup liquid is added each hour for 3 hours to return to test pressure. The test phase of 1, 2, or 3 hours immediately follows after the test, and the section is then returned to the test pressure by adding a measured amount liquid. If the amount of makeup liquid added does not exceed the values posted in makeup water allowances tables, leakages is not indicated. These tables are available in the *Plastic Pipe Institute Handbook of Polyethylene Pipe*.

Similarly, the *nonmonitored makeup water test* consists of initial expansion and test phases. During the initial expansion phase, makeup water is added as required to maintain the test pressure for 3 hours. The test phase calls for a 10-psi (69-kPa) reduction of the test pressure. If the pressure remains within 5% of the target value for 1 hour, no leakage is indicated.

Consult *ASTM F 2164* for hydrostatic leak testing of PE pipe.

CHAPTER 19

FIBERGLASS-REINFORCED (THERMOSETTING RESIN) PLASTIC PIPE

19.1 GENERAL BACKGROUND

19.1.1 Description

Fiberglass-reinforced pipe (FRP), which went on the market in 1945, was initially targeted to the chemical process and oilfield industries, where significant need existed for corrosion-resistant, high-performance piping material. Early FRP was made with about 65% fiberglass and 35% resin by weight, which yielded a very strong product. However, the high glass content made early FRP costly and little of the material found its way into the public works market.

As the technology for manufacturing evolved, larger diameters became available. By the 1970s, several American manufacturers could produce pipe in diameters up to 144 in. (3,700 mm), and the cost to produce FRP gradually decreased. Technology and manufacturing experience advanced to the point where FRP could compete with traditional pipe materials such as steel, ductile iron, and concrete for public works applications, especially where corrosion is a concern.

FRP has the following characteristics:

- Long service life, requiring no additional corrosion protection
- Easy to install because of light weight and long lengths, which allow lighter construction equipment for pipe handling
- Tight joints, using easy-to-assemble couplings or bell and spigot joints
- High strength to accommodate high pressures
- Smooth interior, minimizing frictional losses

19.1.2 Applications

FRP pipe is widely used for both sanitary sewage collection lines and water supply systems, particularly where resistance to the corrosive effects of septic sewage systems is important. Certain types of FRP also are used for sliplining of deteriorated sewer pipe, thus providing a smooth bore and corrosion resistance while allowing the pipeline to stay in service. Other applications include:

- Water transmission and distribution (potable and raw water/waste water)
- Storm sewers and drainage
- Seawater intake, outfalls, and cooling water lines
- Circulating water, makeup, and blow-down lines for power plants
- Penstock lines for mini-hydroelectric power plants
- Industrial effluents

19.2 PRODUCT INFORMATION

19.2.1 Standards

A significant body of internationally recognized performance standards has been developed for this pipe. The common thread in all of these product standards is performance-based criteria, which means the pipe products must demonstrate performance by passing required testing specifications.

Some common product standards for this pipe are:

- *ASTM D 3262, Fiberglass Gravity Sewer Pipe*
- *ASTM D 3517, Fiberglass Pressure Pipe*
- *ASTM D 3754, Fiberglass Pressure Sewer*
- *AWWA C 950, Fiberglass Pressure Pipe*
- *AWWA M 45, Fiberglass Pipe Design Manual*
- *DIN 16868, (German) Glass Fiber-reinforced Polyester Resin Pipes*
- *BS 5480, (British) Pipes and Fittings for Water and Sewage*
- *ISO 7370, Glass Fibre Reinforced Thermosetting Plastics (GRP) Pipes and Fittings*
- *ISO 2084, Pipeline Flanges for General Use*

Dimensions and Thicknesses: FRP is commonly available in diameters from 4 to 102 in. (100 to 2,500 mm). Some manufacturers regularly produce pipe as small as 1 in. (25 mm) and as large as 144 in. (3,700 mm). Lengths up to 60 ft (18 m) are available, but most manufacturers supply standardized 20- and 40-ft (6- and 12-m) lengths.

Table 19-1. Pipe Stiffness

U.S. Standard Pipe Stiffness (psi)	International Specific Stiffness (N/m^2)
9	1,250
18	2,500
36	5,000
72	10,000

The product is manufactured in different pressure and stiffness classes. Pressure classes, covered by AWWA and ASTM standards for pressure applications, range from 50 to 250 psi (345 to 1,724 kPa), in 50-psi (345-kPa) increments. International standards (ISO) recognize pressure classes up to 464 psi (32 bar).

Pipe stiffness, which is a measure of the pipe's rigidity, is categorized in the AWWA and ASTM standards into four classes ranging from 9 to 72 psi (62 to 496 kPa). Pipe stiffness is calculated by the expression 53.69 EI/D^3. Pipe stiffness is also classified in the international standards (ISO) as specific initial stiffness (EI/D^3) with values ranging from 1,250 to 10,000 N/m^2. Both terms are essentially equivalent, with a constant multiplier.

Some U.S. manufacturers produce a pipe class with a pipe stiffness of 46 psi (317 kPa), matching PVC pipe with a standard dimension ratio (SDR) of 35. Refer to Table 19-1.

FRP is produced with either a controlled inside or outside diameter. Most manufacturers who supply pipe for public works applications provide an outside-diameter-controlled series to facilitate connections to other materials, such as steel, ductile iron, or thermoplastic pipes. An international OD series is reserved for FRP alone, with an approximately nominal inside diameter. These pipes also match the "B" series dimensions of *ISO 7370*. Many manufacturers produce FRP with the DI outside diameters up to 24 in. (610 mm) and the international OD series for larger sizes.

The pipe wall thickness depends on the required pressure and stiffness rating and the manufacturer's laminate design. FRPs with higher percentages of glass fiber reinforcement have thinner walls, given their added unit strength and modulus. A table of standard wall thicknesses cannot be provided here given the wide variation in approaches manufacturers use to design their products. Typical wall thicknesses range from 1.25% to 2% of the diameter. Pipes designed for special applications (e.g., microtunneling) will have much larger wall thicknesses given the unique loading conditions.

19.2.2 Types of Joints

The typical jointing system for FRP is a coupling that uses an elastomeric gasket for sealing. This joint design meets the performance requirements of *ASTM D 4161*, including hydrostatic pressure qualification at two times rated pressure and negative pressure qualification at –10.7 psig, when the joint is subjected to both angular deflection and vertical offset. The amount of angular deflection is diameter-dependent, ranging from 3.5% down to 0.5%. The joint should be assembled in straight alignment before angular adjustments are made.

