THE WORLD BANK

ENERGY, WATER AND TELECOMMUNICATIONS DEPARTMENT

PUBLIC UTILITIES NOTES

Manual on

PIPELINE MATERIALS AND SPECIFICATIONS

A Reference Document for the Use of Bank Staff

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Bookman-Edmonston Engineering, Inc.
Central Projects Staff

This paper is one of a series issued by the Energy, Water and Telecommunications Department for the information and guidance of Bank staff working in the power, water and wastes, and telecommunications sectors. It may not be published or quoted as representing the views of the Bank Group, and the Bank Group does not accept responsibility for its accuracy and completeness.
This manual provides a state of the art overview of pipeline materials and specifications relative to their use in water supply and waste disposal projects of the type of concern to the World Bank. The various factors which surround design, installation, protection, testing and procurement of pipe are touched on. Separate chapters deal with Concrete Asbestos Cement, Steel, Cast Iron and Ductile, and Clay Pipe. Advantages and disadvantages experienced with each type of pipe under varying conditions are described and an extensive bibliography is included as an annex. A final chapter concerns difficulties incorporated in procurement of pipe on certain Bank financed projects in the past. Approaches are proposed on how to avoid or deal with problems stemming from differences between various pipe standards and from peculiarities of quality control on projects in developing areas.

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Energy, Water and Telecommunications Department
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<td>ANSI</td>
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<td>ISO</td>
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The World Bank has provided financing for over 110 water supply and sewerage projects in some 40 countries. It is anticipated that the Bank will be providing financing for many more such projects in the future. The majority of these water and sewerage projects include large investments in pipeline facilities.

The review and evaluation of these many projects by the Bank's staff must include consideration of the economic and engineering aspects of pipeline design, construction and performance. In order to assist the staff in performing this review function effectively, the Bank, by letter dated March 21, 1977, authorized the firm of Bookman-Edmonston Engineering Inc., of Glendale, California, to prepare this report on the State of the Art respecting pipeline materials and specifications. After receipt of the draft, it was circulated to Bank Water Supply staff for comment and their replies together with suggestions for amplification have been incorporated in the text which follows. Also, a Chapter prepared by Harold Shipman which relates to pipe procurement on World Bank projects, and an annex by Reginald Bowering on large diameter AC pipe have been added.

Scope of Study and Report

The scope of this study and report was discussed in sessions with the Bank staff. During these sessions, the staff members reviewed their experience in evaluation of past projects and mentioned specific needs for information regarding pipeline materials and specifications. These were noted and are reflected in the information compiled in this report.
An extensive search and review was made of the literature respecting pipeline design and construction. This literature included the reports, proceedings and technical papers of many engineering and technical societies throughout the world and a large number of these references are listed in the bibliography of this report. Of particular utility and applicability were the information and data which are produced by the International Standing Committee on Water Distribution which has a large representation from the European nations, the United States and Africa as well as other parts of the world.

The literature search and review also included specifications and standards for pipe manufacture, installation and testing from many countries, including but not limited to:

- International Organization for Standardization
- British Standards Institution
- British Code of Practice
- Association Francaise de Normalisation
- Deutsches Institut Fur Normung e.V.
- Japanese Industrial Standards
- American Society for Testing Materials
- American National Standards Institute
- American Water Works Association

The various standards respecting the pipe materials under discussion are referred in the text and, where possible, comparisons are presented of materials and performance requirements. However, these standards are lengthy and detailed and summary comparisons are not practical for much of the material. Evaluation of submittals based upon any of the standards should include specific reference to the complete text of the standard for comparison with standards familiar to the individual evaluator.
Pipeline conduits for conveyance of water and sewage developed from efforts to improve upon open ditch conveyance systems. Pipe systems made it possible to cross uneven topography, make pressurized water deliveries and sewerage connections, and avoid traffic interference and esthetic nuisance in city streets and roads.

Early pipelines utilized hollowed out wooden logs, and later wood stave construction, but as early as Roman times lead pipes were used to distribute water. Subsequently circular and elliptical shaped sewers were constructed in place with bricks and clay, and cast iron pipes were fabricated for placement in buried and above ground installations. Clay and cast iron pipelines were installed in European countries more than 400 years ago. In these installations pipe joints were caulked and filled with molten lead. The pipes were heavy-walled and rigid and both the joints and the pipe were subject to damage by ground movement and superimposed impact loads.

The ever increasing urbanization and operating requirements for greater pressures and minimal leakage created a demand for more efficient and economical pipe production, and installation and development of improved high strength materials provided the opportunity for the pipe manufacturers to improve their technology. Development of the steel industry and welding processes brought steel pipe to the fore. Hydroelectric power projects utilizing ever increasing hydraulic heads, stimulated the development of steel pipe for penstock applications. Metal technology also developed
ductile iron which is extensively replacing grey cast iron in water distribution.

With the development of reinforced concrete design theories and techniques, concrete pipe, reinforced and prestressed, was reduced in weight while becoming practical for greater internal pressures (now exceeding 35 kg/cm²). Steel reinforced concrete pipe diameters have progressively increased and sizes up to 6.4 meters are now manufactured and installed. With lighter weights and reduced costs steel reinforced concrete pipe, with newly developed interior coatings, is being used in many areas for sewer construction in place of clay pipe. The manufacturing processes for the latter have high energy costs and also quality control is difficult and unreliable.

For the reinforced concrete pipe types as well as for steel and ductile iron, a significant factor was the development of flexible joints sealed with rubber rings. With these joints pipelines have great flexibility and suffer minimal damage from earth movements while requiring much less time, expense and expertise in assembly.

Technological developments have also greatly enhanced corrosion protection measures ensuring long life to the more recently used pipe materials which would otherwise be destroyed in unfavorable soil environments or attacked by corrosive elements in the pipeline contents such as sewage. Protective measures include coatings and linings as well as cathodic devices.

More recently pipe manufacturers have entered the industry with new pipe materials, asbestos cement, nonreinforced thermoplastics and fiberglass reinforced thermosetting resins. Asbestos cement materials consisting of asbestos fibers embedded in a cement mortar mix were developed as early as World War I times and have gained wide use in diameters up to about 900 mm in municipal water distribution and irrigation systems as well as in sewers.
Plastics and fiberglass reinforced resins are the most recent developments and design and manufacturing procedures and processes, including considerations in joints and fittings, are still evolving with installation and operation experience. Unreinforced plastics have been and will continue to be generally confined to smaller (up to 400 mm) diameters but fiberglass reinforced resin materials are used in diameters exceeding 2,800 mm. In 1975, the Society of the Plastics Industry reported that over 650 million kilograms of various plastics were being converted into pipe annually in the United States. Of this more than 300 million kilograms were being used for pressure piping and nearly 120 million kilograms for sewers and drains.

Pipe materials are manufactured in two general categories, rigid pipe and flexible pipe. In the rigid pipe category are nonreinforced and reinforced concrete, clay, asbestos cement and grey cast iron. Flexible pipes include steel, ductile iron, plastic and pretensioned concrete cylinder pipes.

Rigid pipes in recent times have lesser wall thicknesses and weights as compared to earlier times but are so classified because design theory assumes that these pipes will not experience deflections greater than about two percent of pipe diameter and further assumes no significant support of the pipe walls from surrounding earth materials except for bedding. The work of Marston respecting loads on pipe and structural design procedures, including the work of Schlick and others, have provided the basis for design of the lighter pipe walls and for provision of competent bedding conditions.

Flexible pipe design, based upon the work of Spangler and others, assumes possible deflections up to five percent of the pipe diameter and further assumes support of the pipe walls by the surrounding earth materials including the pipe bedding. The design objective is a balanced system of
pipe material and surrounding backfill which minimizes pipe materials and overall costs.

The early pipelines, both constructed in place and prefabricated, were subject to failures and leakage because of rigidity of the pipe walls and joints and because of lack of sophistication in design, manufacture and installation. Leakage from low pressure pipelines and leakage into sewers was generally tolerated to a much greater extent than today. The development of design theory, materials technology, and manufacturing quality control procedures provided the means for totally eliminating or minimizing failures and leakage. While design and manufacturing errors and failures resulting from them still occur, they are unusual.

Principal causes of difficulties and failures in buried pipelines are installation errors including joint make-up, preparation of pipe bedding and placement of backfill around the pipe. Most reported failures of pipes have been related to poor construction practices, principally in bedding and backfilling; loads in excess of those assumed in design, quite often caused by construction equipment; or pipe broken because of differential settlement or hard spots in the trench bottom. Metal pipelines have also failed because of corrosion due to faulty or damaged coatings or lack of cathodic protection.

New pipe products have encountered problems usually attributable manufacturing procedures which have since been rectified and to lack of foresight or knowledge of pipe design on the part of the developers. An example is prestressed concrete pipe where calcium chloride used in the concrete, lack of required tension in prestressing wires, failure to completely embed prestressing wires, and sulfates in the soil have resulted in failures. As another example, some years ago the manufacturers of asbestos-cement pipe developed a new product line, called transmission pipe. This material is manufactured to a lesser service or safety
factor than distribution pipe and requires more care in bedding and backfill. Unfortunately, this requirement was not clearly communicated to either pipeline design engineers or installers who were eager to take advantage of the lower cost of this pipe. Failures due to external load occurred.

At the present time the reinforced concrete pipe industry is investigating new designs which will place more reliance on the bedding and backfill. Should these products reach the market without adequate advance information, the industry could experience similar problems.

The present State of the Art of pipeline materials is illustrated in Table 1. This table summarizes information for presently utilized pipeline materials including practical ranges of diameter, applications, and comments respecting advantages and disadvantages.
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<td>x</td>
<td>x</td>
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<td>0.13</td>
<td>x</td>
<td>x</td>
<td>Low capital investment</td>
<td>Low Pressure Capability, High Maintenance</td>
</tr>
<tr>
<td>Noncylinder Reinforced</td>
<td>300-4570</td>
<td>4.6</td>
<td>x</td>
<td>x</td>
<td>Durable with low maintenance</td>
<td>May deteriorate in alkali soils, if cement type is improper or acid soil not protected.</td>
</tr>
<tr>
<td>Concrete</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cylinder Reinforced Concrete</td>
<td>900-4570</td>
<td>28</td>
<td>x</td>
<td>x</td>
<td>Good flow characteristics</td>
<td>Difficult to repair</td>
</tr>
<tr>
<td>Noncylinder Prestressed</td>
<td>300 up</td>
<td>21</td>
<td>x</td>
<td>x</td>
<td>Resists backfill and external</td>
<td></td>
</tr>
<tr>
<td>Cylinder Prestressed</td>
<td>300 up</td>
<td></td>
<td>x</td>
<td></td>
<td>Loads well</td>
<td></td>
</tr>
<tr>
<td>Asbestos Cement</td>
<td>50-1500</td>
<td>30</td>
<td>x</td>
<td>x</td>
<td>Corrosion resistant</td>
<td>Low flexural strength, Subject impact damage, Difficult to locate underground, If crystalline, Corrosion resistant, Light weight, easily handled</td>
</tr>
<tr>
<td>Vitrified Clay</td>
<td>76-1070</td>
<td>0</td>
<td>x</td>
<td></td>
<td>Acid resistant</td>
<td>Subject to impact damage, Heavy, requires care in handling</td>
</tr>
<tr>
<td>Cast Iron</td>
<td>40-1200</td>
<td>35</td>
<td>x</td>
<td>x</td>
<td>Durable and strong</td>
<td>Subject to electrolysis, Subject to stress corrosion and attack from acid and alkali soils, Subject to corrosion when unloaded, Heavy to handle</td>
</tr>
<tr>
<td>Ductile Iron</td>
<td>80-1370</td>
<td>60</td>
<td>x</td>
<td>x</td>
<td>Durable and strong</td>
<td>Similar to cast iron</td>
</tr>
<tr>
<td>Steel</td>
<td>60-2100</td>
<td></td>
<td>x</td>
<td>x</td>
<td>High flexural strength</td>
<td>Subject to electrolysis and external corrosion in acid or alkali soils unless properly coated and/or wrapped and cathodically protected, Subject to hydrogen embrittlement, Low resistance to external pressure in larger sizes, Air-vacuum valves imperative in larger sizes</td>
</tr>
<tr>
<td>Prestressed Concrete</td>
<td>250-1370</td>
<td>28</td>
<td>x</td>
<td></td>
<td>Light weight and easily installed, Good flow characteristics when loaded</td>
<td>Subject to electrolysis unless cathodically protected, Low resistance to external pressure in larger sizes, Air-vacuum valves imperative in larger sizes</td>
</tr>
<tr>
<td>Polyvinylchloride</td>
<td>5-400</td>
<td>*</td>
<td>x</td>
<td></td>
<td>Corrosion resistant, not subject to electrolysis, High flow characteristics, Abrasion resistant, not subject to electrolysis</td>
<td>Low service temperatures, High movement due to thermal and hydraulic loads, Mechanical -leaking may damage pipe, Solvent joints require care in assembly, Subject to ultraviolet degradation, Low resistance to external pressure, PVC is notch sensitive</td>
</tr>
<tr>
<td>Polyethylene</td>
<td>10-1200</td>
<td>*</td>
<td>x</td>
<td></td>
<td>Light, easily handled</td>
<td></td>
</tr>
<tr>
<td>ABS</td>
<td>74-300</td>
<td>*</td>
<td>x</td>
<td></td>
<td>Good flow characteristics</td>
<td></td>
</tr>
<tr>
<td>Truss</td>
<td>200-380</td>
<td></td>
<td>x</td>
<td></td>
<td>Abrasion resistant</td>
<td></td>
</tr>
<tr>
<td>Reinforced Thermosetting</td>
<td>40-1800</td>
<td></td>
<td>x</td>
<td>x</td>
<td>Corrosion resistant, not subject to electrolysis, Light weight, easily handled, Good flow characteristics, Abrasion resistant, Repair kits available</td>
<td>Requires close quality control in manufacture, Requires high d2/2&quot; of care in underground lines</td>
</tr>
</tbody>
</table>

* Pressure capabilities of plastic pipes vary with plastic formulation.
CHAPTER II. CONSIDERATIONS IN DESIGN
AND PIPELINE MATERIALS SELECTION

Information specific to design, manufacture and installation of the different types of pipe materials in use today is presented in subsequent chapters of this report. Before presenting this specific information, this chapter presents general discussions of the several factors which are considered in the selection of pipe materials for a pipeline system.

Pipeline materials which are the subject of this report, are intended for conduits which will efficiently transport fluid materials, primarily water and sewage. The scope of this report and the supporting study did not include the compilation of information on pipeline hydraulics, surge pressures and controls, etc., which relate to the design of the waterway. The information compiled relates to the pipe materials and their capability to withstand the internal and external loads imposed upon them.

Technological advancements have greatly improved historically utilized pipe materials and also have produced new materials. Concurrently design theory and procedures have been the subject of extensive engineering research, testing and analysis, which will continue, particularly respecting buried pipelines, with the overall objective of achieving an engineered below-ground structure which will effectively support internal pressure (if applicable) and external loads with minimum overall costs of pipe materials and installation.

Consideration of cost and the competitive bidding process which is generally followed in pipeline projects have contributed to a trend to minimize the quantities of materials in pipe and therefore to reduce wall thicknesses and reinforcing. These considerations require close attention in selecting and designing pipe materials to satisfy
the two principal pipe strength requirements, i.e. internal pressure and external load.

As a result, pipeline practice includes the consideration of pipe in "pressure" and "nonpressure" categories. In the nonpressure category are vitrified clay and precast non-reinforced concrete and, although pipelines of these materials do at times carry limited amounts of pressure, they should not be expected to withstand internal hydraulic pressure in excess of 0.75 kg/cm². Reinforced concrete pipe without a steel cylinder can be designed for pressures up to 5 kg/cm² but should not be utilized for pressures in excess of this.

In the pressure pipe category are steel, prestressed concrete, pretensioned concrete cylinder; grey cast iron and ductile iron; and the plastic materials. Steel pipe is generally accepted as the best and only material applicable for extremely high heads (above 15 kg/cm²) and is widely used in intermediate to high pressures along with prestressed and pretensioned concrete. Ductile iron is used in low to intermediate pressures. Plastic materials can be utilized for low to intermediate heads and, with fiberglass reinforcement, can be used in higher pressures although the lack of installed experience demands careful consideration before a decision to make the latter application.

Design theory for internal pressure provisions is considered to be precise for all practical purposes and strengths of pipe materials to meet design requirements can be developed with long-used structural design procedures. On the other hand, external loads on buried pipe and the load resisting action of the pipe in the buried condition are not subject to precise definition. Because of this, and because presently utilized pipe materials when adequately designed for internal pressures and/or for normal stresses during handling and installation, exhibit significantly differing stiffness and resistance to external loads, pipe for buried installation and service is considered in two types: rigid pipe and
flexible pipe. Considerations respecting design application and installation of these two types of buried pipes, including references for more detailed consideration of these matters, are briefly summarized in this chapter.

The various pipe materials in use vary to some extent respecting: (1) friction factor and resistance to fluid flow; (2) length of useful life; and (3) corrosivity or the absence thereof. These factors can have a major influence upon selection of pipe materials for a particular system and they are also briefly discussed in this chapter. Also presented are considerations in testing and preparation of pipelines for operation as these considerations relate to pipe materials.

Types of Buried Pipes

Pipe materials manufactured for buried service are divided into "rigid" pipes and "flexible" pipes. Rigid pipe is primarily defined as that which is considered capable of deflections of up to two percent of the diameter without failure or damage. Marston, whose work was primarily with vitrified clay pipe, considered the limit of deflection of rigid pipe to be one-half of one percent of the diameter, but more recent work with reinforced concrete pipe reflects the potential for a larger degree of deflection. Flexible pipe is primarily defined as that which can withstand deflections up to five percent without failure or damage.

A design related distinction is made between rigid and flexible pipes where a flexible pipe is considered to derive its ability to resist external load by developing support from passive resistance of the surrounding soil. Rigid pipe is not considered to have this characteristic and is designed to resist external load through the structural strength of its cross section, assuming proper bedding.
Rigid Pipe

Rigid pipe is designed and produced in non-pressure pipe and pressure pipe. Non-pressure types are non-reinforced concrete pipe, including cast-in-place pipe, and vitrified clay pipe. Rigid pressure pipes are cast-iron pipe, asbestos-cement pipe and several types of reinforced concrete pipe.

Rigid pipe is used throughout the world for sewers, storm drains, and transmission and distribution of water. As with all pipe systems, in order for the pipe material to perform to its intended capabilities, the designer, specifier and installer must clearly understand the concerns and concepts of each. The specifications must be so written that the installer clearly understands and can achieve the bedding and backfill assumed by the designer. The designer, on the other hand, must have an awareness of the capabilities of the installer and make allowances for these in his design.

The external load on buried pipes is computed for purposes of design of the pipe cross section by formulae which utilize coefficients and factors based upon the work of Marston and others. A reference for such pipeline loading computations widely used in the United States and elsewhere is the Manual of Practice No. 37 of the American Society of Civil Engineers entitled "Design and Construction of Sanitary and Storm Sewers" (8).

The formula used for the pipe load computations reflects live loads, weight of earth cover and the bedding conditions to be provided for the pipe. The formula is presented following and the factors in the formula are briefly discussed:
Load on Pipe = \( (L.L. \times I.F.) + W_e \times (S.F.) \) 
\( \text{L.F.} \) 

Where:

- \( L.L. = \) Live load in kg/m
- \( I.F. = \) Impact factor
- \( W_e = \) Effective weight of earth over pipe in kg/m
- \( L.F. = \) Load factor
- \( S.F. = \) Safety factor

**Live Load** - The live load in the formula must be assumed by the designer and must be representative of actual field conditions, including future conditions. Established practice is to assume two equal wheel loads separated by a standard spacing and to apply an impact factor of 1.5 to 2.0 depending upon anticipated field conditions. Wheel load factors employed in various countries were found to be generally comparable and British practice is cited following for illustrative purposes. It should be noted that the effect of live loads becomes insignificant when earth cover on the pipe exceeds about three meters under which conditions the live load effect is eliminated from the foregoing formula.