19.3 SHIPPING AND HANDLING FIBERGLASS PIPE

19.3.1 Marking Pipes

During normal handling, the manufacturer will apply legible marking either with a permanent stenciling ink or by embedding a label into the laminate's surface. Each pipe should be marked with appropriate information. As a minimum, the following information should be included:

- Manufacturer's name, including brand name
- Standard by which the pipe has been produced (e.g., *AWWA C 950*)
- Nominal diameter, in.
- Nominal pressure class, psi (e.g., CL150)
- Nominal stiffness class, psi (e.g., SN36)
- Pipe length, ft
- Manufacturer's production serial code, as required by ISO 9000, uniquely identifying the plant, machine, date, and sequence of manufacture

19.3.2 Transporting Pipe

Manufacturers provide dunnage to ship the pipe units, especially if additional transport is required at the job site. If this material is unavailable, support all pipe sections on flat timbers spaced on a maximum of 13-ft (4-m) centers [10 ft (3 m)] for small-diameter pipe under 12 in. (305 mm) with a maximum overhang of 7 ft (2 m). Chock the pipes to maintain stability and separation without abrasion (Fig. 19-1).

Maximum stack height is 8 ft (2.5 m). Strap pipe to the vehicle over the support points using pliable straps or rope. Never use steel cables or chains without adequate padding to protect the pipe from abrasion.

Pipes may be nested (smaller-diameter pipes inside larger sizes) to reduce transportation cost. These pipes may have special packaging and require special procedures for unloading, handling, storing, and transporting. The pipe supplier will furnish special practices or directions. Always store and transport nested pipe in the original packaging.

Figure 19-1. Fiberglass-reinforced pipe is frequently transported and stored as a unitized load. Courtesy of Amitech USA.

19.3.3 On-Site Inspection upon Delivery, Including Repairs

All pipes should be inspected upon receipt at the job site to ensure that no damage has occurred in transit. Depending on storage time, amount of job-site handling, and other factors that may influence the pipe's condition, the pipe should be reinspected just prior to installation. Never use pipe that appears damaged or defective.

Inspect the shipment upon delivery as follows:

1. Make an overall inspection of the load. If the load is intact, ordinary inspection while unloading will normally be sufficient to ensure the pipe has arrived without damage.
2. If the load has shifted or rough treatment is evident, carefully inspect each pipe section for damage. Generally, exterior inspection will be sufficient. When pipe size permits, an interior inspection of the pipe surface under the location of an exterior strap may be helpful to determine damage.
3. Do not dispose of any damaged items. The carrier will give you notice of his disposal procedure.
4. If any imperfections or damage are found, immediately segregate the affected pipes and contact the supplier or manufacturer, who will provide directions for either repairing the damage or replacing the pipe, depending on the extent of the damage.

A qualified individual can usually repair FRP in the field to equal undamaged pipe. Designs for repair can vary greatly depending on pipe thickness, wall composition, application, and the type and extent of the damage. Do not attempt to repair a damaged pipe without consulting the supplier or manufacturer.

19.4 UNLOADING AND HANDLING PIPE

Be sure to maintain manual control of the pipe with guide ropes during unloading. Spreader bars may be necessary for longer pipe lengths. Do not drop or bump the pipe, particularly at pipe ends.

19.4.1 Unitized Loads

Generally, pipes 24 in. (610 mm) and smaller in diameter are packaged as a unit. Unitized loads may be handled with a forklift or crane. Do not lift a non-unitized stack of pipes as a single bundle. Non-unitized pipes must be unloaded and handled separately (one at a time).

19.4.2 Single Pipes

When lifting single pipes, use pliable straps, slings, or rope, and never use steel cables or chains. Pipe sections can be lifted with only one support point, but two support points make the pipe easier to control. Do not lift pipes by passing a rope through the section end-to-end.

If at any time during handling or installation of the pipe, any damage such as a gouge, crack, or fracture occurs, the pipe must be repaired before the section is installed. Contact the supplier or manufacturer for repair recommendations.

19.4.3 Storing Pipe

Storing pipe on flat timbers facilitates placement and removal of lifting slings around the pipe. The storage area should be relatively flat and free of all damaging objects. Pipes should be chocked to prevent rolling in high winds.

If pipes must be stacked, use flat timber supports at maximum 20-ft (6-m) spacing [10-ft (3-m) for small-diameter pipe] with chocks. If available, use the original shipping dunnage.

Check stability of the stacks for conditions such as high winds, uneven storage areas, or other horizontal loads. Stacking of pipes larger than 54 in. (1,400 mm) in diameter is not recommended.

19.4.4 Storing Gaskets and Lubricant

Rubber ring gaskets, when shipped separately from the couplings, should be stored in their original packaging and should not be exposed to sunlight except during the pipe joining. Also, the gaskets must be protected from exposure to greases and oils, which are petroleum derivatives, and from solvents and other deleterious substances. Gasket lubricant should be carefully stored to prevent damage to the container. Partially used buckets should be resealed to prevent contamination of the lubricant.

19.5 INSTALLATION

FRP requires support from the pipe bedding and the pipe zone to properly develop the soil–pipe structure interaction covered in Chapter 6.

Compacted granular materials are ideal for backfilling FRP. A number of different materials, including compacted native soil (gravel, sand, silt, clay, and mixed soils) may be used for backfilling.

19.5.1 Buried Installation

All of Chapter 6 is generally applicable to FRP. Installation specified for fiberglass pipes will vary according to the pipe stiffness, cover depth, native soil characteristics, and available backfill materials.

All flexible and semi-flexible pipes have similar basic requirements. Descriptions of this embedment appear in Fig. 19-2. As installed, fiberglass pipes must receive all the support specified for the pipe zone. Native soil materials in the trench wall must be capable of adequately confining

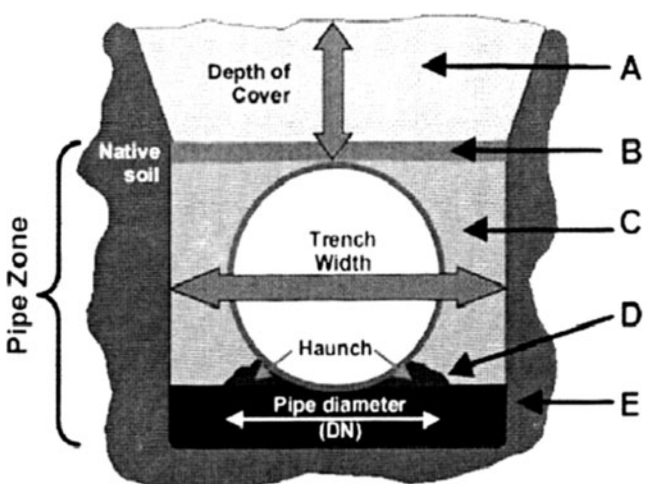

Figure 19-2. Trench construction for buried fiberglass pipe. (A) Trench backfill. (B) Secondary backfill. (C) Primary backfill. (D) Haunch. (E) Bedding. Courtesy of Amitech USA.

pipe zone backfill. Pipe haunches must be properly compacted, especially without any voids between the invert and pipe springline. Care must also be taken during soil compaction so the pipe is not moved or raised from the proper grade line because of the relatively lighter weight of this pipe.

A compacted bed is prepared first, then the pipe is installed, joined, and backfilled. Depending on the choice or availability of backfill material, different levels of compaction effort may be required for the pipe zone backfill. In any case, the initial and long-term deflections of the pipe must not exceed the manufacturer's stated values.

Initial and long-term deflections of the buried pipe must remain within specified or manufacturer's criteria, generally 3% and 5%, respectively. These percentages may vary depending on pipe design. For example, FRP designed for microtunneling has thick walls and consequently would have a lower deflection limit.

The engineer should check pipe deflections as the work progresses to ensure the backfilling work is not deforming the pipe beyond the allowable limits. Reference is made to the proposed backfilling test sections described at the end of Chapter 12 and to descriptions in Section 19.19.1.

- *Trench Backfill:* The material placed in a trench excavation extended from the secondary backfill, if any, to the ground surface.
- *Secondary Backfill:* The option of material above the primary backfill. It usually extends to 1 ft (0.3 m) over the top of the pipe. The maximum trench width is at the top of the pipe.
- *Primary Backfill:* The material between the bedding and the secondary backfill.
- *Haunch:* The material that is placed under the invert of the pipe and compacted to provide strong support in this area.
- *Bedding:* The material used to support the pipe in the bottom of the trench. Material is commonly granular material of a specified gradation.

19.5.2 Maximum Particle Size

The maximum particle size of backfill material in the pipe zone and up to 12 in. (305 mm) over the pipe crown is shown in Table 19-2.

Special care must be exercised when installing FRP in rocky areas. Large rocks and boulders must not fall into the trench and impact the pipe. Rocks larger than 2 in. (50 mm) have been known to damage some thinner-walled FRP by falling only 6 ft (2 m).

Rocks or stones larger than 8 in. (200 mm) should never fall or impact the cover over the pipe until this backfill is at least 2.5 ft (0.75 m) over the top of the pipe.

Table 19-2. Maximum Particle Size of Backfill Material

Nominal Pipe Diameter (in.)	Max. Particle Size (in.)	Max. Particle Size (mm)
Up to 18	½	13
20 to 24	¾	19
27 to 36	1	25
39 to 48	1¼	32
50 and over	1½	38

19.5.3 Aboveground Installations

Designers' details for aboveground installations will depend on the properties of the specific pipe used, typically requiring stiffness class SN36 or higher. Cradle spacing and design, hold-down straps, allowable coupling rotation, and other considerations will be tailored to the project. Proper UV protection will be specified for aboveground installations.

19.5.4 Subaqueous Installations

FRP is used for subaqueous installations such as intakes and outfalls. The standard 40-ft (12-m) or longer pipe lengths reduce the number of underwater joints. Depending on the manufacturer and on available transportation methods, special lengths up to 60 ft (18 m) may be available. Marine harness lugs can also be attached to the ends of the pipe to facilitate joining of the pipes under water.

19.6 JOINING

Typically, FRP sections are made with a constant outside diameter (OD) and are joined using FRP double-bell couplings (Fig. 19-3).

Pipe and couplings may be supplied separately or with a coupling installed on one pipe end. The coupling uses an elastomeric gasket for sealing. Typically, the coupling will have a center stop to assist in keeping the coupling centered over the joint. After installation, the coupling should be checked to ensure that it is centered. Some manufacturers provide assistance for this process. A thin feeler gauge can be run around the outside of the joint between the coupling and pipe spigot to ensure that the gasket has not been dislodged.

Some manufacturers control the OD of the pipe to the same tolerance as the spigot end such that the pipe can be cut anywhere along the length of the barrel, beveled, and used as a spigot end for field length adjustments.

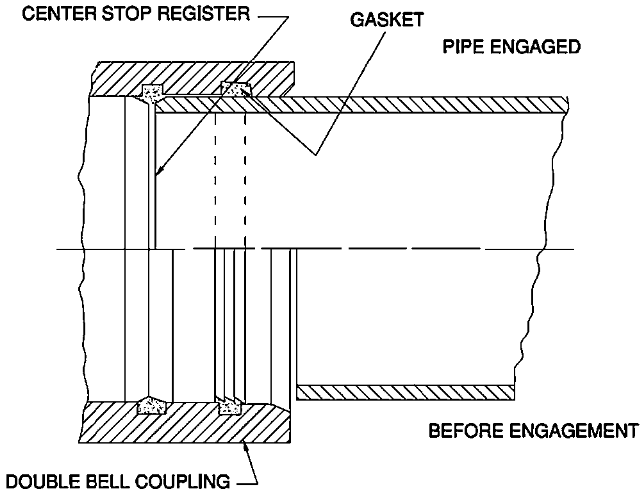

Figure 19-3. Cross section of an FRP joint. Courtesy of Amitech USA.

19.7 OTHER JOINING METHODS

19.7.1 Fiberglass-Reinforced Pipe Flanges

Pipe utilizing FRP flanges is normally manufactured to a constant inside diameter (ID). The use of an O-ring seal for flanges is effective for providing high-quality sealing while minimizing the bolt torque. When connecting two FRP flanges of larger than 12-in. (305-mm) diameter, only one flange will have a gasket groove in the face. The standard bolt patterns to which flanges are manufactured are given *ISO 2084*. Other bolting dimension systems such as AWWA, ANSI, DIN, and JIS can be supplied. Bolt torques should be as recommended by the pipe manufacturer; overtorquing can cause cracks in the flange. The proper O-ring diameter must be used to ensure a seal without cracking the flange.

19.7.2 Flexible Steel Couplings

These couplings can be used for joining similar and dissimilar pipes as well as for repair. The coupling consists of a steel mantle with an interior rubber sealing sleeve. These couplings should be torqued to the pipe manufacturer's specifications, not the coupling manufacturer's.

Tapping a steel coupling with a rubber mallet during torquing has been found to be a practical method of seating the sleeve against FRP. This method is also useful to retorque bolts a few days after initial installation, during which some of the compression may have been lost.