Technical Bulletin No. 2 of the Concrete Pipe Association of Great Britain recommends wheel loads of 9070 kg and an impact factor of 1.3 for roads subject to heavy traffic. For less heavily travelled roads, live wheel loads of 7,260 kg each spaced 90 cm apart and an impact factor of 1.5 are recommended, and two wheel loads of 3,175 kg each spaced 90 cm apart and an impact factor of 2 are recommended for pipes laid in fields and access roads. In agricultural areas where trucks loaded to highway weights are liable to be pulling on and off roads a minimum live load of two wheels of 7,260 kg spaced 90 cm apart is recommended. It is also
recommended that an impact factor of not less than 1.5 be used. Where appropriate, such as in fields or unsurfaced or poorly maintained roads, the impact factor should be 2.

**Effective Weight of Earth** - The computation of the weight of earth over the pipe to be applied in the foregoing formula is generally based upon the formula \( W_e = CwB^2 \) where \( C \) is an empirical coefficient related to the depth of cover and characteristics of the overlying earth materials, \( w \) is the unit weight of the earth materials and \( B \) is the trench width. This formula assumes the pipe installed in a trench having a width adequate for placement of backfill materials. However, it will be recognized that with an extremely wide trench or, in the extreme, where a pipe is laid in open ground and covered with an embankment, the formula becomes impractical.

The latter condition is referred to as a "positive projecting" or "embankment" condition and the trench width at which this embankment condition is controlling is known as the transition width. In the embankment condition the foregoing formula becomes \( W_e = CwB_C \) where \( B_C \) is the pipe diameter and \( C \) is again an empirical coefficient which reflects the effect of the adjacent overlying embankment material which will act as a unit with the earth material located directly over the pipe to impose a load on the buried pipe.

Based upon the foregoing, it would appear desirable to minimize trench width in order to minimize load on the buried pipe. However, there must be adequate space between the pipe wall and the trench side walls to properly compact the sidefills, and particularly to compact materials under the pipe haunches. A minimum clear distance of about 30 cms between the pipe wall and the trench side is required for this. In smaller diameter pipes, this may require a trench width equal to or exceeding the transition width. Further, the actual trench width will depend on construction conditions, available equipment, ability of, and care taken by,
workmen and also upon soil conditions any or all of which may result in an overly wide trench.

These conditions cannot be predicted with accuracy; and in an extensive project, while the desired and assumed trench width may be substantially realized, the locations where it will be exceeded cannot be anticipated nor can the locations where any particular pipe unit will be installed. For these reasons, computation of the load on buried pipe should be based on projecting conduit loading unless specific requirements for limiting trench width are intended to be specified and can be relied upon absolutely.

**Load Factor** - The previously presented formula for computation of overall external load on buried pipes includes the Load Factor in the denominator and provides the means for reflecting the pipe installation conditions, including bedding and backfill. Standards for four classes of buried pipe bedding are illustrated on Figures 1 through 4 including applicable load factors assumed in British, American and International standards for the various classes.

Class A bedding providing for a concrete cradle under the pipe is normally only used in locations where unusually heavy cover or live loads or other conditions make it necessary. When the concrete cradle is constructed, the pipe is usually supported and the concrete placed under it. It is difficult during this process to keep the pipe from floating out of position which is generally achieved by loading the pipe with water or ballast. The concrete arch shown in the ACPA standards and on Figure 1 as having the same load factors as the concrete cradle, depends on excellent compaction of the supporting backfill. If this is not achieved, the pipe will eventually be supporting the additional weight of the concrete arch; and if the backfill is not uniformly compacted, it will settle unevenly and create a point load. For these reasons, it is recommended that it not be used.
CONCRETE PIPE ASSOCIATION
OF GREAT BRITAIN
TECHNICAL BULL. TIN No.1

FOR NORMAL CONDITIONS, L.F. = 3.4
Concrete cradle as above

FOR VERY WET CONDITIONS, L.F. = 3.4
Concrete bedding
Temporary grade to tamp if required

PLAIN CONCRETE CRADLE, L.F. = 2.6

INTERNATIONAL ORGANIZATION
FOR STANDARDIZATION
STANDARD 2783

FOR NORMAL CONDITIONS

AMERICAN CONCRETE PIPE
ASSOCIATION
DESIGN DATA 1

CONCRETE CRADLE

CONCRETE ARCH

Reinforced A_y = 1.0 % L.F. = 4.8
Reinforced A_y = 0.4 % L.F. = 3.4
Plain
L.F. = 2.8

TYPES OF BEDDING AND LOAD FACTORS
CLASS A BEDDING
CONCRETE PIPE ASSOCIATION OF GREAT BRITAIN
TECHNICAL BULLETIN No.1

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION
STANDARD 2768

AMERICAN CONCRETE PIPE ASSOCIATION
DESIGN DATA 7

FOR MOST CONDITIONS, L.F. = 2.2

FOR MOST CONDITIONS IN VERY WET, UNSTABLE SOIL, L.F. = 1.1

NOTE: For dimensions T, the following thicknesses are recommended:
- 600 mm or 24" for soil containing rock bands, hardpan, large boulders or other irregular hard spots
- 450 mm or 18" for soil containing rock bands, hardpan, large boulders or other irregular hard spots
- 300 mm or 12" for soil containing rock bands, hardpan, large boulders or other irregular hard spots
- 200 mm or 8" for soil containing rock bands, hardpan, large boulders or other irregular hard spots

Load factors A in different laying and backfill conditions:

| Bedding angle θ (degrees) | Projection ratio α | Trench and negative projection | Positive projection
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>high compression</td>
<td>ordinary compression</td>
<td>ordinary compression</td>
</tr>
<tr>
<td>60</td>
<td>0.85</td>
<td>2.0</td>
<td>3.1</td>
</tr>
<tr>
<td>90</td>
<td>0.85</td>
<td>2.6</td>
<td>3.1</td>
</tr>
<tr>
<td>120</td>
<td>0.78</td>
<td>3.0</td>
<td>2.6</td>
</tr>
</tbody>
</table>

1) For example, construction is assumed 60% of the minimum members of the aligned concrete section (50% should be deducted).

SHAPED SUBGRADE WITH GRANULAR FOUNDATION L.F. = 1.9

GRANULAR FOUNDATION L.F. = 1.9

TYPES OF BEDDING AND LOAD FACTORS
CLASS B BEDDING
CONCRETE PIPE ASSOCIATION OF GREAT BRITAIN
TECHNICAL BULLETIN No. 1

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION
STANDARD F785

AMERICAN CONCRETE PIPE ASSOCIATION
DESIGN DATA Y

GENERALLY ONLY SUITABLE FOR PIPES UP TO 300 mm DIAMETER IN UNIFORM FINE-GRAINED SOILS WHERE CONDITIONS ARE RELATIVELY DRY.

L.F. = 1.5

TABLE: Types of Bedding and Load Factors

Class C Bedding

<table>
<thead>
<tr>
<th>Bedding Angle (degrees)</th>
<th>Proportion ratio</th>
<th>Load factor A in different laying and backfill conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Trench and negative projection</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ordinary backfill compacted between X and Y</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ordinary backfill non-compacted between X and Y</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ordinary backfill compaction</td>
</tr>
<tr>
<td>0 to 20°</td>
<td>1.00</td>
<td>1.2</td>
</tr>
<tr>
<td>30</td>
<td>0.98</td>
<td>1.1</td>
</tr>
<tr>
<td>60</td>
<td>0.93</td>
<td>1.2</td>
</tr>
<tr>
<td>90</td>
<td>0.88</td>
<td>1.3</td>
</tr>
<tr>
<td>120</td>
<td>0.75</td>
<td>1.7</td>
</tr>
</tbody>
</table>

1) This bedding angle is not recommended

SHAPED SUBGRADE
L.F. = 1.5

GRANULAR FOUNDATION
L.F. = 1.5

LIGHTLY COMPACTED BACKFILL

COMPACTED BACKFILL
CONCRETE PIPE ASSOCIATION
OF GREAT BRITAIN
TECHNICAL BULLETIN No. 1

Trench bottom hand trimmed to support pipe throughout the length of its barrel. Jointing holes must be cut to prevent the pipes resting on their sockets.

L.F. = 1.1

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION
STANDARD 2785

NO CLASS D BEDDING

AMERICAN CONCRETE PIPE ASSOCIATION
DESIGN DATA 7

Loose backfill

L.F. = 1.1

FLAT SUBGRADE

TYPES OF BEDDING AND LOAD FACTORS
CLASS D BEDDING
Type B and Type C bedding are less costly to achieve. Some of the standards require that the circular arc portion of the trench bottom be shaped to the exterior diameter of the pipe. In a recent paper, (42) Professor M. G. Spangler discusses, and strongly recommends, this procedure adding, "It is not acceptable to lay the pipe on a flat bed and then try to tamp soil under the haunches in order to achieve the desired distribution." Preshaping the subgrade is a slow and painstaking task requiring close inspection. If not done properly, bedding conditions are essentially no better, and could be worse, than Class D conditions.

Some of the standards shown for Class B and C bedding on Figures 2 and 3 provide for placement of compacted granular materials beneath and around the lower pipe sector. As implied in Spangler's quoted remarks, this is difficult to achieve uniformly throughout the pipeline length. However, with water jetting and vibration it can be achieved to a great extent and is recommended for rigid pipe bedding with depth of cover up to about 8 meters and live loading as previously cited.

This type of bedding can be specified and relied upon in selecting load factors for pipe loading computations for special heavier loading conditions where the cost of Class A bedding may not be justified. However, for lengthy pipeline projects where close inspection and control cannot be universally assured, it is recommended that the Load Factors shown on Figures 3 and 4 be reduced to about 1.3 or less.

A recommended bedding procedure for rigid pipe provides for scarifying the pipe trench invert to a depth of about 10 percent of the pipe diameter, but not exceeding about 15 cm, whichever is less, and placing granular material with water jetting and vibration, up to about three eighths of the pipe diameter. This procedure assures that there will be no hard spots in the subgrade which would impose a point loading and unforeseen stresses in the pipe.
Class D bedding, which is considered to be "impermissible" by many people in pipeline work, is illustrated on Figure 4. It will be noted that the British standard provides for excavation of slots in the subgrade to accommodate the sockets, bells or collars at joints; whereas the American standard does not so provide. However, in practice slots are excavated and should be a specification requirement when this type of bedding is permitted. Class D bedding is not recommended. Should minimal pipe bedding of this nature be considered for special reasons, a minimum requirement should be that the trench invert be scarified as just mentioned.

A typical pipe trench with pipe strung along side ready for installation is shown in Figure 5. As mentioned previously, it is recommended that a trench in this situation be scarified to soften the invert earth material superficially before placing the pipe in the trench and backfilling.

Safety Factor - The formula for external pipe load provides for a safety factor multiplier which will increase the pipe load computed by the remaining elements of the formula; i.e. live loads and earth loads adjusted for Load Factor. A minimum safety factor of 1.5 is recommended for use in determining the required crushing strength of rigid pipe.

Flexible Pipe

A flexible pipe derives its capacity to support external loads from the passive resistance of the soils supporting the sides of the pipe as it deflects, in addition to its inherent strength. Flexible pipe fails by excessive deflection leading to collapse or buckling and flexible pipe design is directed to control of deflection.

Pipe materials manufactured in flexible pipe may be non-pressure or pressure and include steel, ductile iron and
FIGURE 5

TYPICAL PIPE TRENCH
plastics; pretensioned concrete cylinder pipe is also designed as a flexible pipe.

Because the design of flexible pipe is based upon using the structural capability of the surrounding soil for support, the bedding and backfill and the trench walls must have sufficient strength to provide this support. The native soil, therefore, must have sufficient stiffness to resist deformation and pressures transferred through the bedding and backfill material or compacted backfill must be placed to a width of two diameters on both sides of the pipe. The support exerted by the surrounding soil is maximum at the pipe to soil interface and decreases rapidly as the distance from the pipe increases, reaching an insignificant amount at about two pipe diameters from the pipe wall. The most critical areas for pipe support are beneath the haunches, and special measures must be taken in installation to insure proper support along the bottom of the pipe.

Tests on steel pipe with cement-mortar lining have shown that bond between the lining and the steel will be broken when deflection exceeds that which will cause a crack in the coating or lining of .25 mm. A recommended limiting deflection for flexible pipe with relatively inflexible linings is $\frac{D^2}{4000}$ where D is the pipe diameter. For pipe with flexible lining and coating such as coal tar or plastic linings and coatings on steel and ductile iron and for plastic pipes, the criteria for limiting deflection is set at 5 percent by many engineers. This amount of deflection is not the point at which the pipe would fail, but is selected as the point beyond which additional deflection may measurably restrict the capacity of the pipe. In practice, reduction in capacity may not be noticed at greater deflections.

The Marston formula, $W = CwB^2$, which is widely used for calculating earth loads on pipe was developed for rigid pipe

II-10
and if used for flexible pipe, results in too large a load. A realistic maximum load for a flexible pipe is that of the prism of soil over the pipe, which may be calculated by the formula:

\[ W = \text{whd} \]

where:

- \( w \) = unit weight of soil
- \( h \) = depth of fill over the pipe
- \( d \) = outside diameter of the pipe

The weight of soil over the pipe so computed must be increased by live load and impact factor allowances, if applicable, to obtain the vertical load on the pipe to be utilized in design formula discussed hereinafter.

The design of flexible pipe is based upon the work of Spangler and others who developed a great amount of empirical data from existing and experimental installation and from this data and structural engineering theory developed a formula for predicting pipe deflection. The formula and a discussion of its various factors is included in the previously referenced American Society of Civil Engineers Manual of Practice No. 37 entitled "Design and Construction of Sanitary and Storm Sewers." [8]

The scope of this report does not include an exhaustive discussion of the design of flexible pipe. However, the factors in the formula for prediction of deflection are discussed hereinafter in relationship to matters which must be considered in preparation of specifications and in the installation of pipe materials.

The formula for deflection, which is called the "Iowa Formula", is presented following:

\[ \Delta x = D_1 \times \frac{Kw_3}{E + 0.061E'F^3} \]

in which \( \Delta x \) is the horizontal and vertical deflection of the pipe in centimeters; \( D_1 \) is a deflection lag factor; \( K \) is a
bedding constant; \( W_c \) is the vertical load on the pipe in kg/cm, \( r \) is the mean radius of the pipe in centimeters; \( E \) is the modulus of elasticity of the pipe material in kg/cm\(^2\); \( I \) is the moment of inertia per unit length of cross section of the pipe wall in cm\(^4\)/cm; \( E' \) is the modulus of soil reaction in kg/cm\(^2\).

The deflection lag factor \( D_1 \) is an empirical factor which reflects the tendency of flexible pipe to continue to deform under load and most designers assume this factor to be 1.5 although lesser values as low as 1.25 may be used.

The bedding constant \( K \) relates to the angle subtended in the lower pipe sector by the bedding. Good practice in pipe design assumes a bedding angle of 90 degrees for which the literature indicates a constant \( K \) of 0.10. As previously discussed for rigid pipe installation, it is considered that a good bedding contact can be achieved by scarifying the trench invert and placing granular material around the lower pipe sector with water jetting and vibration. While this procedure can achieve greater than 90 degree bedding, the cited \( K \) factor of 0.10 is recommended unless special bedding is specified and achieved for unusual conditions.

The modulus of soil reaction \( E' \) is further defined as being equal to \( er \) where \( e \) is the modulus of passive resistance and \( r \) is the mean radius of the pipe thereby introducing the element of pipe size as well as the soil characteristics.

Determination of \( e \) and \( E' \) values is, in practice, empirical and is considered to be a matter for further testing and research. Most publications, including the foregoing reference (8), recommend use of an \( E' \) value of 49 kg/cm\(^2\) assuming side fill soil is compacted to 90 percent of maximum density for a distance of two pipe diameters on each side of the pipe and up to a level of 30 centimeters above the top of the pipe.
For flexible pipe installation, the United States Bureau of Reclamation has followed a practice of placing compacted granular material around the pipe up to 0.7 of the pipe diameter and if the undisturbed earth adjoining the pipe trench is found to be stable, the pipe trench is required to provide a minimum of 30 cm between the pipe wall and trench wall for placement of compacted backfill. The author recommends this practice as a minimum and an $E'$ value of 49 kg/cm$^2$.

The $EI$ term in the denominator of the foregoing formula reflects the structural strength of the pipe materials whereas the second term ($0.061E'r^3$) reflects the passive resistance of the soil. For larger pipe diameters, the formula may predict acceptable deflection for pipe wall thicknesses which do not provide sufficient local strength in bending and thrust to develop and utilize the supporting passive resistance. To avoid this, the pipe cross section should provide an $EI$ of not less than 10 to 15 percent of the term $0.061E'r^3$.

In summary, the design of flexible pipe is a cut-and-try procedure whereby a pipe cross section is selected for which predicted deflection is acceptable assuming the empirical factors of soil modulus $E'$, a deflection lag; and bedding. These parameters cannot be satisfactorily measured and can vary substantially particularly respecting actual installation performance. Therefore, it is important to utilize conservative values for them as outlined in the foregoing discussion.

Attention is also directed to the work of Reynold K. Watkins at Utah State University (Principles of Structural Performance of Buried Pipes$^{36}$). The latter has done further work on the concepts in Spangler's formula and has developed some new bases for flexible pipe design. Results of this work are not yet widely adopted, but are considered worthy of careful attention and review.
Friction Factors

Engineers and specification writers ask for, and in general pipe manufacturers attempt to achieve, minimum roughness in pipe wall interiors. Relative smoothness generally varies for the different pipe materials with plastic materials probably achieving the least friction loss.

Quite often manufacturers' representations make claims of lower friction factors than their product can achieve, particularly over the long term. Furthermore, quite often engineers utilize lower than practical friction factors for design purposes. Designers should always bear in mind that the formulae which relate friction factors to pipeline hydraulics are not precise and accuracies of less than 5 percent should not be assumed for pipeline sizing etc. At present, the formulae most widely used for pipeline hydraulic computations are the Darcy-Weisbach using relative roughness as developed by Colebrook and White; the Manning and the Hazen-Williams. All of these equations are being used in design of pipelines with satisfactory results. Reasonable values for friction factors in these formulae for various pipe materials are listed following:

<table>
<thead>
<tr>
<th>Pipe Material</th>
<th>Manning n</th>
<th>Hazen Williams C</th>
<th>Colebrook-White e/cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Finished</td>
<td>.012</td>
<td>135</td>
<td>.031</td>
</tr>
<tr>
<td>Rough</td>
<td>.014</td>
<td>120</td>
<td>.105</td>
</tr>
<tr>
<td>Asbestos</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cement</td>
<td>.012</td>
<td>140</td>
<td></td>
</tr>
<tr>
<td>Vitrified Clay</td>
<td>.013</td>
<td>110</td>
<td></td>
</tr>
<tr>
<td>Cast Iron</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uncoated</td>
<td>.014</td>
<td>130</td>
<td>.010</td>
</tr>
<tr>
<td>Steel</td>
<td>(enameled)</td>
<td>.012</td>
<td>.0076</td>
</tr>
<tr>
<td>Plastic</td>
<td>.011</td>
<td>150</td>
<td>.00021</td>
</tr>
</tbody>
</table>

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It should be recognized that friction factors in commercial pipe can vary from the theoretical by several percent depending upon the diameter (friction factors are slightly lower for larger diameters), interior lining or furnishing process and quality of workmanship.