19.7.3 Mechanical Steel Couplings

Mechanical steel couplings can be used for joining, typically to other types of pipe or to rigid pipes and fittings. However, mechanical steel couplings are not usually specified because of their widely varying designs, and excessive torque can damage the FRP. If required, use a type with a dual bolting system (transition couplings) such that each side can be torqued independently. Bolting torque must not exceed the pipe manufacturer's maximum recommended values.

Buried flexible and mechanical steel couplings often require special corrosion protection with a sleeve of shrinkable polyethylene or other means as specified by the engineer.

19.7.4 Lay-Up (Butt-Strap) Joints

This joint is made with built-up layers of glass fiber reinforcements and polyester resin. It is typically used as a repair method or in situations where the pipe joint is required to transmit axial forces from internal pressure. The length and thickness of the lay-up depends on the pipe diameter and pressure. This type of joint requires clean, controlled conditions and trained personnel. The lay-up should provide hoop and axial strength equal to that of the pipe.

19.8 PIPE FITTINGS

Many fittings are available for FRP, including elbows, tees, wyes, and reducers.

19.9 PIPE PLACEMENT AND ASSEMBLY

All pipes must be carefully handled under controlled conditions. Any pipe that receives an impact load must be reinspected per Section 19.3.3.

Light material weight and corresponding long section lengths of FRP result in easy pipe placement and assembly. Pipes can be delivered with lighter-duty equipment compared to other pipe materials. Gasketed joints allow assembly with pliable straps and manual come-alongs. Bell holes in the bedding material at the joints allow the joint components to remain clean during assembly while allowing the pipe to rest on the flat bed. If angular deflection of pipe joints is required, they should first be assembled in a straight line. The approximate joining force for a coupling joint is 50 lb/in. (0.9 kg/mm) of diameter.

19.10 TAPPING

To add a branch pressure connection in the field, a full circumferential tapping sleeve must be used with FRP. Flexible stainless steel tapping sleeves are best suited for this purpose. Care must be exercised in applying sufficient torque to achieve a good seal, but low enough to prevent pipe damage. Typically, the appropriate torque is significantly less than the sleeve manufacturer's limit. Rigid cast iron tapping sleeves perform poorly with fiberglass pipes.

Machining (drilling) should be done at a slow advance rate (no more than 0.5 mm per revolution) to provide a clean cut. Both steel- and diamond-coated cutters with closely spaced teeth perform satisfactorily. In general, "hot" taps (those made under pressure) with branch diameters greater than one-half the main diameter should not be attempted without consulting the pipe manufacturer.

19.11 FIELD CUTTING OF FIBERGLASS PIPE

Most FRP can be easily cut in the field using diamond-tipped or abrasive cutting tools. The pipe OD is smooth or a spigot can be made by sanding. The cut edge used as a spigot should be beveled with a grinder to prevent damage to the rubber sealing gasket as the joint is made by the typical method (Fig. 19-4). Some manufacturers supply specially marked pipe showing the outer portions that are within the jointing tolerance and that will not require grinding.

19.12 INSTALLATION IN TUNNELS, CASINGS, AND FOR SLIPLINING

FRP can be made in custom diameters and lengths to meet sliplining requirements for a specific project. FRP is designed to have sufficient stiffness to withstand external pressure from grouting the annular space. The lightweight pipe sections are easy to slide inside tunnels, casings, and host pipes. The tight, easy-to-assemble joints are ideally suited for tunnel installations.

The following precautions should be observed when installing pipe in a casing:

- Pipes may be placed into the casing by pulling (drawing) or pushing (jacking). Consult the manufacturer for recommended maximum pulling or pushing forces.
- Pipes should be protected from sliding damage by the use of wooden skids or plastic casing isolators.

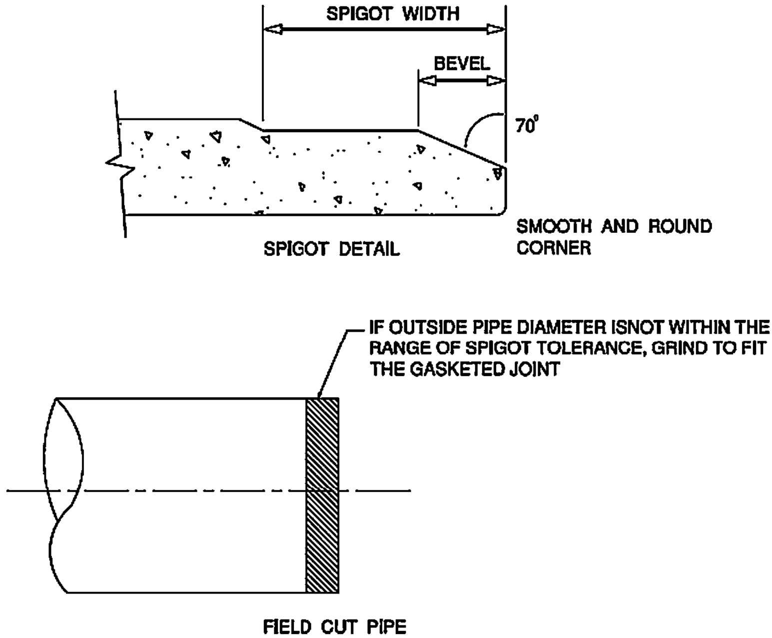

Figure 19-4. Edge detail of ends of field-cut pipe sections. Courtesy of Amitech USA.

- Installations into the casing should be lubricated between the skids and the casing wall. Do not use a petroleum-based lubricant, which may harm some gaskets. Bentonite slurry is often used.
- The annular space between the casing and pipe may be specified for filling with sand, gravel, or cement grout (preferred). Care must be taken to not overstress or collapse the pipe during this step, particularly when grouting. Project drawings and specifications should include pumping pressure information, which is needed to avoid collapsing the inner FRP. In the absence of such information, the pressure limits in Table 19-3 should be observed.

Three typical methods are used to install cement grout; the first is the simplest:

1. Thread a grout hose along with the lead pipe, pump in the grout, and gradually withdraw the hose. A metal pipe, or "slick line," may be preinstalled and pulled out in the same manner; or
2. Drill grout holes through the pipe wall, pump the grout through these holes, and then repair the holes from inside the pipe. Some

Table 19-3. Maximum Allowable Grouting Pressure Outside a Fiberglass-Reinforced Pipe[a,b]

Pipe Stiffness	Maximum Grout Pressure	
(psi)	(psi)	(bar)
18	5	0.35
36	10	0.70
72	20	1.35

[a] Measured at invert and without internal supports.
[b] This table may be interpolated for pipe stiffness under 72 psi.

manufacturers will even preinstall stainless steel bushings through the pipe wall. After pumping the grout, plugs are inserted into the bushings; or

3. Drill into the outer pipe from ground level and pump in the grout. Do not wedge or brace the pipe in a manner to cause concentrated or point loads on the pipe. Consult the supplier prior to this step for advice on suitability of the chosen method. Note: If the pipe will be subjected to negative pressure, the pipe stiffness/installation combination must be sufficient to withstand the load.

19.13 PIPE JACKING AND MICROTUNNELING

FRP is used to rehabilitate old pipelines or install new ones with various methods of trenchless technology, including:

Sliplining: A process in which a deteriorated pipeline is relined with new pipe of a smaller diameter to rehabilitate the original pipeline for ongoing service.

Jacking: A tunneling method in which a new pipe is installed in a single pass. The tunnel excavation begins with a bore head from an access shaft, and the pipe is pushed along by hydraulic jacks that remain in the shaft throughout the process. The connection to the boring head is maintained by successively adding jacking pipe sections at the access shaft so the pipe is laid as the tunnel is bored. Using this method, fiberglass pipe can be combined with an outer concrete pipe to allow for very large jacking loads. The maximum jacking load on an all fiberglass pipe is based on its thinnest cross section, which is generally at a gasket groove.

Microtunneling: This process uses remotely controlled direct jacking without the entry of personnel into the tunnel.

19.14 OTHER CONSIDERATIONS DURING PIPE LAYING

Alternative installation procedures must be considered under the following circumstances:

- If the burial depth requirement exceeds the manufacturer's limits for the selected pipe stiffness.
- If the native soil group at some point along the laying line falls short of the strength required by the manufacturer's limits.

For the first case above, a better pipe zone backfill soil and/or a higher level of compaction may be required with the given pipe stiffness. The design engineer may have to redesign this reach of pipe (upgrade the type of pipe zone support).

For the second case above, three alternative installation methods are available:

1. *Wide Trench:* Increasing the trench width distances the poor native soil farther from the pipe, allowing a deeper installation.
2. *Permanent Sheeting:* Use permanent sheeting of sufficient length [from bedding to at least 12 in. (305 mm) over the pipe crown] to appropriately distribute the pipe's lateral loads, and of sufficient quality to last the design life of the pipe. Note that the backfilling procedure and maximum cover depths are the same as in standard installations.
3. *Stabilized Backfill (Cement):* Typically, 90 to 110 lb (40 to 50 kg) of cement per ton of sand (4% to 5% cement) will be sufficient to stabilize most backfill materials. The sand should have a maximum of 15% passing a No. 200 sieve. Seven-day strength of the stabilized material should be 100 to 200 psi (690 to 1,380 kPa). The stabilized backfill should be compacted to a minimum of 90 standard Proctor density (SPD) in layers of 6 to 8 in. (150 to 200 mm). The stabilized material must be allowed to set 24 hours at maximum initial cover before backfilling to grade. Maximum burial depth is 17 ft (5 m) with stabilized backfill.

19.15 USE OF TEMPORARY TRENCH SHORING

If at all possible, the use of temporary trench shoring or sheeting at pipe level should be avoided. For FRP, the bedding and pipe zone backfill must be compacted hard against the native trench wall. Shoring or sheeting that leaves large voids when extracted will reduce support to the pipe, causing excessive pipe deflections. When temporary shoring and sheeting are necessary and cannot be avoided, one of the following requirements should be met:

1. Install the shoring to a depth of 12 in. (305 mm) above the top of the pipe, leaving the native trench sides fully exposed at pipe level. Undertake this procedure only after thorough review by a competent soils engineer.

   Use a type of sheeting that can be raised in stages, either by pulling up individual sheets or by pulling up the bottom panel independent of the upper panels. This lifting of sheets or panels must be done progressively so that the pipe bedding and pipe zone material can be compacted hard against the native trench side up to 12 in. (305 mm) above the top crown. Use of vibratory equipment attached to the sheeting may help ease it out of the trench while ensuring good soil–backfill contact.
2. Use trench boxes, which are fairly easily to pull in stages using a crane or excavator.

19.16 TRENCH CONSTRUCTION IN ROCK

Minimum dimensions for pipe installations in a rock trench shall be per the design engineer's specifications. Flexible rubber-gasketed joints must be used where the rock ends and the pipe passes into a soil trench area (or reverse). Trench construction will be according to the method applicable for the native soil condition.

19.17 THRUST BLOCKS, CONCRETE ENCASEMENT, RIGID CONNECTIONS

19.17.1 Thrust Restraints

Unbalanced thrust forces at bends, reducers, tees, wyes, bulkheads, and other changes in line direction must be restrained in some manner to prevent joint separation. When the surrounding soil cannot provide this restraint, thrust or stress/thrust blocks must be used. Determination of need and design of these restraints is the responsibility of the owner's engineer subject to the limitations described below.

19.17.2 Thrust Blocks

Thrust blocks must limit the displacement of the fitting to preserve the leaktightness of the joint (coupling). At operating pressures above 150 psi (10 bar), the block usually will completely surround the fitting. However, at lower pressures, the block should surround the fitting by at least 270 degrees of circumference and for the entire length.

Some specifications will allow a small amount of thrust block displacement. The design engineer must provide design criteria for this allowance.

19.17.3 Thrust/Stress Blocks

In addition to thrust blocks, stress blocks are used to restrict the radial deformation of pipeline tee branches, wye branches, and custom fittings. The design engineer must provide details for these components of the work. The block must completely surround the fitting for its entire length and circumference and should be placed against undisturbed earth.

19.17.4 Pipe Anchoring

During concrete placement, an empty pipe will experience large uplift (flotation) forces. The pipe must be restrained against the movement these loads could cause. This restraint is normally accomplished by strapping over the pipe to a base slab or other anchor(s). Straps should be a flat material of minimum 1-in. (25-mm) width, strong enough to withstand uplift forces, spaced not to exceed 13 ft (4 m), with a minimum of one strap per section length. The straps should be tightened to prevent pipe uplift, but not so tight as to cause additional pipe deflection.

19.17.5 Pipe Support

The pipe should be supported in such a way that the concrete can easily flow completely around and fully underneath the pipe. Also, the supports should result in an acceptable pipe shape (less than 3% deflection and no bulges or flat areas). Supports are normally placed at strap locations [not exceeding 13-ft (4-m) spacing].

19.17.6 Preventing Pipe Flotation and Buckling during Concrete Pouring

Concrete anchors and encasements are placed in stages, allowing sufficient time between layers for the concrete to set (no longer exerting buoyant force) (Fig. 19-5).