From time to time, it is proposed, usually by pipe manufacturers, that differences in friction factors be a consideration in the evaluation of bid proposals. In theory, the proposal has merit; however, in practice such a comparison is subject to a number of variables. From the standpoint of long-term economics, it should be recognized that in all but some very special cases pipelines generally are required to carry full design capacity only intermittently. At less than full capacity pipe friction factors become substantially less significant. In the author's experience, attempting to evaluate bids on the basis of relative friction factors raises more disputes than the minor savings can justify.

**Life Expectancy**

It will be recognized that consideration of life expectancy of pipeline materials should fundamentally be based upon experience. However, only clay pipe and cast iron pipe offer examples (quite numerous, in fact) of installed experience in excess of 100 years. Other pipe materials presently in use, although they have been used in some form for more than 50 years, have been improved by technological development and/or are better selected for particular applications. Therefore, experience data for installations completed more than about 30 years ago are not necessarily reliable bases for projections of life expectancy for presently used pipe materials.

As a general comment, it is the author's opinion that present-day pipe materials, if properly designed, manufactured installed, operated, protected and maintained, and if selected
for appropriate applications, should remain useful indefinitely, i.e. in excess of the period or periods of years normally employed in economic analyses and evaluations. An example of an obvious exception would be the alkalinity control of reinforced concrete sewer pipe mentioned later in Chapter IV of this report.

However, it is also recognized that many of the projects in which the World Bank has been and will be involved are or will be located in countries and regions of the world characterized as "underdeveloped". This characterization raises the possibility that pipeline projects in such areas may encounter unusual conditions respecting design, materials selection, manufacturing, installation or operations which may shorten useful life of pipe materials utilized.

Project planning could assume shortened economic life factors in specific instances. However, it would appear to be more reasonable to expend extra effort to assure the use of conservative parameters of design and installation and the selection of pipe materials for which maximum experience data are available and for which manufacturing installation and operation involve the least complexities. This report attempts to provide the basis for these latter considerations.

A detailed report on pipeline performance was published in 1963 by the United States Bureau of Reclamation; and in 1976, the Standing Committee on Water Distribution of the International Water Supply Association published a report on Design Criteria and Experiences in the uses of various pipe materials. The conclusions of these reports respecting pipeline life expectancy, and the results of the United States Department of Transportation Office of Pipeline Safety annual reports were drawn upon for this discussion.

Concrete Pipelines

The Bureau of Reclamation reported on results of their survey and of an earlier survey by the American Concrete
Pipe Association including some 150 installations. The conclusions of the study were in part:

(1) When buried and away from freezing and thawing and other weathering forces, concrete pipe can reasonably be expected to last indefinitely.

(2) There is danger of damage to concrete pipe installed where the soil contains a high content of sulfate or the water is highly aggressive. Sulfate-resistant cement is effective in countering the first factor, and this can be supplemented by coating if thought to be necessary. No cases of failure due to leaching (a result of aggressive water) were reported or observed in the literature.

(3) The vast majority of owners indicate that average annual costs of maintaining the pipe and joints of concrete transmission lines to be none or negligible.

(4) Concrete pipes are seldom attacked by electrolytic action.

(5) Difficulties experienced in the use of prestressed concrete pipe have been attributed to overstressing of the wire reinforcement, use of calcium chloride in the concrete, and the presence of excessive sulfates in the surrounding soil."

Low water cement ratio and high density concrete are required to resist the effects of sulfate concentration. Fortunately, a low water cement ratio is required in the pipe manufacturing process. Centrifugally cast pipe also has a high density concrete. A recent study by the Cement Industry Technical Committee of California presented the recommendations shown in Table 2 which, if followed, should assure long life of concrete pipe.
<table>
<thead>
<tr>
<th>Soluble:</th>
<th>Sulfates:</th>
<th>Sulfates:</th>
<th>Maximum:</th>
<th>Minimum:</th>
</tr>
</thead>
<tbody>
<tr>
<td>In Soil:</td>
<td>In Water:</td>
<td>Cement:</td>
<td>Water/Cement</td>
<td>Cement:</td>
</tr>
<tr>
<td>%</td>
<td>mg/l</td>
<td>Type:</td>
<td>Ratio:</td>
<td>Content-kg/m³</td>
</tr>
<tr>
<td>0-0.02</td>
<td>0-150</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.02-0.10</td>
<td>150-1,000</td>
<td>No special requirement</td>
<td>0.55</td>
<td>213</td>
</tr>
<tr>
<td>0.10-0.20</td>
<td>1,000-2,000</td>
<td>Moderate Sulfate Resistant</td>
<td>0.50</td>
<td>254</td>
</tr>
<tr>
<td>0.20-1.50</td>
<td>2,000-15,000</td>
<td>Moderate Sulfate Resistant</td>
<td>0.45</td>
<td>306</td>
</tr>
<tr>
<td>Over 1.50</td>
<td>Over 15,000</td>
<td>High Sulfate Resistant</td>
<td>0.50</td>
<td>254</td>
</tr>
</tbody>
</table>

The International Standing Committee Report did not comment on concrete pipe, but in the case of prestressed concrete concluded that the average life of such pipe is 73 years with a minimum of 50 years and a maximum of 100 years. Two principal problems with prestressed concrete pipe reported by the USBR were use of calcium chloride in the concrete and the presence of excess sulfates in the soil, and the International Committee report lays failures of pipelines in Jordan, Regina and Karachi to this cause. Needless to say, care should be taken to avoid use of calcium chloride in manufacturing concrete pipe.

The USBR Report of Pipeline Performance Survey describes a pipeline 6 and 12 inches (150 mm and 300 mm) in diameter known as "Ball's Patent Indestructible Cement Pipe" which was installed in New Brunswick, Canada in 1859. Three kilometers of the ten kilometer long pipeline were still in use more than 100 years later. This pipe is very similar to modern steel-cylinder, reinforced concrete pipe.

Asbestos-Cement Pipelines
As discussed later in the chapter on asbestos-cement pipe, there are two distinct formulations and methods of
curing the pipe, and the life expectancy of the material is affected thereby. The USBR report concludes:

"Based on the data reviewed, it may be concluded that asbestos-cement material is very durable, and the pipe is capable of maintaining high carrying capacities. When cured by the high-pressure steam process (autoclaving), it has excellent resistance to sulfates. From its nature, it requires care in handling, backfilling, and bedding preparation to avoid breakage."

The International Committee Report comments on only two installations totalling 46 km in length and states that the results are statistically unreliable, but estimates an average life of 65 years with a minimum of 50 years and a maximum of 100 years.

Since asbestos-cement pipe was introduced some 60 years ago and was not widely used until some time after introduction, there are less than 50 years of installed experience. However, a large amount of this pipe is now in service and showing little or no signs of deterioration. It must be concluded that this type of pipe, properly designed and installed, can be expected to last indefinitely.

**Steel Pipe**

The USBR reported on about 100 steel pipelines having diameters from 32 mm to 3,350 mm, 43 percent of which were less than 600 mm in diameter and another 40 percent between 600 mm and 1,200 mm in diameter. The report comments that in most installations over 20 years old where asphalt was used for protection, the asphalt was reported to have failed and it appears that asphaltic protection is not reliable for this application. Comments on the performance of coal tar enamel or mortar coatings were favorable.

The International Committee report comments that, "Perfectly protected steel pipes are claimed to last forever. This is no doubt true, but no protection can be said to be perfect." Results of the Office of Pipeline Survey
reports for the period 1968 through 1976 indicate that bare steel pipe had 4.5 times as many failures as coated pipe, and coated pipelines without cathodic protection had 2.5 times as many failures as coated lines with cathodic protection. It is apparent that installation of cathodic protection, or at least the facilities for later installation, is a prudent course and application in conjunction with protective coatings is recommended. The International Committee estimates the life expectancy of steel pipe at a minimum of 30 years, a maximum of 100 years and an average of 56 years.

Cast Iron and Ductile Iron Pipe

Because of its heavy wall, cast iron pipe in a non-corrosive environment has been known to last nearly indefinitely. However, long term, in-ground tests by the United States Bureau of Standards have shown that the corrosion rate for cast iron and ductile iron is practically the same as for steel in a given environment. These studies have been questioned by the Cast Iron Pipe Association and defended by the investigators. While the studies may be debated, it is noted that CIPA recommends that both cast iron and ductile iron pipe be encased in a polyethylene sleeve. In a corrosive environment, this additional protection is mandatory. For purposes of economic analysis, a maximum life of 100 years with an average of 80 years is recommended by the International Standing Committee.

Plastic Pipe

Experience with plastic pipe is too limited at present to give any reliable statistical data. The rapid development of new products, and the improvement in production techniques has blurred the significance of even the short experience available. The materials are inert and when properly installed should last indefinitely. The care used
in installation may be the controlling factor in the determination of life expectancy. It has been noted that while joint failures will be exposed quickly, failures of the pipe itself as a result of installation deficiencies may be delayed longer than for other materials. The Standing Committee report concluded that while the statistics on plastic pipes were unreliable, the maximum life expectancy that could be stated at this time is 67 years.

**Clay Pipe**

The referenced reports do not cover clay pipe experience or life expectancy. However, it is well known that this material has an extremely long life in its limited application for nonpressure sewer installations.

**Corrosion and Cathodic Protection**

Buried metallic pipelines are subject to corrosion from three principal sources: (1) bacterial or biochemical oxidation such as is caused by the sulfate reducing bacteria that can cause external corrosion and have been identified as the cause of interior tuberculation, (2) galvanic corrosion, and (3) stray currents generated from external sources. Methods by which corrosion is reduced are selection of noncorrosive materials, application of protective coatings, and impressed current. Various protective coatings are discussed under sections on the type of pipe for which they are applicable. However, even where protective coatings are applied to steel pipe, and reinforced concrete cylinder pipe, it is recommended that nonconductive joints be electrically bonded at time of installation so that a current can be impressed in the line if galvanic action is detected. This is a relatively inexpensive process during installation, but is prohibitively expensive if it must be added later. A bonding jumper installation for cement-mortar lined and coated steel cylinder pipe may be seen in Figure 6.
Mild steel jumper rod field welded in place

Field applied cement mortar

Steel Bell Ring

Inside Face
Spigot Ring with Gasket

Steel Cylinder
Field applied cement mortar

Mild steel jumper rod

½d ≤ 2d
(See Detail Above)

Spigot End

Bell End

Mild steel jumper rod

3d 3d 3d
L

NOTE
When one jumper rod is required, it shall be installed at field top of pipeline. When two jumper rods are required, one rod shall be installed at each springline.

Field Top

Springline

Springline

Pipeline

BONDED JOINT FOR STEEL CYLINDER PIPE
Because iron corrodes more rapidly in an acidic solution than in an alkaline solution, pH should be a good indicator of corrosivity, but because soil conditions are so variable it has been found impracticable to correlate laboratory tests with field conditions and soil resistivity tests have become a substitute for chemical analysis. During planning and design of pipeline projects, soil resistivity surveys should be conducted and low resistivity areas identified. Electrical bonding of joints should be provided in such areas and it is advisable to make such provisions in all except areas of very high resistivity. After installation, electrical continuity should be verified and after a period of about one year corrosion surveys should be performed to identify pipe to soil potential and determine whether cathodic protection is economically justified and if so to design the protective system.

It has been found that temperature is a controlling factor in corrosiveness. Soils of low resistivity which would indicate severe corrosion potential in temperate zones have been found noncorrosive in Artic zones. On the other hand, otherwise noncorrosive soils may be found corrosive in the tropics and all soils in such areas should be assumed corrosive unless local experience has proved otherwise.

The foregoing discussion has dealt entirely with corrosion in buried pipelines. Pipelines installed above-ground do not experience the problems discussed. However, above-ground metallic pipe materials must be painted or coated to prevent rusting. Concrete pipe and cement mortar coatings on steel pipelines should not be employed in above-ground installations because weathering will cause them to crack and fail. Thermoplastic pipes which are subject to ultraviolet attack are also not recommended for aboveground installation.
**Thrust Anchorage**

Pipelines which do not have thrust resistant joints require restraint at changes in horizontal and vertical alignment. The theory and method of analysis are well discussed in numerous texts and need not be recounted here. Where thrust resistant joints can be installed as by welding or bolting, the thrust can be resisted by the friction between the soil and the exterior of the pipe. An equation for calculating the length of pipe required to resist thrust is:

\[
L = \frac{T \times S.F.}{(W + \frac{W}{f} + 2W_s)}
\]

where:

- \(T\) = Resultant thrust on the pipe in kg
- \(S.F.\) = Safety factor
- \(f\) = Coefficient of friction between pipe wall and earth material
- \(W_p\) = Weight of the pipe in kg/m
- \(W_w\) = Weight of water in the pipe in kg/m
- \(W_s\) = Weight of soil prism over the pipe kg/m

In the case of concrete, asbestos-cement or rubber gasketed plastic pipes, it is necessary to install thrust blocks capable of resisting the thrust by their own weight or by transmitting it to the soil. Thrust blocks are usually massive and in areas which are, or may become, congested by utilities, can be a problem. Studies and testing are now being conducted at Utah State University of "pinned" thrust blocks. These are reinforced concrete with the reinforcing steel embedded in a concrete pillar poured in a hole under the angle point. Results of this investigation should be published.
in the near future. Although not a new concept, the design factors developed should be of interest to the profession.

**In-Place Hydrostatic Testing of Pipelines**

In order to assure the acceptability of a completed pipeline, it should be given a hydrostatic or leakage test before acceptance. Water pipelines and sewer force mains should be given a water pressure test at 3.5 kg/sq. cm above the pipe pressure classification. Gravity sewers 600 mm in diameter or smaller are given either a water exfiltration test (if the difference in elevation between manholes is less than 3 meters) or an air test, if located above the water table. If located below the water table, a water infiltration test is used. Gravity sewers larger than 600 mm in diameter, or 600 mm in diameter and smaller if the elevation difference between manholes is greater than 3 meters, are given an air pressure test or water infiltration test as appropriate.

An acceptable allowable leakage for pressure pipelines may be computed by the formula:

\[
E = \frac{CND\sqrt{P}}{73}
\]

where:

- **E** = Maximum allowable leakage in liters per hour for the section of pipeline tested
- **N** = Number of joints in length tested
- **D** = Diameter of pipe in millimeters
- **P** = Test pressure in kg/sq. cm
- **C** = 1.0 for reinforced concrete pressure pipe with rubber gasket joints, cylinder type
- **C** = 3.0 for reinforced concrete pressure pipe with rubber gasket joints, noncylinder type
- **C** = 0.50 for cast iron pipe with mechanical or rubber gasket joints and asbestos-cement pipe
- **C** = 1.0 for other types of cast iron joints (caulked)

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No leakage is allowed for welded steel pipe with welded joints.

Comparable formulas for exfiltration tests in sewers are:

\[ E = 0.0009 \ L D \sqrt{H} \] for mortared joints

\[ E = 0.0002 \ L D \sqrt{2} \] for all other joints

Where:

\[ E = \] Allowable leakage in liters per minute

\[ L = \] Length of sewer tested in meters

\[ D = \] Diameter of pipe in meters

\[ H = \] Difference in elevation between the water surface in the upper manhole, and the invert of the pipe at the lower manhole, or if ground water is present above the invert of the pipe at the lower manhole, the difference in elevation between the water surface in the upper manhole and the ground water at the lower manhole.

Where a gravity sewer is below the ground water table, water infiltration tests are used in place of leakage tests. In an infiltration test, the upper end of the sewer is sealed off and the amount of leakage into the pipe or portions thereof is measured by the rise in water level in manholes. The infiltration limits are the same as for the leakage test.

An alternative to the infiltration test is an air pressure test in which the time for air pressure to drop between certain limits is measured. In conducting an air pressure test, the initial air pressure must be held for sufficient time to allow the temperature of the air to reach equilibrium with the pipe wall.
Disinfection of Potable Water Mains

Effective disinfection of potable water mains is directly affected by effective avoidance of contamination during construction. The pipe interior should be kept clean during construction. Even though it is standard practice to flush mains before disinfection, such flushing will not remove caked deposits in the line. If flushing is not effective, it is necessary to use "bugs" or "pigs" to clean the line. Material which becomes lodged in the joint spaces is particularly difficult to decontaminate.

To help combat this source of contamination, the Water Research Centre in Medmenham, England has developed a bactericidal gasket lubricant which is commercially available under the name "Medlube". Tests of this material have indicated a high degree of effectiveness. Use of bactericidal lubricant, however, should not be considered a replacement for routine disinfection or a cause for relaxing the quality of installation practice.

There are a number of disinfecting agents that have been used, but reports indicate that none is as effective as chlorine. If the line has been properly cleaned and flushed, the line may be adequately disinfected by filling with water having a free chlorine residual of one mg/liter. The free residual must be maintained above 0.5 mg/liter for 24 hours. If bacteriological tests are not satisfactory, the line should again be flushed and filled with water having a free chlorine residual of 50 mg/liter. The free chlorine residual in this case must remain above 25 mg/liter for 24 hours.

To repeat, however, maintaining pipe and joints clean during construction is the key to successful disinfection of pipelines. If this is accomplished, disinfection can be achieved with a minimum of expense.
CHAPTER III. NONREINFORCED CONCRETE PIPE

Nonreinforced concrete pipe has a long history of use for storm drains, sewers, land drainage and irrigation systems extending back to its development in Holland in the 1830's. Within the limitations of its application it is an economical material and may be installed with a minimum of skilled labor.

Fields of Application

In applications where open channel flow is anticipated, or where operating pressures will not exceed 0.75 kg/cm$^2$, nonreinforced concrete pipe may be used. It is most suitable for storm drains, land drainage or irrigation systems. It has also been used for sewers, but is more subject to attack by sulfuric acid than concrete pipe made by centrifugal spinning processes.

Limitations

Listed in Table 3 are the hydrostatic proof tests required in various standard specifications. As can be seen, nonreinforced concrete pipe is limited in its use to locations where internal pressure is a minimum. Rather than a hydrostatic proof test, DIN 4032 requires a water impermeability test in which the pipe, after soaking, is filled with water at a pressure of 0.5 kg/cm$^2$ and the water loss measured after a period of 15 minutes.
### TABLE 3
NONREINFORCED CONCRETE PIPE HYDOSTATIC PROOF TESTS

<table>
<thead>
<tr>
<th>Standard</th>
<th>Proof Test</th>
<th>Maximum Hydrostatic Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>BS4101</td>
<td>0.35 kg/cm²-1/2 min.</td>
<td></td>
</tr>
<tr>
<td>ASTM C14</td>
<td>0.7 kg/cm²-10 min.</td>
<td>2.8-3.5 kg/cm² (varies with diameter)</td>
</tr>
<tr>
<td>ASTM C118</td>
<td>0.7 kg/cm²-10 min.</td>
<td>2.8 kg/cm²</td>
</tr>
<tr>
<td>ASTM C505</td>
<td>1/3 maximum</td>
<td></td>
</tr>
</tbody>
</table>

External load supporting capability is determined by crushing load tests. British standards allow this test to be either a two or three-edge bearing test while United States standards allow only the three-edge bearing test. The ISO standards call for a vee block bearing test. However, as is discussed in Chapter II, the bedding factors recommended for pipe manufactured to the various standards are comparable. British Standards (BS4101), do not differentiate in crushing strength between the two types of tests and it may be considered that results are comparable for these tests.