Maximum lift or rise height varies with nominal pipe stiffness, such as:

- SN18: larger of 12 in. (305 mm) or 25% of the pipe diameter
- SN36: larger of 18 in. (450 mm) or 33% of the pipe diameter
- SN72: larger of 24 in. (600 mm) or 50% of the pipe diameter

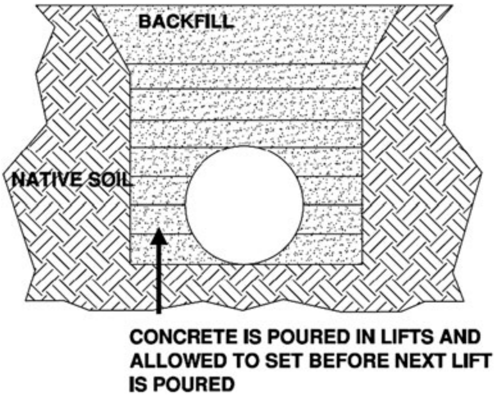

Figure 19-5. Concrete poured in lifts or rises. Courtesy of Amitech USA.

19.17.7 Rigid Connections

Excessive bending stresses in the pipe may develop when a pipe is encased, such as at a wall, encased in other concrete, meeting a junction with a manhole, or flanged to a pump, valve, or other structure if differential movement occurs between the pipe and the rigid connection.

To minimize discontinuity stress at rigid connections and allow for limited differential settlement, a coupling is set into the rigid structure interface, and the first section of pipe exiting the rigid connection (rocker pipe) should be of limited length, as follows:

- Up to 3 ft (1 m) in diameter: use one diameter length of spool pipe.
- More than 3 ft (1 m) in diameter: use two diameter lengths of spool pipe.

A single rocker pipe can be used, but multiple rocker pipes should not. Any misalignment problems must be remedied by rebedding the nearest full pipe section leading to the rocker pipe.

Precaution must be taken to properly compact foundation soil and backfill in the vicinity of large structures. The surrounding soil must be free of debris and able to support the pipe and the large structure to minimize differential movement from settlement and to ensure stability of the short section of pipe and its connections. Consider using cement-stabilized backfill in the vicinity of the structure.

19.18 VALVES

Valves should be sufficiently anchored outside the pipe system (i.e., usually to the valve chamber walls) to absorb the pressure thrust. The specifications should provide this design. Normally, fiberglass pipes are not designed to resist axial or compressive loads that may be applied to the pipe during valve closure.

19.19 TESTING AND ACCEPTANCE

19.19.1 Deflection

The inside of the pipe should be inspected immediately after installation (typically within 24 hours after reaching maximum cover). Maximum installed diametrical deflection must not exceed the manufacturer's specified values. The maximum expected initial pipe deflection is about 2% for most installations. Figure 19-6 provides guidance for calculating deflection. Deflection checks must continue periodically throughout the entire project. Never let pipe laying get too far ahead before verifying the installation quality. This practice will permit early detection and correction of inadequate installation methods. Pipes installed with initial deflections exceeding the specified values (usually 3% when 5% long-term deflection is permitted) must be reinstalled so the initial deflection is within limits.

19.19.2 Hydrotesting

Some projects require the completed pipe installation to be hydrostatically tested prior to acceptance and service. This practice can permit early

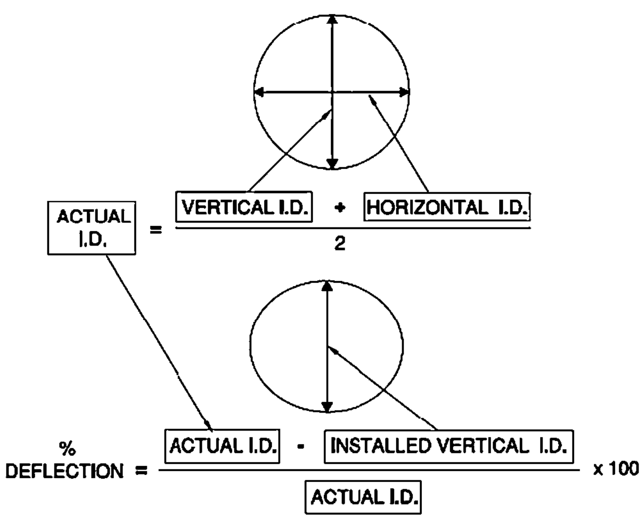

Figure 19-6. Calculating deflections of a buried pipe. Courtesy of Amitech USA.

detection and correction of some installation flaws or damaged products. If specified, field hydrotests must be done regularly as installation proceeds. Generally, the installation should not exceed testing by more than about one-half mile (1 km).

The design engineer's specifications will dictate test procedure, pressure levels, and leakage allowance. Under no circumstance should the test pressure exceed 150% of the fiberglass pipe's pressure rating at the lowest point on the profile or test reach.

FRP expands under pressure and may require more water than the calculated volume; this characteristic should not be mistaken for leakage. Typically, the volume increase will amount to about 0.04% at the rated pressure (PN) and 0.06% at a test pressure of 1.5 PN. Also, temperature differences between the water and the pipe may cause the pipe to expand or contract, changing the internal volume. System temperature should be allowed to stabilize for about 1 hour before the field pressure test is initiated.

APPENDIX A

EXCAVATOR'S CHECKLIST

1. Working Area Provided for Constructor
   a. What specific items has the owner provided?

      How long; how wide; what are the variations, such as exceptionally narrow locations?

      Are the total working area and vertical clearances sufficient for all cranes, backhoes, and/or trench spoil? Will trench spoil be hauled, returned to job? Are entry permits included to work with all public or private agencies?
   b. What access rights have *not* been provided?
      Consider time to obtain any missing approvals or permits.
   c. Review all relocations "completed" by others at time of bidding. What has not been relocated, such as wires, pipes or cables? Aboveground or buried?
   d. Review all obstructions shown on the drawings and/or identified by staff
      (in a complex area, surface or aerial photos may help to make this inventory).
      Check dimensions and location of obstructions. What is not shown on the construction drawings?
      If possible, check location of buried pipes, such as the flow line elevations of sewers.
2. Emergency Services
   a. Develop a list of telephone numbers or other communication methods for emergencies on each job. This will include police, fire, and medical agencies and names of the responsible persons at each place.

   b. Develop a similar list for all utilities, television cables, and other wire services adjacent to the work and which could be affected by construction.
3. Licenses and Permits Required
   a. What local licenses and permits are not provided by the owner? Check the need for business, equipment, and environmental permits from all levels of government.
   b. Hauling permits for highways and streets: these will need lengths of loads, axle weights, routes to be used, and speed limitations. Identify overweight or over-length conditions. Verify the time needed to get these permits.
   c. Prepare an acceptable plan for all traffic flows around construction, detours, use of flaggers, etc.
   d. Check "One-Call" services that identify buried pipes or wires of others. Get phone numbers, fax numbers, etc. for future use.
   e. Road and street work: get permits to change traffic signs and make plans for traffic control in detours.
   f. Other permits may be required to work around buried or aboveground pipes and penstocks, railroads, highways, canals, pedestrian walkways.
   g. What is needed to temporarily relocate any of the above?
   h. Cathodic protection systems of others always need to be defined by the owners, and agreements made on protecting these.
4. Special Temporary Services Provided by the Constructor
   a. What is needed for business or private property protection? Are temporary fences needed to control access by public, children, or livestock? Consider that fences must be maintained.
   b. What temporary services are needed by homes or businesses? Consider water, sewer, telephone, television cable systems, and other wire services.
      Contact the owners of these service systems for advice and/or permissions.
   c. Estimate requirements for temporary trench bridges, trench plates, and emergency access.
   d. What about lawns, gardens, landscaping, and other property improvements? What has to be replaced?
   e. Agricultural property: maintain agricultural irrigation systems, especially during the growing season, and protect crops or other growth. Save and replace topsoil used for farming.
5. Workplace Neighbors
   a. Are other constructors nearby or on same site: could there be conflicts?
   b. Schools, playgrounds, foot traffic, skateboarders. Should the school district be notified? Will attractive nuisance laws apply?

   c. Wells or groundwater facilities: who owns these and do they need to be contacted?
   d. Could sanitary or industrial waste disposal sites be affected? Are incinerators nearby?
   e. Industrial activity: should any of this be avoided?
   f. Working in cemeteries can create long, time-consuming delays.
   g. Are aggregate minerals or gravel deposits involved with the work? Agreements may be needed.
   h. Working near airports or heliports may involve federal laws and permits.
   i. Check whether newspaper or television coverage could communicate safety concerns.
6. Constructor's Temporary Facilities
   a. How much space is needed for service yard, equipment maintenance, employee parking, business office, fuel storage, and waste and scrap disposal?
   b. Are fuel storage permits and/or business licenses required?
   c. Office: consider telephone, radio, fax, computer services, water, sewer, heating fuel, air conditioning, yard lights, safety or security fencing, guard services, materials lab. Are permits needed for these?
   d. How many of these same facilities and services will be needed by the project engineer?
   e. Develop storage for unlaid pipe, valves, specials, etc. and similar materials somewhere on the job site. Provide storage for sensitive or fragile equipment (electronics, valves, etc.).
7. Environmental Issues
   a. Air quality: are burning permits needed? What material can be burned? Scrap, job debris, waste oil? Watch for likely restrictions to burning coal tar or epoxy products.
   b. Watch for contamination of natural waters, soil, or air. What disposal permits are needed for solid or liquid waste? Will any waste product need hauling to a special dump site? What is involved in hauling to that site?
   c. Land use: what is needed for erosion control, silt fences, any other methods to control runoff from the job?
8. Miscellaneous Issues
   a. Are animal species important along the route of work (bird nesting, migration routes, feeding areas, game preserves)?
   b. Some locations require preservation of wetlands or vernal pools.
   c. Indian artifacts, reservations, public parks, animal zoos, all need consideration if they lie anywhere near the work.

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APPENDIX B
INDUSTRY ORGANIZATIONS

These are major producers of pipe, related trade associations, and other prominent organizations which can provide more detailed literature on pipe laying.

Standard Specifications

ASTM International
100 Barr Harbor Drive
PO Box C700
West Conshohocken, PA 19428-2959
Phone: 610/832-9500
Fax: 610/832-9555
www.astm.org

American Society of Civil Engineers
1801 Alexander Bell Drive
Reston, VA 20191
Phone: (800) 548-2723 ext.
Fax: 703-2965-6343
www.asce.org/

DIN Deutsches Institut für Normung e. V.
Burggrafenstraße 6
10787 Berlin
Germany
Phone: +49 30 2601-0
Fax: +49 30 2601-1231
www.din.de/

Japanese Industrial Standards
Address: 1-24, Akasaka 4, Minatoku, Tokyo 107-8440, JAPAN
Phone: +81-3-3583-8000
Fax: +81-3-3586-2014
www.jsa.or.jp/

BSI British Standards, Customer Services
389 Chiswick High Road
London
W4 4AL
United Kingdom
Telephone: +44 (0)20 8996 9001
Fax: +44 (0)20 8996 7001
Email: cservices@bsigroup.com
www.bsi-global.com/

Natural Resources Conservation Service
14th and Independence Ave., SW.,
Washington, DC 20250
Phone: 202-720-8851
Fax: 202-720-2998
www.nrcs.usda.gov/

American National Standard Institute
Washington, DC. Headquarters
1819 L Street, NW
Washington, DC 20036
Tel: 1.202.293.8020
Fax: 1.202.293.9287
www.ansi.org/

American Iron and Steel Institute
Washington, D.C.
1140 Connecticut Ave., NW
Suite 705
Washington, D.C. 20036
Phone:202.452.7100
www.steel.org/

National Corrugated Steel Pipe Association (NCSPA)
14070 Proton Road Suite 100 LB 9
Dallas, TX 75244
Email: info@ncspa.org
Phone: 972.850.1907
Fax: 972.490.4219
www.ncspa.org/

U.S. Army Corps of Engineers
Headquarters, US Army Corps of Engineers
441 G. Street, NW
Washington, DC 20314-1000
Phone: 202-761-0011
Email: hq-publicaffairs@usace.army.mil
www.usace.army.mil/

Federal Highway Administration (FHWA)
1200 New Jersey Ave., SE
Washington, DC 20590
Phone: 202-366-0660.
www.fhwa.dot.gov/

Manufacturer's Standardization Society (MSS)
127 Park Street NE
Vienna, VA 22180
Phone: 703-281-6613
Fax: 703-281-6671
mss-hq.org/

National Fire Protection Association (NFPA)
1 Batterymarch Park
Quincy, Massachusetts
USA 02169-7471
Phone: +1 617 770-3000
Fax: +1 617 770-0700
www.nfpa.org/

National Sanitation Foundation (NSF)
NSF International
P.O. Box 130140
789 N. Dixboro Road
Ann Arbor, MI 48113-0140, USA
Phone: (+1) 734-769-8010
Fax: (+1) 734-769-0109
Email: info@nsf.org
www.nsf.org/

U.S. Department of Transportation (USDOT)
1200 New Jersey Ave, SE
Washington, DC 20590
Phone: 202-366-4000
www.dot.gov/