Testing arrangements for the crushing tests are described in the various standard specifications. A comparison of the proof test requirements found in various standards is shown in Table 3. This table also indicates the limitation in sizes of nonreinforced concrete pipe produced under the various standards. As can be seen, there is wide variation in the standards and specific reference must be made to any reference standard or standards to evaluate comparability.

**Manufacturing Methods**

Nonreinforced concrete pipe is usually manufactured by mechanical compaction processes, compacting the concrete by
tamping or by the packerhead process. In the packerhead process, compaction of the concrete is accomplished by means of a rapidly revolving and rising element which packs the concrete against an outer form. Tamped pipe is made by tamping the concrete into the forms by means of rapid blows from tamper bars. The Vihy process is a variation of the tamped pipe in which the pipe form rests on a rotating table which is turned as the form is filled.

Nonreinforced concrete pipe may also be manufactured by placing and vibrating the concrete inside steel forms or by centrifugal casting, although centrifugal casting is seldom used for this type of pipe. In order of relative quality of product, rated from lowest to highest, are packerhead, tamped, centrifugally cast and cast and vibrated. The Vihy process mentioned above produces a high quality tamped pipe but with less consolidation of the concrete than the spinning or casting and vibrating processes.

**Joints**

In general, pipe of this type has an ogee or tongue and groove joint made up with mortar filling and bands. However, there is an ASTM specification for nonreinforced concrete irrigation pipe with rubber gasket joints. Typical joint configurations are shown on Figure 7.

**Fittings**

Bends and junctions in nonreinforced concrete pipe are made by cutting straight sections of pipe and mortaring the cut pieces together in the desired configuration. These fittings may be shop fabricated but frequently are constructed in the field. If the pipe is to carry internal pressure, junction fittings should be encased in concrete after installation.
FIGURE 7

OGEE JOINT

TONGUE AND GROOVE JOINT

BELL END WITH MORTARED JOINT

BELL END WITH ROUND RUBBER GASKET JOINT

JOINT TYPES FOR NONREINFORCED CONCRETE PIPE
Installation

Installation procedures for nonreinforced concrete pipe with mortar joints are the same as for reinforced concrete pipe and the reader is referred to that chapter for a description of the procedure.

Cast-In-Place-Pipe

A pipe which was developed in the irrigated farming areas of the Western United States and has found application for storm drains and sewers is cast-in-place, nonreinforced concrete pipe. The trench for the pipe is excavated with a semicircular bottom to the dimensions of the outside of the pipe. The pipe is then cast in the trench using a slip-form machine in a process that is similar to extrusion. Two different types of machines are available, both guided by a portion of the machine that slides on the trench bottom. In one system the pipe is cast in two sections, the bottom half being cast with one machine and the top half by another. The other method, known as No-Joint, is proprietary and only one machine is used.

In the two machine method the distance between the machines must be controlled in order to prevent the formation of a cold joint at the horizontal seam. This has been accomplished by tying the two machines together with cables.

The upper portion of the pipe is supported by metal forms installed after the lower portion is placed. The forms are about 1.25 meters long and create a circumferential offset in the upper half of the pipe of about 6 to 8 mm. In the case of pipe which has open channel flow, this is not a problem.

The pipe does not require skilled labor to construct. A six-man crew is required in addition to labor required for furnishing concrete. The equipment is portable.
Although the pipe, because of its ideal bedding, has strength to resist any reasonable external loads, it will eventually develop circumferential cracks from shrinkage. In the case of storm drains with open channel flow this usually will not cause a problem. In cases where the pipe is under pressure, liners have been installed to prevent leaking.

Certain precautions are necessary in the construction of this type of cast-in-place pipe. It cannot be cast in sandy soils which will not stay in place to form the lower circumference of the pipe, nor can it be constructed where the bottom of the pipe trench is within ground water at the time of construction.

It is not advisable to construct the pipe in extremely hot weather. When air temperatures at the site exceed 35°C, it is recommended that work be suspended. In very hot weather the final backfill and filling the line with water should be accomplished as soon as practical, preferably within 24 hours.

It is important that all pipe openings be kept sealed while the concrete is curing, and to fill the pipe with water as soon as practical. The pipe has been known to split when left empty after construction.

Machines are available for casting the pipe in sizes from 600 mm to 3,050 mm. It is claimed that production rates of from 40 meters per hour for the smaller diameters to 10 meters per hour for the largest sizes have been achieved.

A cross section of the completed pipe is shown in Figure 8, and construction of a cast-in-place concrete pipe is shown in Figures 9 and 10.
CAST-IN-PLACE MONOLITHIC CONCRETE PIPE
FIGURE 9

TRENCHING FOR CAST-IN-PLACE PIPE
FIGURE 10

SLIPFORM MACHINE CONSTRUCTING CAST-IN-PLACE PIPE
Reinforced Concrete Pipe - Noncylinder Type

Noncylinder reinforced concrete pipe is used for relatively low pressure applications such as culverts, storm sewers, sanitary sewers, and relatively low pressure transmission of water such as is found in irrigation systems. Internal pressures are generally limited to about 3.8 kg/cm², although in the United States the Bureau of Reclamation Standard Specifications for Reinforced Concrete Pressure Pipe permit its use up to 4.5 kg/cm².

The pipe consists of one or more reinforcement cages of rods or wire mesh embedded in a concrete wall. If steel rods are used for reinforcement, they are generally helically wrapped on a mandrel and welded to longitudinal rods. The cages are then encased in concrete by a number of different proprietary methods; however, these are, in general, variations of vertical casting with vibration or centrifugal spinning discussed in Chapter III. This type of pipe is generally manufactured in sizes from 300 mm to 3,660 mm in diameter and in lengths up to 6 meters.

Inner and outer circular steel cages for reinforcement are cast within the pipe wall. During pipe manufacture the reinforcing steel must be rigidly held in place. The usual procedure used is to tack weld steel "chairs", or studs to the reinforcing steel which act as spacers to maintain the concrete cover over the pipe and proper spacing between cages and this requires close inspection.

ASTM Designation C361 permits the use of an elliptical cage of steel as an alternative to a double cage in pressure classes up to 1.5 kg/cm². When this is permitted, the pipe units must be clearly and permanently marked in order that the pipe may be properly placed in the line with the minor axis of the ellipse vertical. It is advisable that these
marks be placed on the pipe interior in order that the inspector can visually ascertain that each pipe section is properly installed after backfill is placed. When elliptical reinforcement is used, chairs are placed along the major and minor axes and the reinforcement cage tied in position by means of tie wires extending through the forms. Minor errors in placement can greatly reduce the external load carrying capacity of the pipe. Experience has shown that a high percentage of pipe with elliptical reinforcement is either mis-marked or has the reinforcing steel out of position. For this reason, it is recommended that such reinforcement not be permitted.

Listed in Table 5 are various standard specifications for reinforced concrete pipe, noncylinder type and in Table 6 are the ranges of diameters and nominal pressures for which the pipe is intended. These standards vary widely in the use for which the pipe is intended and in the nature of the specification. The British, French, Japanese and American Water Works Association Standards specify dimensions and proof tests, but ASTM Designations C76 and C361 specify the manufacturing details of the pipe, including wall thicknesses and reinforcing steel. The ASTM C76 pipe is designed for crushing loads only. The ASTM C361 pipe is designed for specific pressure classes and for increments of 150 cm of earth cover.

A recent development is a glass fiber reinforced concrete pipe called Slimline produced by ARC Concrete Limited, an English firm. The manufacturer asserts that the pipes will withstand an internal pressure of 140 kN/m² (1.4 kg/cm²). The joint is a rubber gasket type conforming to British Standard 2494 and will hold pressure when tested in accordance with ASTM C425. Because of the placement of the glass fiber, a flush socket and spigot type joint is used, reducing the amount of trench excavation and eliminating the need for excavating bell holes for each joint. In addition, the ratio
<table>
<thead>
<tr>
<th>Standard</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BS 556</td>
<td>Concrete Cylindrical Pipes and Fittings Including Manholes, Inspection Chambers and Street Gullies</td>
</tr>
<tr>
<td>DIN 4035</td>
<td>Reinforced Concrete Pipe, Reinforced Concrete Pressure Pipe and Reinforced Concrete Fittings</td>
</tr>
<tr>
<td>AFNOR NF P16-341</td>
<td>Circular Pipe of Reinforced and Nonreinforced Concrete for Sewerage</td>
</tr>
<tr>
<td>JIS A 5302</td>
<td>Reinforced Concrete Pipes</td>
</tr>
<tr>
<td>JIS A 5303</td>
<td>Centrifugal Reinforced Concrete Pipes</td>
</tr>
<tr>
<td>JIS A 5332</td>
<td>Piled Reinforced Concrete Pipes</td>
</tr>
<tr>
<td>AWWA C302</td>
<td>Reinforced Concrete Pressure Pipe, Noncylinder Type for Water and Other Liquids</td>
</tr>
<tr>
<td>ASTM C76</td>
<td>Reinforced Concrete Culvert, Storm Drain and Sewer Pipe</td>
</tr>
<tr>
<td>ASTM C361</td>
<td>Reinforced Concrete Low-Head Pressure Pipe</td>
</tr>
<tr>
<td>ASTM C506</td>
<td>Reinforced Concrete Arch Culvert, Storm Drain and Sewer Pipe</td>
</tr>
<tr>
<td>ASTM C507</td>
<td>Reinforced Concrete Elliptical Culvert, Storm Drain and Sewer Pipe</td>
</tr>
<tr>
<td>Standard</td>
<td>Range of Diameters (mm)</td>
</tr>
<tr>
<td>------------------</td>
<td>-------------------------</td>
</tr>
<tr>
<td>BS 556</td>
<td>100-1830</td>
</tr>
<tr>
<td>DIN 4035</td>
<td>250-3600</td>
</tr>
<tr>
<td>DIN 4036</td>
<td>250-3600</td>
</tr>
<tr>
<td>AFNOR NF P 16-341</td>
<td>250-2000</td>
</tr>
<tr>
<td>JIS A 5302</td>
<td>150-1800</td>
</tr>
<tr>
<td>JIS A 5303</td>
<td>150-3000</td>
</tr>
<tr>
<td>JIS A 5332</td>
<td>150-3000</td>
</tr>
<tr>
<td>AWWA C302</td>
<td>300-2440</td>
</tr>
<tr>
<td>ASTM C76</td>
<td>300-3650</td>
</tr>
<tr>
<td>ASTM C361</td>
<td>300-2740</td>
</tr>
<tr>
<td>ASTM C506</td>
<td>380-3350</td>
</tr>
<tr>
<td>ASTM C507</td>
<td>460-3650</td>
</tr>
</tbody>
</table>
of diameter vs wall thickness is stated to be 12, as compared to 8 to 10 for pipe made with steel reinforcement, allowing further reduction in trench width requirement as well as reduction in handling weight. It should be noted that a ratio of 1:12 is standard American practice.

Respecting the use of glass fiber reinforcement, if the pipe is deflected under external load and the glass fibers are exposed to sulfuric acid, as in a sewer, in a strained condition, loss of strength could result. An extended exposure to this condition will be required before the material can be considered proven.

Concrete pipe used for sanitary sewers is subject to attack by sulfuric acid formed from the transported material. In order to resist this action, a number of techniques have been used. Concrete sewer pipe has been lined with vitrified clay liner plates which are immune to attack. The places are, however, porous and, over time, the concrete pipe still is exposed to the acid.

PVC sheets with a T-lock back which is cast into the pipe wall has been effective. Views of this type of lining are shown in Figures 11 and 12. Pipe with PVC liner has been in use in Los Angeles, California since the 1950's. However, failures have been reported due to improper anchoring and attack below the liner caused by acid run-down. Also various coatings such as coal-tar, coal-tar epoxy, epoxy mortar and other resin formulations, have been applied, but the impermeability of some of these over time is questionable. The perfect liner has not yet been developed. Other approaches to the problem of sulfuric acid attack on concrete pipe are the use of sulfur impregnated concrete, and replacement of cement with sulfur. These techniques in the manufacture of sewer pipe are presently under investigation. As far as is known, neither is in commercial production at the present time.
FIGURE 11

T-LOCK POLYVINYL CHLORIDE SHEETS IN PIPE FORMS
FIGURE 12

POLYVINYL CHLORIDE LINED SEWER PIPE
An alternative method recently developed is to control the alkalinity of the concrete used, and the thickness of the concrete over the steel to provide the desired economic life of the sewer. This technique is reported in a recent publication of the United States Environmental Protection Agency titled "Process Design Manual for Sulfide Control in Sanitary Sewerage Systems". (53)

Briefly the concept is to increase the alkalinity at the interior face of the pipe. Concrete pipe made with granitic aggregates usually has an alkalinity of 16 to 24 percent with pipe manufactured by a spinning process having higher values than that made by a cast process. However, when calcareous aggregates are used the alkalinity of the pipe material may be 100 percent or higher. Parenthetically, asbestos cement pipe has an alkalinity of about 50 percent.

By use of tables and charts contained in the referenced publication, the time required to consume the concrete cover over the reinforcing steel may be estimated, and the combination of cover and alkalinity may be adjusted to provide for an economic life for the pipe.

Joints

Pipe joints for reinforced concrete pressure pipe are made with modifications of a bell and spigot joint and have a rubber gasket for the sealing device. When concrete pipe is used for sewer or culvert pipe (nonpressure), it may have tongue and groove joints as described under nonreinforced concrete pipe and shown in Figure 13, or when used under pressure or nonpressure conditions it may have a gasketed joint using a round rubber ring or a compression type gasket as shown in Figures 14 and 15.

Two variations of retained rubber gaskets are shown, one with the gasket retained in a groove cast in the pipe end, and the other with the gasket retained between steps.
TONGUE AND GROOVE JOINTS FOR REINFORCED CONCRETE PIPE
ROLLED GASKET JOINT

RETIRED RUBBER GASKET JOINTS

RUBBER GASKET JOINTS FOR REINFORCED CONCRETE PIPE
cast in the pipe bell and pipe spigot. All three joint
types have been used successfully.

The gaskets retained in a groove or between steps re-
quire the application of a lubricant for assembly to prevent
the gasket from being dragged from position. The gasket
also apparently has less compression after assembly than the
rolled gasket joint. For these reasons the rolled gasket
joint requires more effort to assemble. The retained gasket
on the other hand actually requires some internal pressure
to seat or seal it. In large diameter pipe with low internal
pressure this may not occur, and special procedures may be
required to seat the gaskets and prevent the joints from
leaking. However, once the gasket is properly seated the
pressure may be reduced without loss of gasket seal.

Pipes with rubber gasket joints may be deflected to
provide for changes in alignment, the amount of deflection
being limited by the joint design. The amount of deflection
must not be great enough to allow the gasket to lose com-
pression or the pipe ends to touch. To achieve greater
deflections pipe ends are sometimes bevelled up to 5 de-
grees. Beyond this limit fabricated bends are required.

Jointing compounds may be used for culvert or drain
pipe which may be either cold applied or hot poured bitu-
minous compounds. It has happened that a mixture that
worked entirely satisfactorily in cool temperatures has
almost entirely run out of a joint when the weather became
extremely warm. Manufacturers' recommendations for these
compounds should be carefully followed.

In Plant Tests
In plant hydrostatic proof tests of the pipe required
by various standards are shown in Table 7. Crushing strength
tests specified in BS 556 and ASTM C76 require that the pipe
sections withstand the proof load required for the particular

IV-7
<table>
<thead>
<tr>
<th>Standard</th>
<th>Proof Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>BSI 556</td>
<td>20 psi</td>
</tr>
<tr>
<td>AWWA C302</td>
<td>120% of working pressure</td>
</tr>
<tr>
<td>ASTM C76</td>
<td>None</td>
</tr>
<tr>
<td>ASTM C361</td>
<td>120% of working pressure</td>
</tr>
<tr>
<td>JIS A5303 and A5332</td>
<td>2-6 kg/cm²</td>
</tr>
</tbody>
</table>
diameter and class of pipe without developing cracks wider than 0.01 inch (0.025 mm) in the pipe wall. Pipe manufactured to AWWA C302 and ASTM C361 is accepted on the basis of tests of samples of the pipe materials used in the manufacture.

**Fittings**

Fittings for reinforced concrete pipe are frequently fabricated of steel and lined and coated with cement mortar. However, in the United States a different technique is used for fabricating bends and elbows. This is to cut a section of pipe on an appropriate bevel using an explosive such as primacord, cutting the reinforcement steel, rotating the pipe sections to form the desired angle, rewelding the steel and filling the joint with mortar and welded wire mesh. Where internal pressures are expected to be in excess of 50 feet, the fitting is then encased in reinforced concrete. Details of such a fitting are shown on Figure 16. Shown on Figure 17 are details of outlets in the pipe wall. The diameter of these outlets should not exceed 30 percent of the pipe diameter.

**Handling and Shipping**

An important consideration in the production and installation of concrete pipe is the handling of the finished pipe. A newly made piece of pipe must be moved into the curing area, and then moved to the storage area. The pipe must be loaded onto trucks and railroad cars and unloaded at the jobsite. Equipment that is designed to perform all of the necessary handling operations and personnel experienced in blocking and tying down the pipe on the shipping vehicle is normally found in the manufacturing plant. As a result, the pipe generally arrives at the jobsite in good condition.

Concrete pipe which is stored outdoors in a hot dry climate should be kept moist. If not, minor cracking of the
Steel plate reinforcing collar. Minimum area = \( \frac{1}{2} \) times the area of reinforcement cut by half the opening. Provide 2-collars with double cage pipe. Weld collars to reinforcement.

Non-cylinder reinforced concrete pipe.

Steel plate sleeve cast into pipe wall.

**FIGURE 17**

**TYPICAL FLANGED TEE**

**IN**

**NONCYLINDER REINFORCED CONCRETE PIPE**
pipe wall may develop which will permit seepage under pressure. These cracks may seal in time by autogenous healing but except in unusual circumstances this should not be relied on, and in no case should it be allowed as a standard procedure. It is not uncommon in such climatic conditions to specify that the pipe must not be hauled to the trench-side more than a certain number of days, such as one week, before it is installed.

Excellent instructions for handling the pipe on the jobsite are contained in Technical Bulletin No. 1, "Construction of Flexibly Jointed Concrete Pipelines" published by the Concrete Pipe Association of Great Britain and in the Concrete Pipe Installation Manual of the American Concrete Pipe Association. It is recommended that a copy of one or both of these publications be on the jobsite.

**Installation**

Of the steps in pipe installation, the site preparation, excavation, foundation preparation, pipe bedding, pipe zone backfill and final backfill are common to all types of rigid pipe and have been discussed earlier. Herein we are concerned only with the jointing procedures.

In laying the pipe, general practice is to face the socket or spigot end of the pipe in the direction of laying. This helps prevent bedding materials from being forced into the socket during jointing. Installation of large diameter concrete pipe is illustrated on Figure 18.

Depending upon the use for which the pipeline is intended, several types of joints and jointing materials are available. For pressure pipe the round rubber ring type gasket is the only one which has proven satisfactory, although cases of bacterial degradation of natural rubber gaskets have been reported. This problem appears to be minimal with synthetic rubber compounds. Various types of compression joint sealants and joint fillers are used for
FIGURE 18

INSTALLATION OF LARGE DIAMETER REINFORCED CONCRETE PIPE
sanitary sewers, storm drains and culverts. Among these the most common are: flat rubber gaskets, mastic and cement mortar.

Mastic sealants consist of bitumen and inert mineral filler which are usually cold applied. The sealant is applied to the tongue or spigot end of the pipe and the pipe spigot inserted into the bell of the adjoining pipe. A sufficient amount of sealant should be used to fill the annular space with some squeeze out. During cold weather better workability of the mastic sealant can be obtained if the mastic and jointing surfaces are warmed.

Cement sealants consist of a mortar made of Portland cement, sand and water. The joint surfaces should be thoroughly cleaned and soaked with water immediately before the joint is made. A layer of mortar is placed in the lower portion of the bell end of the installed pipe and on the upper portion of the tongue or spigot end of the section to be installed. This type of joint has been used for many years in irrigation systems for internal pressures up to 15 meters of head. These pipelines, as may be expected, require more maintenance than pipelines with rubber gasket joints.

Bands of Portland cement mortar are sometimes specified to be placed around the exterior of the pipe joint, particularly where a metal ring is part of the joint. A slight depression should be excavated in the bedding material to enable mortar to be placed underneath the pipe and the entire external jointing surface cleaned and soaked with water. Special canvas or cloth diapers or wrappers can be used to hold the mortar as it is placed. Backfill material should be placed around the pipe immediately after the mortar band is placed.

Regardless of the specific type of joint and joint sealant or filler used, each joint should be checked to be sure all pipe sections are in a home position. For rubber
gasket joint sealants, it is important to closely follow the manufacturer's installation recommendations to assure that the gasket is properly positioned and under compression within the spigot and socket of the pipe joint.

**Jointing Procedures**

Joints for pipe sizes up to 600 mm in diameter installed on a nongranular and firm bedding can be assembled by means of a bar and wood block. The axis of the pipe section to be installed should be aligned as nearly as practicable with the axis of the last installed pipe section, and the spigot end inserted slightly into the socket. A bar should then be driven vertically into the bedding and wedged against the bottom socket end of the pipe section being installed. A wood block should be placed horizontally across the socket end of the pipe to act similar to the external assembly. Mechanical details of the specific apparatus used for pipe pullers or "come-along" devices may vary, but the basic lever action principle is used to develop the necessary controlled pulling force.

Larger diameter pipe is assembled using cranes or special equipment designed for the purpose such as a counterbalanced boom mounted on the side of a tractor. Alternatively the pipe sections can be assembled using internal blocking and winches.

**Connections**

When a pipe connects to a rigid structure such as a building, manhole or junction chamber, the bedding and foundation for the connecting pipe section should be densely compacted to minimize differential settlement. Inadequate compaction could result in the pipe being sheared off or cracked at the connecting point. Special connection joints are available which provide flexibility of the connecting pipe section, and if used, the manufacturer's installation
recommendation should be followed. If such special connections are not used a flexible joint should be installed not more than one pipe diameter from the face of the structure.

Acceptance Tests

The tests required by the material specifications assure that the pipe delivered to the jobsite meets or exceeds the requirements established for a particular project. Project specifications should include acceptance tests to assure that the assembled pipe will function as designed. Field tests applicable to all pipeline projects are soil density or compaction of the trench filling materials, line and grade, and visual inspection. In addition, when the pipeline is to be used as a pressure line, field hydrostatic tests are required and for sanitary sewers leakage limits are usually established for infiltration and exfiltration. Soil density test procedures are set out in many publications and are beyond the scope of this paper.

Reinforced Concrete Pipe-Cylinder Type

Reinforced concrete pipe with a steel cylinder within the pipe wall is used for higher internal pressure ratings than allowable for the noncylinder type.

With the exception of the steel cylinder, the pipe is in all respects similar to noncylinder reinforced concrete pipe. The joints are formed by steel rings welded to the steel cylinder for the bell and spigot which contain a rubber gasket. The configuration of the joint and wall are shown on Figure 19. As shown in the figure, the joint is filled with mortar both inside and outside. This is to protect the steel joint rings from corrosion by maintaining an alkaline environment. If the pipeline is to be installed in an environment where relatively large amounts of movement
CIRCUMFERENTIAL STEEL REINFORCEMENT

LONGITUDINAL STEEL REINFORCEMENT

MORTARED IN FIELD

BELL RING

SPIGOT RING

INSIDE FACE

RUBBER GASKET

STEEL CYLINDER

MORTARED IN FIELD

REINFORCED CONCRETE PIPE
CYLINDER TYPE
are anticipated after installation, this joint filling will retard or prevent movement and maybe eliminated. In any case it will probably be damaged by the joint movement and not be effective. In this case the joint rings must be given an effective corrosion resistant coating.

The pipe is manufactured in accordance with AWWA C300, Reinforced Concrete Pressure Pipe, Steel Cylinder Type, for Water and Other Liquids. This specification includes pipe from 600 mm to 2,440 mm in diameter. However, pipe up to 4,570 mm in diameter is produced to the same standard. Cylinder type reinforced concrete pipe is used for domestic water system transmission and distribution systems, sanitary sewer force mains, irrigation systems and industrial cooling water systems with pressures from 3.5 kg/cm$^2$ to 28 kg/cm$^2$. 

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CHAPTER V. PRESTRESSED CONCRETE PIPE

In recent years prestressed concrete pipe has become available throughout the world. Two basic types of pipe are manufactured, noncylinder and cylinder prestressed concrete pipe. The choice of which to use is dependent largely on the confidence one has in the ability of the pipe manufacturers to produce high quality concrete cores, free from rock pockets or other defects, to assure water tightness under the higher pressures for which this pipe is used.

Manufacture of prestressed concrete units of any type is a sophisticated technique requiring modern equipment specifically designed for the process and qualified operators. The equipment is costly and in general prestressed concrete pipe is manufactured in a central plant and transported to the installation site. In cases of extremely large diameter pipe, where large quantities of pipe are required, manufacturers have erected plants on site. Plant personnel should be well qualified and experienced in the production of prestressed concrete.

Records should be maintained of each of the materials used in the pipe production and of the tension under which the wire is wrapped. Specifications should provide for a minimum compressive strength of concrete at time of prestressing and this strength should be confirmed by testing concrete samples from the mix used in casting the pipe cores. It is vitally important that calcium chloride not be used to accelerate strength gain of the concrete because the chlorides will cause corrosion of the prestressing wires. For the same reason, aggregates which contain chlorides such as beach sand should not be used. It was noted in Chapter II that failures of prestressed concrete pipe in several locations were attributed to the use of calcium chlorides in the concrete.

Because circular prestressing has some inherent difficulties, the prestress method should be such that the tension applied to the wire during prestressing is continuously sensed.
and recorded and any change from the desired tension is automatically and immediately corrected or the equipment automatically shut down. Experience gained from construction of prestressed tanks indicates that perhaps the greatest problems occur in systems which apply tension by drawing a larger diameter wire through a die reducing the diameter to the desired amount but in effect cold working the wire. This procedure results in a number of fatally serious problems such as:

1. Temperature rise in the drawn wire.
2. Variation in the wire hardness, strength and surface conditions.
3. Variation in wire tension as a result of attempts to maintain tolerances in wire and die sizes and in speed of die drawing.

This procedure should not be permitted for prestressed pipe manufacture.

Early experience in prestressed concrete pipe encountered pipe failure which was attributed to voids under the prestressing wire which resulted in moisture pockets and corrosion of the wire. These voids occurred because mortar was applied over the wire after the wrapping was completed and did not get totally around the wire cross section. This was solved by applying a cement slurry to the concrete core immediately ahead of the wire wrapping so that the wire was embedded in the mortar. It is understood that this procedure is now universally utilized for all types of prestressed pipe manufacturing but it is important to assure that it is followed.

**Fields of Application**

Code of Practice 2010 of the British Standards Institution states that prestressed concrete pipe can be used for transmission of water, slurries and sludges, trade waste and sewage, and brines. Prestressed concrete pipe has been successfully used for ocean outfalls. Because the minimum diameter pipe normally manufactured by this technique is about 400 milli-
meters it is generally too large for distribution system piping and would normally be used for transmission mains.

**Prestressed Concrete Pipe—Noncylinder Type**

Prestressed concrete noncylinder pipe consists of a compacted concrete core longitudinally prestressed with pretensioned high-tensile steel wires embedded in the core. After the concrete in the core has reached sufficient compressive strength, it is circumferentially prestressed to withstand internal pressure and external design loads with high tensile wire and finally a cement mortar coating is applied to protect the circumferential prestressing wire.

**TABLE 8**

**STANDARDS FOR PRESTRESSED CONCRETE PIPE—NONCYLINDRICAL TYPE**

<table>
<thead>
<tr>
<th>Standard</th>
<th>Range of Nominal Diameters—mm</th>
<th>Works Hydrostatic Proof Pressure—kg/cm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>BS 4625</td>
<td>400—1800</td>
<td>1 1/2 times working</td>
</tr>
<tr>
<td>JIS A5333</td>
<td>500—2000</td>
<td>4—18</td>
</tr>
</tbody>
</table>

Although this type of pipe is manufactured in various parts of the world, few standard specifications for manufacturing prestressed concrete noncylinder pipe are available, the principal ones being British Standard 4625, and Japanese Industrial Standard 5333 as summarized in Table 8. The United States Bureau of Reclamation has prepared detailed specifications for this type of pipe which are contained in many of their contract documents. Although these specifications are for pressures up to 40 kg/cm², discussions with manufacturers indicate an upper
limit of about 35 kg/cm² for the joints. The joints for prestressed concrete noncylinder pipe are of the rubber gasket type, either roll on or retained in a groove, previously described under noncylinder reinforced concrete pipe. Some typical joints are shown in Figures 20 and 21. In assembling the rolled gasket joint, no lubricant is used on the gasket or pipe bell, and higher pressures are required for assembly than are normally required for the lubricated gasket type of joint.

Manufacturing Methods

The previous general description outlines the manufacturing procedure for prestressed pipe as generally followed in the United States and elsewhere. Processes employed in other countries include those described following in this section.

A widely used process for manufacturing prestressed concrete pipe is that of Rocla Pipes Pty., Ltd. This process has been franchised in numerous countries around the world. Rocla pipe is constructed by pretensioning longitudinal wires in the forms after which the concrete is introduced and compacted by centrifugal spinning. After the concrete core is removed from the form and cured, it is wrapped with high tensile strength wire which is coated with mortar.

A different production method is used in manufacture of Sentab pipes which are licensed by the Sentab Pressure Pipe Consortium of Malmo, Sweden. Sentab pipes are cast vertically under thorough vibration between an outer and inner form. In the outer form a specially constructed reinforcement cage is inserted, which is secured by longitudinal reinforcement wires that are clamped and prestressed between the ends of the outer form.

The outer form, which is in two parts, can be expanded by means of a special spring assembly. The inner form is lined with a rubber cover. Immediately after placing the concrete, pressure is applied between the rubber jacket and the inner form thereby compressing the concrete. Once the pressure
FIGURE 21

EPOXY MORTAR SPIGOT JOINT
FOR
NONCYLINDER PRESTRESSED CONCRETE PIPE
exceeds the force of the springs holding the outer form, it expands. The concrete and the circular reinforcement embedded in it are thereby forced outwards, the circular reinforcement being prestressed by taking up the excess pressure representing the "give" of the springs. The pressure is then maintained constant until the concrete has gained sufficient strength. Such a process depends on a high degree of maintenance and frequent testing of the springs to ensure that spring constant is maintained.

In-Plant Tests

BS 4265 requires that after circumferential prestressing each pipe shall withstand a hydrostatic proof pressure equal to 1-1/2 times the working pressure except where the design strength of pipe has been increased to provide for surge or waterhammer, in which case the hydrostatic proof test shall be the working pressure plus the allowance for surge, or 1-1/2 times the working pressure, whichever is greater. It should be noted this proof test pressure provides a safety factor of only 1.0 for the surge condition. It is critical, therefore, that surge in pipelines manufactured under this standard be carefully analyzed or special provision be made in the specifications for a more rigid test commensurate with design provisions. BS 4265 also provides that a sample of each design of prestressed concrete noncylinder pipe shall be subjected to a 3-edge crushing test load equivalent to the load that will be imposed on the pipe by the backfill alone, plus hydrostatic pressure test, and in addition an external 3-edge bearing test load equivalent to the total load of the backfill together with any surface acting transient loads plus an internal hydrostatic test pressure equal to the working pressure plus 10 percent.

Fittings and Special Pieces

Fittings and special pieces for prestressed concrete pipe are generally fabricated of steel plate which is then mortar-lined and coated. The bell and spigot ends are also steel and
require protective coating of coal tar epoxy, metalized zinc, or other satisfactory materials to protect them against corrosion.

Handling and Shipping

Prestressed concrete pipe properly manufactured is a rugged material, but should be loaded for transportation in such a way that the pipe units are secure and no movement can take place on the vehicle during transit. Unloading should be carried out by means of cranes of adequate capacity using properly designed slings and spreader beams or specially designed lifting gear. Slings should be placed around the circumference of the pipe and should not be threaded through the pipe as this may damage the jointing surfaces. For the same reason hooks located in the bells or spigots of the pipe should not be used. Pipes may be placed directly on the ground providing it is reasonably level and free from rocks. If the pipe is to be stacked in tiers, timbers should be placed between succeeding tiers.

Installation Methods

As with any pipe, trench width must be adequate to permit proper bedding and backfill, but should not be so excessive as to load the pipe beyond its design capabilities. The bottom of the trench should be prepared to an even bed complying with the class of bedding assumed in the design. Properly designed prestressed concrete pipe can be installed in any class of bedding provided that it is trimmed to provide a uniform support for the pipe. Grooves should be excavated to provide ample clearance for the bells to insure that the pipe does not rest upon the bell. Laying procedures are, in general the same as those described for reinforced concrete pipe.

Prestressed Concrete Cylinder Pipe

Prestressed concrete cylinder pipe is comprised of a high tensile steel wire wound on a concrete core containing a steel cylinder. The pipe provides optimal utilization of concrete
and steel for higher pressure applications and has an excellent record of performance. Because of its economic benefits in use of steel and concrete and its minimal weight, prestressed concrete cylinder pipe is replacing concrete cylinder pipe in many applications.

There are two types of prestressed concrete cylinder pipe, the difference being in the construction of the core. In one type, called lined cylinder pipe, the core consists of a steel cylinder lined with concrete and having the prestressing wire wrapped directly on the steel cylinder and a mortar coating applied. In the other type, called embedded cylinder pipe, the core consists of a steel cylinder embedded in concrete. The wire is wrapped on the exterior surface of the concrete and then coated with mortar. Lined cylinder pipe is designed generally for pressures up to 17.6 kg/cm² and embedded cylinder pipe up to 24.6 kg/cm², but both types have been designed and constructed for higher pressures. For higher pressures multiple layers of wire wrap are sometimes used.

The two types of pipe are comparable in performance although cathodic protection be required, the lined cylinder pipe may require more energy since the wire and cylinder are in contact. There is no known case to verify this supposition, however.

Only two standards have been published for prestressed concrete cylinder pipe. British Standard 4625 is written in such a way that either type of cylinder pipe can be manufactured under it in sizes from 400 mm to 1,800 mm only, while AWWA C301 describes both types in diameters from 400 mm to 3,600 mm. It should be noted that, as with the noncylinder prestressed pipe, cylinder prestressed concrete pipe is being manufactured in diameters as large as 6.4 meters.

Joints for prestressed concrete cylinder pipe are formed of steel spigot and bell rings welded to the steel cylinder with a round rubber ring 1 in a groove. Both British Standard 4625 and AWWA C301 require that the joint rings
be welded to the cylinders prior to hydrostatic testing of the cylinders. BS 4625 requires that the joint rings be given a sprayed zinc coating, AWWA C301 states that, "The portions of the rings that will be exposed on the completed pipe shall be protected from corrosion by an approved coating". Typical joint and pipe wall details are shown on Figure 22.

**Fields of Application**

Prestressed concrete cylinder pipe is used for transmission mains, distribution feeder mains, pressure siphons, penstocks, industrial pressure lines, water intake lines, sewer force mains and sewer outfall lines.

**Manufacturing Methods**

Manufacture of prestressed concrete cylinder pipe is a closely controlled process. The steel cylinders are formed and welded after which the joint rings, which have been fabricated and sized by stretching slightly beyond their elastic limit, are welded to the cylinders. Each steel cylinder is then hydrostatically tested to 1,550 kg/cm². The tested cylinder is then lined with concrete compacted by centrifugal spinning (lined cylinder pipe) or is placed inside forms and the concrete core is placed around it and compacted by vibrators (embedded cylinder pipe). After the core has cured to suitable compressive strength, the prestressing wires are anchored to embedded fittings and the wire wound around the core at a controlled tension. A Portland cement paste is applied immediately ahead of the wire to insure that the wire is completely embedded. A cement mortar cover is then placed over the wire and the completed pipe is subjected to controlled curing.

British Standard 4625 requires that after circumferential prestressing, each pipe shall withstand an in-plant hydrostatic proof test, but no crushing test. AWWA C301 provides only for
testing the individual pipe materials and does not provide for an in-plant hydrostatic proof test or load test.

**Fittings**

Fittings for prestressed concrete cylinder pipe are fabricated from steel plate or cylinders, lined and coated with concrete or mortar reinforced with welded wire mesh.

**Handling and Shipping**

Prestressed concrete cylinder pipe is handled and shipped in the same manner as described for prestressed noncylinder pipe, and requires the same care.

**Installation**

Prestressed concrete cylinder pipe is installed in the same manner as other types of rigid pipe designs. In common with other pipe types having steel joint rings, the inside and outside annular joint recesses should be properly filled with mortar.

An interesting installation problem was encountered on the Rialto Feeder of The Metropolitan Water District of Southern California. At three locations the pipe was installed on grades of 40 to 80 percent. In order to avoid handling the heavy pipe sections on these grades, the Contractor installed rails in the trench bottom and lowered the pipe into position by sliding it on rails.

**Special Comments**

One firm having experience with prestressed concrete cylinder pipe and specifically a five kilometer pumping plant discharge pipeline with a diameter of 3.4 meters, found that this pipeline has been in service since 1966 and annual inspections find the pipe in excellent condition.

Cathodic protection was installed on the pipeline (joint bonding jumpers were installed during construction) to protect
it from corrosion from cathodic protection in a crossing oil pipeline and this protection appears to be performing satisfactorily.

Experience with prestressed concrete cylinder pipe in diameters up to five meters in diameter installed by The Metropolitan Water District of Southern California, shows that one reach of this pipe has a length of some 9.3 kilometers and it has been in service since 1972. It is reported to be in excellent condition.
FIGURE 22

**LINED CYLINDER PRESTRESSED CONCRETE PIPE**

**EMBEDDED CYLINDER PRESTRESSED CONCRETE PIPE**

**PRESTRESSED CONCRETE CYLINDER PIPE**
CHAPTER VI. PRETENSIONED CONCRETE CYLINDER PIPE

Pretensioned concrete cylinder pipe is a type of pipe that has been manufactured and used extensively for many years in the western and southwestern parts of the United States for cross country transmission mains, distribution feeder mains, force mains and for plant piping in water and sewage treatment plants. Although its performance has been excellent, with the exception of two plants constructed in Colombia by Ameron its use has been restricted to this Western and South-western United States area, and the only standards for its manufacture are American Water Works Association Standard C303, United States Federal Specification SSP-381 and standard specifications prepared by the United States Bureau of Reclamation. These standards cover pretensioned pipe in sizes from 250 mm to 1370 mm in diameter and to a maximum design pressure of 28 kg/cm$^2$. Larger diameter pipelines have been constructed.

The basic element of the pipe is a welded steel cylinder with steel joint rings welded to its ends, formed and tested in the same manner as for other types of steel cylinder concrete pressure pipe. The cylinder is lined with centrifugally placed concrete mortar. Continuous, mild steel reinforcing rod is then helically wound, under measured tension, around the lined cylinder in a cement slurry. A mortar coating is then placed over the reinforcing rods by means of high velocity impaction.