Plastic Pipe Institute
105 Decker Court, Suite 825
Irving TX, 75062
Phone: 469-499-1044
Fax: 469-499-1063
plasticpipe.org/

Ocupational health and Safety
Administartion
U.S. Department of Labor
Occupational Safety & Health
Administration
200 Constitution Avenue
Washington, D.C. 20210
Phone: 1-800-321-6742
www.osha.gov

Standard Specifications and Advisory Publications

American Water Works
Association
6666 W. Quincy Ave.
Denver, CO 80235
Phone: 303/794-7711
Toll Free: 800/926-7337
Fax: 303/347-0804
www.awwa.org

Steel Pipe

American Iron and Steel Institute
1149 Connecticut, NW, Suite 705
Washington, DC 20036
Phone 202/452-7100
Fax: 202/463-6573
www.steel.org

Steel Tank Institute/Steel Plate
Fabricators Association
944 Donata Court
Lake Zurich, IL 60047
Phone: 847/438-8265
Fax: 847/438-8766
www.spfa.org/

National Corrugated Steel Pipe
Association
13140 Coit Road, Suite 320, LB120
Dallas, Texas 75240
Phone: 972/233-9107
Fax: 972/490-4219
www.ncspa.org

The American Petroleum Industry
1220 L Street NW
Washington, DC 20005-4070
Phone: 202/682-8000
www.api.org

AASHTO
American Association of State
Highway & Transportation
Officials
444 North Capitol Street N.W.,
Suite 249
Washington, DC 20001
Phone: (202) 624-5800
Fax: (202) 624-5806
E-mail: info@aashto.org
www.transportation.org/

Concrete Pipes
Reinforced (*ASTM C 76, C 361; AWWA C 302, C 300*)
Prestressed (*AWWA C 301*)
Bar-Wrapped Concrete Cylinder Pipe (*AWWA C 303*)

American Concrete Pipe Association
1303 West Walnut Hill Lane, Suite 305
Irvine, TX 75038-3008
www.concrete-pipe.org

American Concrete Pressure Pipe Association
11800 Sunrise Valley Drive, Suite 309
Reston, VA 20191
Phone: 703/391-9135
Fax: 703/391-9136
www.accpa.org

Ameron Water Transmissions Group
10681 Foothill Boulevard, Suite 450
Ranch Cucamonga, CA 91730
Telephone: 909/444-4100
www.ameronpipe.com

Hanson Concrete Products
Pressure Pipe Division
PO Box 569470
Dallas, TX 75356-9470
Phone: 972/262-3600
Fax: 972/264-6236
www.hansonplc.com

Vitrified Clay Pipe

National Clay Pipe Institute
253-80 Center Street
P. O. Box 759
Lake Geneva, WI 53147
Phone: 262/248-9094
Fax: 262/248-1564
www.ncpi.org

Ductile Iron Pipe

American Cast Iron Pipe Co.
1501 N. 31st Ave.
Birmingham, AL 35207
Phone: 205/325-1928
Fax: 205/307-2755
www.acipco.com

Ductile Iron Pipe Research Association
245 Riverchase Parkway East, Suite O
Birmingham, AL 35244
Phone: 205/402-8700
Fax: 205/402-8730
www.dipra.org

Uni-Bell PVC Pipe Association
2711 LBJ Freeway,
Suite 1000,
Dallas, Texas 75234
U.S.A
Phone 972.243.3902
Fax 972.243.3907
Email: info@uni-bell.org
www.uni-bell.org/

National Fire Protection Association (NFPA)
1 Batterymarch Park
Quincy, Massachusetts
USA 02169-7471
Phone: +1 617 770-3000
Fax: +1 617 770-0700
www.nfpa.org/

Polyethylene Pipe

Performance Pipe
5085 W Park Blvd, Suite 500
Plano, TX 75093
Phone: 972/599-6600
Toll Free: 800/527-0662
Fax: 972/599-7348
www.driscoplex.com

Fiberglass-Reinforced (Thermosetting Resin) Pipe

Amitech America
18585 Samuels Road
Zachary, LA 70791
Toll Free: 866/626-7473
www.amitechusa.com

Hobas Pipe USA
1413 Richey Road
Houston, TX 77073-3058
Toll Free: 800/856-7473
www.hobaspipe.com

Excavation Safety

Bruce Supernant and Kim Basham
Video: "Éxcavation Safety"
ASCE Continuing Education
P.O. Box 79536
Baltimore, MD 21279-0536
Phone: 800/548-2723
store.asce.org/view

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APPENDIX C

MODIFIED IOWA FORMULA

The primary formula used for predicting horizontal deflection for flexible pipe is the Modified Iowa Formula. It establishes the relationship between the load on the pipe ($D_l K_s W_c r^3$), the pipe support (EI) and the soil support ($0.061E'r^3$) and demonstrates the importance of the soil interaction with the pipe.

The equation is:

$$\Delta x = \frac{D_l K_s W_c r^3}{(EI + 0.061E'r^3)}$$

where:

Δx = horizontal increase in diameter, in.
D_l = deflection lag factor
K_s = bedding factor; generally assumed to be 0.1 (0.083 to 0.110 depending on the bedding angle)
W_c = PD = load on pipe per unit length of pipe, lb/linear in.
r = radius of pipe (assumed equal to $D/2$ in the derivation of the Iowa Formula), in.
t = pipe wall thickness, in.
E = modulus of elasticity of the pipe material, psi
I = Moment of Inertia of the pipe wall cross-section, in.^{4} per linear inch = in.^{3}
E' = horizontal modulus of soil reaction, psi
P = vertical soil pressure on top of the pipe, psi
D = diameter of the pipe, in.

Interestingly, the Modified Iowa Formula was never meant to design pipe, just to predict deflection. Vertical deflection is a much more important value. Vertical deflection of a flexible pipe is essentially equal to the vertical deflection of the side-fill soil (that soil on the immediate side of the pipe from the top of the pipe to the bottom of the pipe).

It should be recognized that the shape of the pipe should take the form of an ellipse rather than a series of eccentric curves or, worse yet, an inversion. Notice that r in the formula is assumed to be one-half the diameter. A substantial variation in the curvature of the pipe would impact the results of the formula. Forms other than relatively uniform ellipses can lead to the premature failure of the pipe due to buckling. Such detrimental pipe deflections occur when the soil is improperly compacted and can become accentuated with flexible pipe having low levels of pipe stiffness (EI/r^3).

The horizontal modulus of soil reaction, E′, is a function of the type of soil, the compaction of the soil, the diameter of the pipe, and the height of cover over the pipe. Tables have been prepared based on experience, but it should be recognized that E′ is an imprecise value that can not be determined through basic soil mechanics.

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