The mortar lining is usually from 1.25 cm to 2 cm thick and the thickness of coating over the rods about 2 cm, although this can be varied to meet external load require- The rod wrapping provides additional stiffness to the pipe to resist external load and handling. The pipe cannot be economically designed as a structural member.
without reliance on the support provided by the pipe backfill and flexible pipe design procedures are followed. It is important, therefore, that the pipe bedding and backfill be carefully controlled. A section of the pipe wall and joint may be seen in Figure 23.

Figure 24 shows the spigot end of a completed pipe and Figure 25 shows completed pipe with the mortar cover removed to show the rod wrap and cylinder.

So far as is known, the only specifications for pretensioned concrete cylinder pipe are those mentioned above. The AWWA specification is a performance type while the Federal and Bureau of Reclamation specifications are manufacturing types giving cylinder thickness and total steel area for each diameter and pressure class of pipe.

**Limitations**

Because the pipe, particularly in the larger sizes, is a flexible pipe, it is critical for satisfactory performance that the bedding and backfill be so installed that the deflection of the pipe will be controlled and kept within safe limits.

Although the mortar lining and coating provides a protective cover for the steel cylinder, it is advisable to install bonding connections across the joints so that cathodic protection can be installed should it be found advisable. In high sulfate soils it is possible to use sulfate resistant cement on the exterior of the pipe.

**Manufacturing Methods**

Certain special equipment is required for the manufacture of pretensioned concrete cylinder pipe. In winding the reinforcement rod on the cylinder, a device for accurately tensioning the rod is necessary. The rod winding is part of a continuous operation in which a Portland cement slurry is applied to the cylinder just ahead of the rod and the mortar coating is applied by high velocity impact.
PRETENSIONED CONCRETE CYLINDER PIPE
FIGURE 24

SPIGOT END OF PRETENSIONED CONCRETE CYLINDER PIPE
FIGURE 25

PRETENSIONED CONCRETE CYLINDER PIPE WALL CONSTRUCTION
immediately following it in order to ensure that the rod is completely coated with cement mortar. Specialized equipment is required to accomplish this operation efficiently.

Prior to any lining or coating, each steel cylinder with joint rings welded to its ends is subjected to a hydrostatic test using water pressure which stresses the steel to a unit stress of at least 1400 kg/cm² but not more than 1760 kg/cm². Quality control of the lining and coating is by standard procedures for testing concrete.

Fittings

Both of the referenced standards include specifications for fabrication of special adapters and regular fittings. These are fabricated of welded steel sheet or plate and lined and coated with cement mortar as described for prestressed concrete pipe.

Handling and Shipping

Because of the flexibility of pretensioned concrete pipe, it is recommended that wooden cross braces be installed in pipe 900 mm in diameter and larger prior to loading the pipe at the plant for shipping. This bracing should be left in place until the pipe is installed and partially backfilled. It is also recommended that the pipe ends be kept closed with plastic sheets or similar material until ready for installation to prevent too rapid drying of the interior mortar lining. As with any pipe, proper blocking and tie-down are required during shipping.

Installation Methods

The process of assembling the pipe sections can be divided into three basic operations. Prepare the bell and spigot, join the pipe sections, and fill the joint recesses. The bell and spigot are prepared by cleaning both and lubricating them with a vegetable soap compound. Because the
joint rings are steel, they require protection to prevent corrosion and the lubricant should be kept in the area of the gasket groove in order to get a good bond with the joint mortar. The gasket is then lubricated and stretched into the groove. The interior joint recess is pointed with mortar after the section is in place. A spacer block should be placed in the bell before the sections are joined to keep the space to the proper width. The position of the rubber gasket should be checked with a feeler gage.

The filling of the joint recess requires two operations since both the inside and outside annular spaces must be filled. The inside annular space on pipe larger than 600 mm in diameter is filled by hand with a stiff mortar.

In hand pointing inside joints, three or four sections of pipe should be placed beyond the joint to be pointed before the pointing operation. In hot weather inside joints should not be pointed before the backfill is in place, otherwise, the sun's heat will tend to crack the joint mortar.

In smaller diameters which cannot be entered by workmen, the shoulder of the bell is covered with a stiff mortar before the spigot is inserted and a swabbing device, such as an inflated rubber ball wrapped in burlap and with a wire attached is placed in the previously laid section of pipe. The wire is threaded through the next pipe section to be laid. When the sections are joined, the spigot squeezes the mortar into position against the shoulder of the bell. Then the swabbing device is pulled past the joint by means of the wire, and the excess mortar is wiped away leaving a smooth, flush inside joint.

Outside joint spaces are filled with cement mortar grout after bands or diapers are fixed around the openings. The joint band should be fastened with metal strapping or some similar material. With the band in place an opening is made into which grout can be poured. The grout should be
poured in such a way that it will flow around the pipe in one direction only to avoid air pockets on the bottom.
CHAPTER VII. ASBESTOS CEMENT PIPE

Asbestos cement pipe was developed in Europe prior to World War I and has experienced steady growth throughout the world. The pipe is manufactured for both pressure and non-pressure use, and in diameters from 50 mm to 1,500 mm although not all standards cover all sizes. Tables 9 and 10 list standards for pressure and nonpressure asbestos cement pipe.

Pressure Pipe

Table 9 includes two standards (ISO 2785 and AWWA C401) which present detailed procedures for selection of pressure pipe classes. Both standards include curves for pipe selection which reflect both bursting pressure and external load for various pipe classes, including the effect of recommended safety factors.

Table 11 presents a comparison of requirements for hydrostatic test pressures for asbestos cement pressure pipe in the various standards. To the extent possible, the table illustrates the correlation between the various pipe classes in relation to test pressures, i.e., the different pipe classes which require the same or closely comparable test pressures are grouped in the same horizontal line in the table.

The pipe classification systems illustrated in Table 11 reflect internal pressure capability but, because of differing assumptions regarding safety factors and units of measure, the class designations are not the same. For example, ISO Class 25 requires a test pressure of 25 kg/cm² which class a designer would select for a working pressure of about 7 kg/cm² assuming a safety factor of about 3.5. AWWA Class 100 also requires test pressure of 25 kg/cm² but reflects a working pressure of 100 pounds per square inch or 7 kg/cm² plus a safety factor of about 3.5.
<table>
<thead>
<tr>
<th>Title</th>
<th>Range of Dimensions in mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISO R160</td>
<td>Asbestos cement pressure pipe</td>
</tr>
<tr>
<td>BSI 486</td>
<td>Asbestos cement pressure pipe</td>
</tr>
<tr>
<td>AFNOR NF P 41-302</td>
<td>Asbestos cement pipe for pressure pipelines</td>
</tr>
<tr>
<td>JIS A 5301</td>
<td>Asbestos cement water pipes</td>
</tr>
<tr>
<td>JIS A 5315</td>
<td>Asbestos cement joints for asbestos cement water pipes</td>
</tr>
<tr>
<td>DIN 19800</td>
<td>Asbestos cement pressure pipe</td>
</tr>
<tr>
<td>ASTM C296</td>
<td>Asbestos cement pressure pipe</td>
</tr>
<tr>
<td>ASTM C668</td>
<td>Asbestos cement transmission pipe</td>
</tr>
<tr>
<td>ASTM C500</td>
<td>Testing asbestos cement pipe</td>
</tr>
<tr>
<td>AS 1711</td>
<td>Asbestos cement pressure pipe</td>
</tr>
<tr>
<td>AWWA C400</td>
<td>Asbestos cement pressure pipe, 4 inch through 24 inch (100 mm through 610 mm) for water and other liquids</td>
</tr>
<tr>
<td>AWWA C402</td>
<td>Asbestos cement transmission pipe, 18 inch through 42 inch (460 mm through 1070 mm) for water and other liquids</td>
</tr>
<tr>
<td>ISO 2785</td>
<td>Guide to the selection of asbestos-cement pipes subject to external loads with or without internal pressure</td>
</tr>
<tr>
<td>AWWA C401</td>
<td>Standard practice for the selection of asbestos-cement water pipe</td>
</tr>
<tr>
<td>Standard</td>
<td>Description</td>
</tr>
<tr>
<td>------------</td>
<td>--------------------------------------------------------------</td>
</tr>
<tr>
<td>ISO R 391</td>
<td>Building and sanitary pipes in asbestos-cement</td>
</tr>
<tr>
<td>ISO R 392</td>
<td>Asbestos-cement pipe fittings for buildings and sanitary purposes</td>
</tr>
<tr>
<td>ISO R 881</td>
<td>Asbestos-cement pipes, joints, and fittings for sewerage and drainage</td>
</tr>
<tr>
<td>AFNOR NF P 16-304</td>
<td>Tubes - Evacuation pipe in asbestos-cement for deep sanitation work</td>
</tr>
<tr>
<td>DIN 19831 &amp; 19841</td>
<td>Asbestos-cement drain pipe</td>
</tr>
<tr>
<td>ASTM C428</td>
<td>Asbestos-cement nonpressure sewer pipe</td>
</tr>
<tr>
<td>ASTM C644</td>
<td>Asbestos-cement nonpressure small diameter sewer pipe</td>
</tr>
<tr>
<td>ASTM C663</td>
<td>Asbestos-cement storm drain pipe</td>
</tr>
</tbody>
</table>
### TABLE 11

ASBESTOS CEMENT PRESSURE PIPE
HYDROSTATIC TEST PRESSURES

<table>
<thead>
<tr>
<th>Series</th>
<th>ISO R160 Test Pressure: kgf/cm²</th>
<th>BS 486 Test Pressure: kgf/cm²</th>
<th>NF A1-302 Test Pressure: kgf/cm²</th>
<th>AWWA C400 &amp; Test Pressure: kgf/cm²</th>
<th>ASTM C296 Test Pressure: kgf/cm²</th>
<th>JIS A5301 Test Pressure: kgf/cm²</th>
<th>AS 1711 Test Pressure: kgf/cm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>200 6</td>
<td>12</td>
<td>13</td>
<td>215</td>
<td>18</td>
<td>18</td>
<td>12</td>
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<tr>
<td></td>
<td>400 12</td>
<td>18</td>
<td>18</td>
<td>221</td>
<td>22</td>
<td>22</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>600 18</td>
<td>24</td>
<td>22</td>
<td>230</td>
<td>22</td>
<td>22</td>
<td>18</td>
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<tr>
<td></td>
<td>800 24</td>
<td>30</td>
<td>22</td>
<td>250</td>
<td>22</td>
<td>22</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>1,000 50</td>
<td>30</td>
<td>28</td>
<td>300</td>
<td>22</td>
<td>22</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>515</td>
<td>27</td>
<td>28</td>
<td>315</td>
<td>22</td>
<td>22</td>
<td>18</td>
</tr>
<tr>
<td>II</td>
<td>15 15</td>
<td>20</td>
<td>20</td>
<td>250</td>
<td>22</td>
<td>22</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>20 20</td>
<td>25</td>
<td>25</td>
<td>250</td>
<td>22</td>
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<td>18</td>
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<tr>
<td></td>
<td>25 25</td>
<td>30</td>
<td>30</td>
<td>250</td>
<td>22</td>
<td>22</td>
<td>18</td>
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<td>30</td>
<td>30</td>
<td>250</td>
<td>22</td>
<td>22</td>
<td>18</td>
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<tr>
<td></td>
<td>35 35</td>
<td>30</td>
<td>30</td>
<td>250</td>
<td>22</td>
<td>22</td>
<td>18</td>
</tr>
</tbody>
</table>

### Minimum Ratio Between Test Pressure and Burst Pressure

<table>
<thead>
<tr>
<th>Diam. (mm)</th>
<th>Ratio</th>
<th>Diam. (mm)</th>
<th>Ratio</th>
<th>Diam. (mm)</th>
<th>Ratio</th>
<th>Class</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>50-100</td>
<td>2</td>
<td>-100</td>
<td>2.0</td>
<td>60-100</td>
<td>2.0</td>
<td>100</td>
<td>1.14</td>
</tr>
<tr>
<td>125-200</td>
<td>1.75</td>
<td>150-225</td>
<td>1.75</td>
<td>125-200</td>
<td>1.75</td>
<td>150</td>
<td>1.14</td>
</tr>
<tr>
<td>250-1000</td>
<td>1.5</td>
<td>250-500</td>
<td>1.50</td>
<td>250-</td>
<td>1.50</td>
<td>200</td>
<td>1.14</td>
</tr>
<tr>
<td></td>
<td></td>
<td>600-</td>
<td>1.25</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Nonpressure Pipe

The available standards for asbestos cement sewer (non-pressure) pipe are listed in Table 10.

ASTM C428 specifies seven classes of asbestos-cement pipe for nonpressure sewer pipe based on the three edge crushing strength of the pipe. The concept of this standard is that the pipe has the same classification as its crushing strength, that is all Class 3300 sewer pipe, regardless of size has a three edge bearing strength of 3,300 lbs. per lineal foot (4900 kg/m). The safety factor is left to the designer and should be 1.5 unless unusual conditions are identified or anticipated. This classification system has been used since 1958. However, in 1974 an Ad Hoc committee of the Asbestos Cement Pipe Producers Association, in attempting to find a simplified product line, contracted with the University of Utah to investigate the buried strength of the pipe. As a result of the studies, new standards have been presented to the ASTM. The new standards, if approved, will classify asbestos-cement sewer pipe related to depth of cover and class of bedding. These designations will be:

<table>
<thead>
<tr>
<th>Pipe Designation</th>
<th>Class C Bedding</th>
<th>Class B Bedding</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Depth of Cover</td>
<td>Depth of Cover</td>
</tr>
<tr>
<td>Series 6/10</td>
<td>6 ft. (2m)</td>
<td>10 ft. (3.0m)</td>
</tr>
<tr>
<td>Series 12/16</td>
<td>12 ft. (4m)</td>
<td>16 ft. (5.25m)</td>
</tr>
<tr>
<td>Series 18/22</td>
<td>18 ft. (6m)</td>
<td>22 ft. (7.22m)</td>
</tr>
</tbody>
</table>

Each pipe designation, i.e., series 12/16, identifies the maximum depth of soil cover for which the specific series of pipe may be safely installed with bedding conditions Class C and B, corresponding to those discussed under concrete pipe, respectively. Therefore, Series 12/16 is suitable for installation with a depth of soil cover up to 12 feet (4m) using

VII-5
Class C bedding and a depth of soil cover up to 16 (5.25 m) feet using Class B bedding.

Shown in Table 12 below are the applied flexural proof loads for small diameter pipe and in Table 13 are shown the minimum crushing loads which will be included in the new standard:

<table>
<thead>
<tr>
<th>Designated Pipe Diam. mm</th>
<th>Pipe Length m</th>
<th>Test Span m</th>
<th>Total Applied Load All Series kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>3</td>
<td>2.74</td>
<td>250</td>
</tr>
<tr>
<td>150</td>
<td>3</td>
<td>2.74</td>
<td>680</td>
</tr>
<tr>
<td>200</td>
<td>3</td>
<td>2.74</td>
<td>1,360</td>
</tr>
</tbody>
</table>

In pipe sizes 200 mm and smaller, the longitudinal beam strength must be considered, and is the controlling criteria for 3 m, and 4 m lengths.

ISO Standard R881 contains a table for selection of classes of nonpressure pipe based on external pipe loads. The pipe is classified according to external load carrying capability (Class $X_1 = 2000$ kg/m, Class $X_2 = 3300$ kg/m).

**Fields of Application**

Asbestos-cement has a proven record of performance in transmission of water, sewage and storm water. Selection of the proper class of pipe requires consideration of the combined effects of external loads and internal pressure. The selection process is well described in ISO 2785 and AWWA C401 as well as manufacturer's publications. It should be noted that these publications are only applicable to the type of pipe for which they are prepared. Use of the selection charts places the responsibility for choice of safety factors on the designer.
<table>
<thead>
<tr>
<th>Pipe Diameter (mm)</th>
<th>Series 6/10 kg/m</th>
<th>Series 12/16 kg/m</th>
<th>Series 18/22 kg/m</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>1,000</td>
<td>1,560</td>
<td>2,050</td>
</tr>
<tr>
<td>125</td>
<td>1,170</td>
<td>1,780</td>
<td>2,460</td>
</tr>
<tr>
<td>150</td>
<td>1,340</td>
<td>1,940</td>
<td>2,790</td>
</tr>
<tr>
<td>200</td>
<td>1,860</td>
<td>2,680</td>
<td>3,790</td>
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<td>250</td>
<td>2,050</td>
<td>2,980</td>
<td>4,170</td>
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<tr>
<td>300</td>
<td>2,150</td>
<td>3,200</td>
<td>4,500</td>
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<tr>
<td>375</td>
<td>2,460</td>
<td>3,535</td>
<td>5,430</td>
</tr>
<tr>
<td>450</td>
<td>2,830</td>
<td>4,090</td>
<td>6,360</td>
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<td>525</td>
<td>3,200</td>
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<td>8,260</td>
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<td>600</td>
<td>3,570</td>
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<td>10,340</td>
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<tr>
<td>675</td>
<td>3,940</td>
<td>7,220</td>
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<tr>
<td>750</td>
<td>4,760</td>
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<td>13,470</td>
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<td>825</td>
<td>5,140</td>
<td>9,670</td>
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<tr>
<td>900</td>
<td>5,660</td>
<td>10,640</td>
<td>16,140</td>
</tr>
<tr>
<td>990</td>
<td>6,060</td>
<td>12,200</td>
<td>17,340</td>
</tr>
<tr>
<td>1,025</td>
<td>7,510</td>
<td>13,320</td>
<td>18,820</td>
</tr>
</tbody>
</table>
Manufacturing Methods and Pipe Characteristics

Asbestos-cement (AC) pipe is manufactured by two different methods. In the Mazza process, the asbestos-cement slurry is picked up on a canvas belt and transferred under high pressure rollers onto a steel mandrel which constitutes the inner form for the pipe. The Magnani method forms the pipe around a canvas sleeve mounted on a perforated mandrel which is rotated in a slurry bath. Excess moisture is removed from the pipe material by pulling a vacuum through the perforated mandrel. The Magnani process permits the forming of an integral bell on the pipe barrel, but it also results in a different fiber orientation and the pipe has lower hydrostatic and flexural strength than that produced by the Mazza process. Pipe manufactured by the Magnani process is generally suitable only for lower pressure applications.

In-plant tests for asbestos-cement pipe are internal hydrostatic pressure, hydrostatic bursting, crushing and water absorption. The procedures and results of these tests are described in each of the standards.

There are two distinctly different methods of curing asbestos cement products, "normal-curing" and "autoclave curing" and these methods produce pipe having rather different characteristics. In "normal-curing" the material formulation is Portland cement plus asbestos fiber. The curing is conducted at atmospheric pressure either under water or in a moist atmosphere for varying periods of time. A variation of this method is to cure in warm, saturated air at a temperature below the boiling point of water and at atmospheric pressure. This method is frequently referred to as "steam-curing" but in fact is not and should not be so referred because of possible confusion with autoclave curing which uses steam under pressure. For practical purposes both water curing and moist air curing methods produce about the same sulfate resistance, much less than with autoclave curing. For all other characteristics the differences between "natural curing" and "autoclave curing" appear to be sufficiently small that they can be ignored as serious factors in AC pipe procurement.
The presence of free lime in cement products has been found to be one of the most important causes of the deterioration of such products, especially in sulfate containing environments. Autoclaving of cement products has been found to improve their chemical stability. In autoclave curing the material formulation is Portland cement, asbestos fiber and finely ground silica. The autoclave curing is accomplished by first storing the fresh pipe in a moist atmosphere for 24 hours and then treating it in an autoclave operated at pressures between 7 and 14 kg/cm² under saturated steam conditions for periods of 16 or more hours. Under the autoclave curing, the silica becomes soluble and reacts with the free lime liberated by the Portland cement during hydration.

Transposing the curing method and the formulation accomplishes very little because the free lime that is formed will not be dissipated and will remain in the product. For example, the tests performed by P. W. Manson and L. R. Blair (74) reported that a "normal-cure" formulation, normally cured for 28 days in water, was found to contain 12.8 percent free lime. This same "normal-cure" formulation, when cured in an autoclave at 7 kg/cm² for 16 hours, still contained 10.9 percent of free lime. By comparison, an "autoclave-cure" formulation (containing silica) treated under identical autoclaving conditions (7 kg/cm² for 16 hours) was found to be essentially free of calcium hydroxide. Conversely, the free lime is not removed by normal-curing an autoclave-cure formulation because, at the low curing temperatures, the silica does not become soluble to react with the free lime which is formed. It has been found that when the autoclave formulation is subjected to a 28-day normal-cure, it still will contain 9.1 percent free lime, whereas the same autoclave formulation, when subjected to high temperature-high pressure curing will contain essentially no free lime.

The Manson and Blair investigation previously cited (74) also reported on the relationship of cement type and free lime.
lime to sulfate resistance. Table 14 is excerpted from their report. The cement types listed are in conformance with ASTM Standard C150. Type V is sulfate resistant cement.

**TABLE 14**

Relationship of Cement Type and Free Lime to Sulfate Resistance (Bureau of Reclamation Sulfate Test)

<table>
<thead>
<tr>
<th>Type</th>
<th>Free Lime: (28 Cycles)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal Cure</td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>15.5</td>
</tr>
<tr>
<td>II</td>
<td>14.5</td>
</tr>
<tr>
<td>V</td>
<td>13.7</td>
</tr>
<tr>
<td>Autoclave cure</td>
<td></td>
</tr>
<tr>
<td>(0.6/l silica-to-cement ratio)</td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>0.4</td>
</tr>
<tr>
<td>II</td>
<td>0.6</td>
</tr>
<tr>
<td>V</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Another problem that has been found with the "normal-cured" pipe is that very soft waters have a tendency to take the free lime into solution increasing the hardness of the water and deteriorating the pipe. This condition is also counteracted by autoclave-curing.

As a result of the findings regarding free lime in the pipe, the AWWA and ASTM standards recognize various types of pipe depending on the amount of free lime in the finished product. The AWWA Standards specify Type I with no limit on the amount of free lime and Type II with 1.0 percent or less free lime. The ASTM Standard specifies Type I with not more than 3 percent free lime, Type II with not more than 1.0 percent, and Type III with no limit. Thus autoclaving is not required for AWWA Type I and ASTM Type III pipe. However in the United States asbestos cement pipe is almost universally autoclave cured because, in addition to the chemical benefits, the reduced curing time permits reduction in plant storage area with a consequent cost saving. Both standards recommend conditions for selecting the type of pipe, the
AWWA Standards being more definitive. Australian Standard 1711 limits the free lime to one percent. The ISO Standard recognizes "autoclave-curing" only in a footnote and the other standards listed, as well as ISO, have no requirements regarding lime and call for "normal curing".

In recent years concern has been expressed that water carried through asbestos-cement pipe could pick up asbestos fibers and be a cause of gastrointestinal cancer. This question has been investigated by the U. S. Public Health Service and the American Water Works Association Research Foundation, and was discussed at the meeting of the International Agency for Research on Cancer in Lyons, France. (70, 76) The conclusion of these studies was that there was no indication of a health hazard resulting from asbestos-cement fibers present in water transported through asbestos-cement pipe.

**Limitations**

As discussed above, "normal cured" asbestos-cement pipe is attacked by soil sulfates. Sulfate concentrations in the soil in excess of 0.1 percent or in water in excess of 1,000 mg/l will have a deleterious effect. In such locations pipe should be supplied with bitumen coatings or should be autoclave cured. If bitumen coatings are supplied care must be taken that the coating is not damaged during shipping and installation. Autoclave cured pipe is the best approach to this problem.

Asbestos-cement pipe is susceptible to attack by sulfuric acids and is not suitable for locations where high sulfide concentrations will prevail and in sewers which do not flow full. The alkalinity level of asbestos-cement pipe is higher than that of granitic concrete pipe and the rate of corrosion is lower. The life expectancy of asbestos-cement sewer pipe can be estimated in the same manner as previously described for reinforced concrete pipe using a lower corrosion rate for ACP. Epoxylining has been used with asbestos
cement sewer pipe but proved too costly to be competitive with other materials, and as far as is known the process is not in use at the present time.

Used as a water pipe, asbestos-cement has produced good results when proper care is used in handling, installing, bedding and backfilling. In a 1967 paper (78) Wilson reported the following relative maintenance costs per mile experienced by the East Bay Municipal Utilities District in 1966-67:

<table>
<thead>
<tr>
<th>Material</th>
<th>Cost per mile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cast Iron (1,650 miles)</td>
<td>$75.60</td>
</tr>
<tr>
<td>Steel (700 miles)</td>
<td>67.00</td>
</tr>
<tr>
<td>Asbestos-cement (800 miles)</td>
<td>39.90</td>
</tr>
</tbody>
</table>

He also reported that those agencies which kept detailed records of pipeline failures reported that approximately 70 percent of asbestos cement pipe breaks were caused by equipment operation or loss of support due to another excavation too close to the pipeline.

Because of the flexibility provided by its short lengths and double gasketed ends, asbestos-cement pipe has performed well in areas where land subsidence is a consideration. The irrigation distribution system of Wheeler Ridge-Maricopa Water Storage District in California, for which the author's firm performed design and construction management, was constructed in an area where subsidence of 90 to 140 centimeters was anticipated. Measures were taken to preconsolidate the area prior to construction of the pipeline system. A special high deflection joint was designed and higher crushing strength pipe specified. This special joint is illustrated on Figure 26. A similar joint called a "Flexi-Coupling" is offered by Construction Material Marketing Company of Bangkok. The performance of this system has exceeded the expectations of the designers in minimizing pipeline failures resulting from land subsidence.
Joints

In addition to the bell and spigot joint formed in the Magnani process, two types of joints are used with asbestos cement, both based on the sleeve coupling principle:

1. An asbestos-cement sleeve containing two rubber rings in grooves as the sealing element. A variation in this is a sleeve coupling which has a third gasket in its center to act as a spacer and prevent the pipe ends from coming in contact. These two types of joints are also shown in Figure 26 and pictures of the pipe ends and collars are shown on Figures 27 and 28.

2. A metallic sleeve with rubber rings compressed against each edge and against the pipe wall by two bolted steel rings. A widely used product of this type is the Gibault Joint, a cast iron sleeve for use on the unmachined barrel of asbestos-cement pipe. If metal sleeves are used, a suitable anti-corrosion coating should be applied.

A recent development of Johns-Manville Corporation, is a fiberglass collar with the gasket locked into the collar. Historically, the collar has been the weakest part of an asbestos-cement pipeline, partially due to the larger diameter of the collar. The fiberglass collar, being of less thickness than an ACP collar, appears to meet the difficulty as well as providing a greater resistance to failure by impact. In addition, the problem familiar to pipe installers sometimes called a "fish mouth" where the gasket is pushed out of its groove would also appear to be avoided because the gasket is held in place during joint assembly.

Fittings

Fittings for low pressure applications in asbestos-cement pipe have been fabricated by gluing sections of pipe together with epoxies. However, for higher pressures, fittings are of cast iron or fabricated from steel. These types
FIGURE 26

STEPPED TAPER PIPE END

SMOOTH PIPE END

DETAIL OF HIGH DEFLECTION COUPLING

JOINTS FOR ASBESTOS CEMENT PIPE
FIGURE 28

COUPLING FOR ASBESTOS CEMENT PIPE
or fittings being metallic, also require anti-corrosion coating. In a corrosive environment, the metal fittings become the weak link in the system. Because there are a myriad of these units in a pipeline system, cathodic protection is not feasible and reliance must be placed on the quality and integrity of the coating. In addition to mastic and cement-mortar lining and coating, fusion epoxy coatings have been used.

For small outlets, such as for services or air release and vacuum valves, heavy tapped couplings or service saddles are used. Heavy tapped couplings are thick walled, extra length asbestos-cement couplings into which a threaded bushing is epoxied. The service saddle is a malleable iron or bronze fitting with a tapped outlet and gasket which is secured to the pipe with one or more straps depending on pipe diameter and pressure class. The maximum size outlet, whether a tapped coupling or service saddle is used, is about 50 mm. Above this size lined and coated, fabricated steel fittings or cast iron fittings are used.

**Handling and Shipping**

It has been mentioned before that asbestos-cement is a brittle material and is subject to damage if carelessly handled or improperly packaged for shipping. There have been cases reported of damage to pipe when shipped as sea freight and, as a result, specifications have been written calling for full plant type testing "on the dock" after arrival. This procedure should be extended to the point of delivery wherever conditions hazardous to the pipe may be encountered in transit. Pipe loaded on freight cars or trucks should have timbers between each tier of pipe and should be clocked so that pipe materials are never in contact. Straps on stacked pipe should be placed in line with the blocking.

The barrel of an asbestos-cement pipe which has been hit may not show external damage, but may have a cone shaped
section knocked out on the inside, much like a sheet of glass. Pressure testing will reveal this type of damage. Pipe or couplings which have been hit on the ends may have a hairline crack nearly invisible to the unaided eye, but if brushed with water will show a dark line. Pipe having either type of damage should be rejected. Pipe ends which have been chipped can be removed and the ends remachined with special tools.

It is recommended that pressure pipe larger than 300 mm in diameter and sewer pipe larger than 460 mm in diameter be unloaded with equipment. When unloading the smaller sizes with ropes and skids, the pipe should be lowered all the way down the skid and not allowed to roll free. If the pipe is shipped with couplings installed on one end, hooks which engage the ends of the pipe should not be used for unloading since they can damage the coupling groove.

**Installation Methods**

Excavation and preparation of the trench bottom requires the same procedures and care as for other pipe. Bell holes must be excavated for the pipe collars and these should be large enough to provide a minimum of 5 cm clearance around the collar. Although some installation manuals show the pipe installed on earth mounds to provide clearance around the pipe, this procedure should not be permitted because complete filling cannot be assured and the pipe can fail from beam action or from point loading at the locations of the mounds.

When the joint is assembled, it is important to assure that the pipe ends within a coupling are not in contact. The pipe ends or couplings shown in Figure 26 are designed to prevent this, but even so it is possible to "over-assemble" a joint. When "machined overall" pipe sections are used, they should be assembled with care. A field practice to avoid contact is to swing the pipe once to each side after the joint is assembled to back the pipe section out of the joint slightly. The pipe end and the coupling groove must be clean and the pipe end lubricated. When shaped gaskets are used, they must be
installed in the proper direction. After assembly, the position of the gasket should be checked with a feeler gage. The feeler gage may be formed from a strip of metal 0.4 mm by 6 mm about 10 cm long bent in a Z shape with the middle section 20 mm long and having equal legs of 40 mm each. The gage is inserted from the exterior of the coupling until it is in contact with the gasket. It is then slid completely around the pipe. If the gage fails to touch the gasket at any point or if the gasket felt to be out of position, the joint must be taken apart and reassembled.
CHAPTER VIII. VITRIFIED CLAY PIPE

Vitrified clay pipe has been widely used for sewers throughout the world and is renowned for its long life and resistance to acid attack. This pipe is also used in drainage applications including storm drains. Clay pipe has disadvantages in that it is brittle, heavy and difficult to handle. Because of this, much effort is being expended to find alternative materials for sewer pipe.

Vitrified clay pipe is manufactured from clay and shales which are ground and blended to produce the required quality of pipe. The pipe is formed by extruding the clay through a die. Both the pipe barrel and bell are formed in the process. The pipe is then cured in a warm, moisture-controlled room to reduce the moisture content of the "green" pipe to 3 percent or less. The curing process may take from one to three days for 75 mm pipe to one to three weeks for 1,050 mm pipe. After the pipe is thoroughly dried, it is fired in a kiln at a temperature of about 1,100°C at which point it is vitrified.

A list of standards for clay pipe is shown in Table 15. In selecting clay pipe for a sewerage system, consideration must be given not only to crushing strength and physical measurements, but also to other characteristics, some of which are not covered by specifications. Specification requirements include allowable absorption and acid resistance. In tests for absorption, pipe is immersed in boiling water, then cooled and wiped dry. The maximum gain in weight caused by water absorption is specified. Where acid resistance of the pipe is a consideration, limits of acid-soluble material in the pipe are specified.

A characteristic which is covered by standard specifications is abrasion resistance. Abrasion resistance is important in sewers carrying combined wastes and storm
<table>
<thead>
<tr>
<th>Standard</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASTM C12</td>
<td>Installing Vitrified Clay Pipe</td>
</tr>
<tr>
<td>ASTM C301</td>
<td>Standard Methods of Testing Clay Pipe</td>
</tr>
<tr>
<td>ASTM C425</td>
<td>Compression Joints for Vitrified Clay Pipe and Fittings</td>
</tr>
<tr>
<td>ASTM C700</td>
<td>Vitrified Clay Pipe, Extra Strength, Standard Strength and Perforated</td>
</tr>
<tr>
<td>ASTM C828</td>
<td>Tentative Recommended Practice for Low Pressure Air Test of Vitrified Clay Pipe Lines (4 to 12 in.) (100 to 30 mm)</td>
</tr>
<tr>
<td>AFNOR NF P16-321</td>
<td>Elements of Clay Piping</td>
</tr>
<tr>
<td>AFNOR NF P16-421</td>
<td>Dimensions and Weights of Pipe</td>
</tr>
<tr>
<td>AFNOR NF P16-422</td>
<td>Dimensions and Weights of Fittings</td>
</tr>
<tr>
<td>DIN 1180</td>
<td>Clay Drain Pipe</td>
</tr>
<tr>
<td>BS 65/540</td>
<td>Clay Drain and Sewer Pipe Including Surface Water Pipes and Fittings</td>
</tr>
<tr>
<td></td>
<td>Part I - Pipes and Fittings</td>
</tr>
<tr>
<td></td>
<td>Part II - Flexible Joints</td>
</tr>
<tr>
<td>BS 539</td>
<td>Dimensions of Fittings for Use With Clay Drain and Sewer Pipe</td>
</tr>
</tbody>
</table>
water. Many cities have clay pipe sewer systems that have been in service more than 100 years which attests to the abrasion resistant characteristics of this type of pipe.

In the past, most clay pipe was salt glazed. The current trend, however, is to use unglazed pipe because it is also resistant to corrosion and nonabsorptive but can be produced at lower cost. The resistance of clay pipe to corrosion from acids and alkalies gives it an advantage over some other materials for handling wastes with high acid concentrations or in conditions where the generation of hydrogen sulfide may result in the formation of sulfuric acid.

Vitrified clay pipe manufactured in conformance with ASTM Designation C700 (ANSI A106.8) is furnished in two strength classifications, standard and extra strength, while pipe manufactured in accordance with AFNOR P16321 is only one strength. The minimum three edge bearing strength of various sizes and strength classes of pipe are shown in Table 16.

**Fields of Application**

Vitrified clay pipe is an unreinforced pipe having virtually no resistance to internal pressure and is designed to resist external loads only. Its use, therefore, is limited to conveyance of sewage, industrial wastes and storm water with open channel flow. It is frequently perforated and used for underdrainage, filter beds, leaching fields and similar subdrainage purposes. As is discussed earlier, by selecting the proper bedding and backfill procedures, it should be possible to choose a pipe class which will satisfy nearly any field condition.

A large part of the City of Fort Lauderdale, Florida, was built on what was once a mangrove swamp. The swampy area was drained and the ground level raised above water level by means of digging canals and using the excavated
<table>
<thead>
<tr>
<th>Nominal Diameter (mm)</th>
<th>ASTM Standard Strength (kg/m²)</th>
<th>ASTM Extra Strength (kg/m)</th>
<th>C700 Strength (kg/m)</th>
<th>APNOR NF P16-321 (kg/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>76</td>
<td>2,980</td>
<td>2,980</td>
<td>1,530</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>1,785</td>
<td>2,980</td>
<td>1,530</td>
<td></td>
</tr>
<tr>
<td>150</td>
<td>1,785</td>
<td>2,980</td>
<td>1,835</td>
<td></td>
</tr>
<tr>
<td>200</td>
<td>2,080</td>
<td>3,274</td>
<td>2,140</td>
<td></td>
</tr>
<tr>
<td>250</td>
<td>2,380</td>
<td>3,570</td>
<td>2,450</td>
<td></td>
</tr>
<tr>
<td>300</td>
<td>2,680</td>
<td>3,870</td>
<td>2,450</td>
<td></td>
</tr>
<tr>
<td>350</td>
<td></td>
<td></td>
<td>2,650</td>
<td></td>
</tr>
<tr>
<td>380</td>
<td>2,980</td>
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<td>4,315</td>
<td></td>
</tr>
<tr>
<td>400</td>
<td></td>
<td></td>
<td></td>
<td>2,855</td>
</tr>
<tr>
<td>450</td>
<td>3,274</td>
<td></td>
<td>4,910</td>
<td>2,853</td>
</tr>
<tr>
<td>500</td>
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<td>530</td>
<td>3,570</td>
<td></td>
<td>5,730</td>
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<tr>
<td>600</td>
<td>3,870</td>
<td></td>
<td>6,550</td>
<td>3,060</td>
</tr>
<tr>
<td>690</td>
<td>4,170</td>
<td></td>
<td>6,995</td>
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</tr>
<tr>
<td>760</td>
<td>4,910</td>
<td></td>
<td>7,440</td>
<td></td>
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<tr>
<td>840</td>
<td>5,360</td>
<td></td>
<td>8,185</td>
<td></td>
</tr>
<tr>
<td>915</td>
<td>5,950</td>
<td></td>
<td>8,930</td>
<td></td>
</tr>
<tr>
<td>990</td>
<td></td>
<td></td>
<td>9,820</td>
<td></td>
</tr>
<tr>
<td>1,070</td>
<td></td>
<td></td>
<td>10,420</td>
<td></td>
</tr>
</tbody>
</table>
materials as fill. In the process, large quantities of organic materials were left in place and covered over. In addition to the fill material being unstable, as the organic material decomposes, the filled areas settled. By means of special subgrade treatment such as piling, T boards and compacted gravel, and the use of PVC jointed clay pipe, it is reported that clay pipe has been used successfully for sewage collection.

**In-Plant Tests**

In addition to the external load test discussed earlier, AFNOR Specification NF P16-321 requires tests of hydrostatic pressure, water absorption and sulfuric acid resistance. ASTM C700 includes the same tests, but allows the hydrostatic pressure test as an alternative to the water absorption test. Allowable water absorption under NF P16-321 is 6 percent for pipe equal to or smaller than 300 mm in diameter and 7 percent for larger pipe. Under ASTM C700, it is 8 percent for all sizes. The hydrostatic pressure test under NF P16-321 requires no sweating under a pressure of 1 kg/cm² for 30 minutes or 3 kg/cm² for 30 seconds; under ASTM C700, the pressure is 0.7 kg/cm² and the test time varies from 7 to 21 minutes depending on wall thickness. The acid resistance test requirement of NF P16-321 is a loss of weight of less than 1 percent and for ASTM C700 is less than 0.25 percent. Pipe manufactured in conformance with either standard should give equivalent performance.

**Joints**

Clay pipe joints are of the bell and spigot type and jointing procedures are determined by the materials used to make the joint type. The mortar-jute joints, which were first used to make "tight" joints, are not recommended because they are rigid, not resistant to acid, and hard to
make up properly, particularly in the lower section. Pressure mortar joints made by packing mortar against a removable flange form are an improvement over the mortar-jute joints, but do not eliminate the disadvantages of the cement-mortar which is subject to acid attack. Joints made with hot-poured bitumen, called hot-poured joints, are made up very much like lead joints on bell and spigot cast iron joints. Disadvantages of bitumen joints are their tendency to become brittle when cold and to flow in warm weather, the difficulty of pouring in cold weather and the tendency to form steam with moisture on the pipe surface preventing proper adhesion.

There is also a sulfur-silica material, a mixture of sulfur and sand, that is poured hot and sets as it cools. It tends to be brittle and may be attacked by sulfur-eating bacteria. Its use is not recommended.

Cold bituminous materials are used in three methods of joint assembly. These methods do not have the disadvantages of the hot-poured joints but do have the tendency to crack in cold weather.

Plasticized bitumen is a material in which a softening agent produces a "butter" that can be troweled into the annular space around the spigot end in the bell. This material will air-set as the solvent evaporates.

An extruded bituminous ribbon gasket, which may be fortified with fibers or dust, is available for making joints. The ribbon is wound around the pipe and caulked into the bell without using heat.

In making slip-seal joints, which are also called die cast or premolded joints, complementary precast rings of bituminous material are placed around the spigot and inside the bell. Both rings have a tapered design. When pushed together, they become wedged, causing the joint to become sealed. These rings are generally cast on the pipe at the factory.
The most recent development in joints for vitrified clay pipe is the compression type joint made with natural or synthetic rubber, or various plastics and resins. These jointing materials are covered by ASTM Designation C425. A variation of this type of joint is one made with a fiber glass/polyester socket and urethane spigot used on plain end clay pipe. This system, because the pipe does not have clay bells, saves on excavation and backfill. These compression type joints are highly recommended but the bituminous joint types are widely used and appear to have been satisfactory.

**Fittings**

Vitrified clay fittings such as tees, wyes and bends are available and their manufacture is covered in the various standards. The fittings are available for the applicable types of joints. There is also equipment available for tapping clay pipe by drilling and a device called a "Shewer Tap" manufactured by Midwest Manufacturing, Inc. of Shawnee Mission, Kansas, which is a collar to be epoxied into the hole. These collars are available for compression joints for vitrified clay, round rubber ring joints for asbestos cement and lead for cast iron.

**Handling and Shipping**

Vitrified clay pipe is a brittle material which must be carefully handled to avoid damage. In addition, the pipe in all but the smallest sizes, is heavy and cranes or other equipment are necessary to handle it. If the pipe has pre-molded joint rings, hooks should not be allowed to come in contact with the joint surfaces, and it should be so handled that no weight, including the weight of the pipe itself, will bear on or be supported by the jointing material. The spigot ring should not be dragged on the ground or be damaged by contact with gravel, crushed stone or other hard objects.
Installation Methods

The field supporting strength of vitrified clay pipe is materially affected by the type of bedding and backfill provided for the pipe. The considerations for bedding and backfill discussed under concrete pipe apply to clay pipe.

The compression type joint which is prevalent today requires care in installation. Care should be taken in lowering the pipe into the trench to prevent damaging the joint material or disturbing the trench conditions. The pipe should not be dragged along the ground or trench bottom.

In joining the pipe, the manufacturer's recommendations for pipe assembly must be closely followed. With the factory applied compression joints, care must be taken to wipe the mating surfaces clean before joining. After cleaning the ends, lubricate both joint surfaces, line up the socket and spigot, and shove the pipe together with a steady pressure. For small diameter pipe, this assembly can be done by hand. For larger sizes, a bar may be used where a firm trench bottom permits. When using a bar, care should be taken not to damage the lip of the socket or coupling. A wood block should be used to cushion the bar pressure and eliminate breakage.

Under other conditions, a come-along or other special device may be required. When using a "come-along", the spigot must be properly positioned in the bell before exerting pressure.
CHAPTER IX. GREY CAST IRON AND
DUCTILE CAST IRON PIPE

Cast iron is essentially an alloy of iron and carbon
containing amounts of silicon and manganese. In grey cast
iron, the type used for cast iron pipe and fittings, the
major part of the carbon content occurs as free carbon or
graphite in the form of flakes interspersed throughout the
mass of metal. The engineering properties of grey cast iron
are principally due to the presence of these carbon graphite
flakes.

Ductile cast iron is a variety of cast iron which,
because the carbon content is in spheroidal rather than
flake form, will elongate appreciably before fracture. This
characteristic causes ductile iron pipe to be classed as a
flexible, rather than rigid, pipe and requires that the same
considerations be given in design and installation as other
flexible types of pipe. Ductile iron fittings are available
for use with ductile iron pipe. In common with cast iron,
ductile iron pipe and fittings are cast, usually centrifugally
in metal or sand-lined molds.

In this discussion "cast iron" refers to grey cast iron
and cast ductile iron is referred to as "ductile iron".

Cast iron has been used for manufacture of pipe for
water and sewer systems for hundreds of years; there is
record of its manufacture in Germany as early as 1455, and
the basic principle of the process is the same today as it
was then. However, advancements in metallurgy have improved
the strength of cast iron pipe. Pipe with a bursting tensile
strength of 1,480 kg/cm² and a ring modulus of rupture of
3,160 kg/cm² has been available for many years.

Grey and ductile cast iron pipe are two different
materials as far as engineering and construction are con-
cerned. Cast iron pipe is a rigid pipe and ductile iron
pipe is a flexible pipe. Cast iron pipe design is based on
combined loadings using bedding factors as described in Chapter II. After the wall thickness is determined from a combined loading analysis, a corrosion allowance and a foundry tolerance is added. Ductile iron pipe, on the other hand, uses the wall thickness resulting from external load design or from internal pressure design whichever is larger to which is added the same corrosion and foundry tolerance. Deflection is limited to three percent.

Although the wall thickness of grey cast iron pipe is greater than that of ductile iron pipe, it is more subject to impact damage than ductile iron pipe.

Because of its high strength and ductility, higher impact resistance, lower weight, and good machinability, the use of ductile iron pipe in place of cast iron pipe is expanding.

**Grey Cast Iron**

Because cast iron pipe has such a long history, it is found in virtually every set of standard specifications. There are variations, however, between these standards, both in strength classifications and in joint types. Standards for grey cast iron are listed in Table 17. The American National Standards Institute and American Water Works Association are identical. They provide different specification designsations for cast iron pipe centrifugally cast in metal molds (ANSI A21.6, AWWA C106) than for cast iron pipe centrifugally cast in sand lined molds (ANSI A21.8, AWWA C108) and do not specify pit cast pipe. ISO R13 and BS 4622 cover pipe manufactured by all three methods. The only differences between the two ANSI-AWWA Standards are the size ranges, 76 mm to 610 mm for ANSI A21.6 and 76 mm to 1,220 mm for ANSI A21.8 and the hydrostatic pressure specified in A21.8 for pipe 760 mm in diameter and above.

Test requirements for grey cast iron in ISO and British standards are listed in Table 18.
<table>
<thead>
<tr>
<th>Designation</th>
<th>Nominal Size Range mm</th>
<th>Test Pressure kg/cm(^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISO R13</td>
<td>80-600</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>600-1,000</td>
<td>Class LA 15</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Class A 20</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Class B 25</td>
</tr>
<tr>
<td>BS 4522</td>
<td>80-700</td>
<td>Spigot and Socket - 35</td>
</tr>
<tr>
<td></td>
<td>80-300</td>
<td>Flanged centrifugally cast and flanged sand cast</td>
</tr>
<tr>
<td></td>
<td>350-600</td>
<td>Class 4 - 20</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Flanged centrifugally cast - 16</td>
</tr>
<tr>
<td></td>
<td>83-700</td>
<td>Flanged sand cast - 16</td>
</tr>
<tr>
<td>JIS 5525</td>
<td>50-200</td>
<td>3.5</td>
</tr>
<tr>
<td>(1) DIN 2851 through 28515 incl.</td>
<td>40-1,200</td>
<td>16</td>
</tr>
<tr>
<td>ANSI 21.6 and 21.8 (AWWA C106 &amp; C108)</td>
<td>76-1,220</td>
<td>Burst test to stress of 1,266 kg/cm(^2)</td>
</tr>
</tbody>
</table>

(1) Pipe sizes range in DIN Standards vary with joint type.
<table>
<thead>
<tr>
<th>Type of casting</th>
<th>Nominal Diameter</th>
<th>Type of test</th>
<th>Minimum (kg/cm²)</th>
<th>Hardness: 230HB</th>
<th>Test Pressure: Cl.1 : Cl.2 : Cl.3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pipes Centrifugally cast in metal moulds</td>
<td>Up to &amp; including 300 mm</td>
<td>Deflection on ring (modulus)</td>
<td>40</td>
<td>35</td>
<td>35 : 35 : 35</td>
</tr>
<tr>
<td></td>
<td>Over 300 mm and up to and including 600 mm</td>
<td>Tensile on machined test bar</td>
<td>20</td>
<td>35</td>
<td>35 : 35 : 35</td>
</tr>
<tr>
<td></td>
<td>Over 600 mm</td>
<td>Tensile on machined test bar</td>
<td>18</td>
<td>20</td>
<td>20 : 20 : 20</td>
</tr>
<tr>
<td>Pipes centrifugally cast in sand moulds</td>
<td>Up to and including 600 mm</td>
<td>Tensile on machined test bar</td>
<td>18</td>
<td>35</td>
<td>35 : 35 : 35</td>
</tr>
<tr>
<td></td>
<td>Over 600 mm</td>
<td>Tensile on machined test bar</td>
<td>18</td>
<td>215</td>
<td>215 : 215 : 215</td>
</tr>
<tr>
<td>Pipes vertically cast in sand moulds and special castings</td>
<td>Up to &amp; including 600 mm</td>
<td>Tensile on cast test bar</td>
<td>14</td>
<td>20</td>
<td>20 : 20 : 20</td>
</tr>
<tr>
<td></td>
<td>Over 600 mm</td>
<td>Tensile on cast test bar</td>
<td>14</td>
<td>215</td>
<td>215 : 215 : 215</td>
</tr>
</tbody>
</table>

*Classes 1, 2 and 3 are in British Standards and are equivalent to Class LA, A and B in ISO Standards.*
Ductile Iron

Ductile iron pipe is manufactured by the same processes as grey iron pipe. Standards for ductile iron pipe are listed in Table 19 which also shows size ranges and requirements for hydrostatic test pressures. In general, the tensile strength of the material and the hydrostatic proof pressures are similar in the various standards. All of the standards include procedures for selection of pipe wall thicknesses and these procedures are the same for all but the AWWA/ANSI standards. In AWWA C150 and ANSI A21.50, all thickness is determined separately for internal pressure and for external loads and the larger thickness is adopted. In the other standards, wall thickness is based only on internal pressure.

AWWA C151 and ANSI 21.51 include seven thickness classes of ductile iron pipe; whereas the ISO Standards list one; the British Standard two differing with the type of joint; the Japanese Industrial Standard three; and the DIN Standards four varying with joint type. AWWA Standard C150 (ANSI A21.50) described in detail the procedure for selecting the pipe class under their concept.

Fields of Application

Grey and ductile cast iron pipelines are used for water, sewerage, gas and slurries. Acidic waters may cause tuberculation on the interior pipe wall which will materially affect the capacity of the pipeline. In the case of such waters, cement-mortar lining should be specified. ANSI Standard A21.4 (AWWA C104) requires cement-mortar linings for cast iron and ductile iron pipe. Such linings are not effective for sewer pipe because they are subject to the same sulfuric acid attack as concrete pipe. For highly aggressive wastes, ductile iron pipe is being supplied with a heat fusion applied polyethylene lining.
<table>
<thead>
<tr>
<th>Standard</th>
<th>Range of Diameter</th>
<th>Hydrostatic Test Pressures</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mm</td>
<td>kg/cm²</td>
</tr>
<tr>
<td>ISO R2531</td>
<td>80-1000</td>
<td>80-300mm 50</td>
</tr>
<tr>
<td></td>
<td></td>
<td>350-600mm 40</td>
</tr>
<tr>
<td></td>
<td></td>
<td>700-1000mm 32</td>
</tr>
<tr>
<td>BS 4772</td>
<td>80-1200</td>
<td>80-300mm 50</td>
</tr>
<tr>
<td></td>
<td></td>
<td>350-600mm 40</td>
</tr>
<tr>
<td></td>
<td></td>
<td>700-1000mm 32</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1100-1200mm 25</td>
</tr>
<tr>
<td>DIN 28610</td>
<td>80-1200</td>
<td>Screwed &amp; TYTON Joints 40</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bolted Gland Joints 25</td>
</tr>
<tr>
<td>JIS G5526</td>
<td>75-1&quot; 7</td>
<td>Diam-mm C1.1 60 50</td>
</tr>
<tr>
<td></td>
<td></td>
<td>350-600 50 45 40</td>
</tr>
<tr>
<td></td>
<td></td>
<td>700-1000 40 40 35</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1100-1500 30 30 30</td>
</tr>
<tr>
<td>AWWA C151/</td>
<td>76-1370</td>
<td>35</td>
</tr>
<tr>
<td>ANSI 21.51</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

IX-6
ISO, British and American standards call for pipe to be furnished with a bituminous coating and the Japanese standards require a coating "free from harmful components." The results of a thirteen year in-ground test of ductile cast iron pipe by the National Bureau of Standards of the U. S. Bureau of Commerce have recently been published. (62) Their study concluded that ductile iron will corrode at nearly the same rate as carbon steel in some soils and at a somewhat slower rate in other soils.

This conclusion has been hotly disputed in the technical literature by representatives of various cast iron pipe manufacturers and manufacturers' organizations. These arguments are basically that the tests were only in corrosive soil and, therefore, are not representative of field conditions. The discussers do not deny that ductile iron pipe corrodes, only that it corrodes in all soils. The discussers, and the Cast Iron Pipe Research Association (CIPRA), both recognize that, as with steel pipe, when low resistivity soils are encountered, protection is required, and the author agrees. One discusser recommended zinc coating plus coal tar varnish or double coating of tar epoxy which can be supplemented with a loose polyethylene sleeve.

It should be noted that the CIPRA in justifying the new standards for ductile iron pipe stated, "along with all this, ANSI has adopted a proven method of corrosion prevention for ductile iron pipe in ANSI 21.5. Where corrosive soil conditions are present, polyethylene encasement provides a permanent control system. Added wall thickness for the purpose of corrosion control has not proven to be effective in severely corrosive soils." Again, the author agrees. The British Standard Code of Practice for Iron Pipelines in Land recommends that where the corrosive nature of the ground requires additional protection to the pipe exterior a protective coating such as loose polyethylene sleeves, protective tapes or concrete be used.
Backfilling with select material such as sand or limestone has been used as corrosion protection, but it was found that the proper quality of backfill was difficult to achieve in the field. Clods of clay or other materials which became mixed with the backfill negated its effectiveness and the use of select backfill for corrosion protection has been abandoned.

For aboveground installation, cast iron pipes are subject to interior attack as described above but the pipe exterior requires only a rust preventative coating.

**Joints**

Grey cast iron pipe is manufactured with several different types of joints, although not all standards specify all types of joints. Listed in Table 20 are the types of joints specified in the various standards for cast iron pipe, and Figure 29 shows the configurations of the various joint types for both grey and ductile iron.

Ductile iron pipe is also available in a number of joint configurations from various manufacturers as listed for various standards in Table 21. These include bell and spigot pipe ends for caulked joints, mechanical and push-on rubber gasket joints, plain and pipe for slip-on couplings, and flanged joints with the flanges either cast on the pipe or threaded. There is also available a proprietary push-on type joint for small diameter pipe capable of resisting tensile forces called the LOK-TYTON joint. In this joint, the gasket has molded into it a number of steel struts which engage a groove in the spigot end of the pipe.

**In Plant Tests**

ISO Recommendation R13 and British Standard 4622 for grey cast iron pipe provide for tensile tests on bars cut from the pipe and Brinnel hardness tests, in addition to
### TABLE 20
GREY CAST IRON PIPE JOINTS
JOINT TYPE

<table>
<thead>
<tr>
<th>Standard</th>
<th>Bell &amp;</th>
<th>Spigot</th>
<th>Flanged</th>
<th>Mechanical</th>
<th>Push-on</th>
</tr>
</thead>
<tbody>
<tr>
<td>BS 4622</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>ISO R13</td>
<td>Yes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ANSI 218 &amp; AWWA C106 &amp; 108</td>
<td>Yes</td>
<td></td>
<td></td>
<td>C115</td>
<td>Yes</td>
</tr>
<tr>
<td>DIN 28511 through 28516</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>JIS G5525</td>
<td>Yes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### TABLE 21
DUCTILE CAST IRON PIPE JOINTS
JOINT TYPE

<table>
<thead>
<tr>
<th>Standard</th>
<th>Bell &amp;</th>
<th>Spigot</th>
<th>Flanged</th>
<th>Mechanical</th>
<th>Push-on</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISO 2531</td>
<td>Yes</td>
<td></td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BS 4772</td>
<td></td>
<td></td>
<td>Yes</td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>DIN 28610, 28614 &amp; 28615</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>JIS</td>
<td></td>
<td></td>
<td>Yes</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>AWWA C151</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

IX-9
hydrostatic tests. The test requirements are virtually the same in these two standards and were shown previously in Table 18.

Both the ISO and BSI standards also provide for a ring test for pipe centrifugally cast in metal molds up to 350 mm in diameter. The ANSI Standards require ring tests for all sizes cast either in metal or sand lined molds. The ISO and BSI standards require hydrostatic proof tests on each pipe, but no bursting test. The ANSI Standards require that, in addition to hydrostatic tests, a bursting test be performed on at least one full-length pipe sample per month.

Ductile iron pipe is accepted on the basis of tensile tests of specimens cut from the wall of a pipe section and hydrostatic proof tests. The hydrostatic proof test requirements under several standards are shown in Table 19. Tensile strength and elongation requirements are shown in Table 22. Details of the test methods are included in the Standards.

### TABLE 22

**DUCTILE CAST IRON PIPE TENSILE TESTS**

<table>
<thead>
<tr>
<th>Standard</th>
<th>Min. Tensile Strength: kg/mm²</th>
<th>Min. Elongation at Fracture: %</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISO 2531</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Centrifugally cast</td>
<td>42</td>
<td>10</td>
</tr>
<tr>
<td>Metal or sand molds</td>
<td>40</td>
<td>5</td>
</tr>
<tr>
<td>BS 4772</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Centrifugally cast</td>
<td>42</td>
<td>10</td>
</tr>
<tr>
<td>86-1,000 mm</td>
<td>42</td>
<td>7</td>
</tr>
<tr>
<td>Over 1,000 mm</td>
<td>42</td>
<td>5</td>
</tr>
<tr>
<td>Not Centrifugally cast</td>
<td>42</td>
<td>5</td>
</tr>
<tr>
<td>JIS 5526</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>5</td>
</tr>
</tbody>
</table>

IX-10
Fittings

Fittings for cast iron and ductile iron pipe are specified in BS No. 4622, ISO Rl3, JIS G5525 and ANSI 21.10 (AWWA C110). The ANSI Standards provide for acceptance on the basis of tensile and transverse tests while the British and ISO Standards provide for hydrostatic tests. All of the standards include dimensions of fittings. The fittings included in the various standards are listed in Table 23.

Handling and Shipping

Although cast iron pipe is a relatively rugged material, damage from rough handling in transit does occur. Each pipe, therefore, should be inspected as it is unloaded, a simple test being to "ring" each pipe with a hammer. At the manufacturing plant the pipe should be so loaded on transporting vehicles that they will not shift in transport.

In unloading, cranes should be used whenever possible. Smaller pipe, up to 400 mm diameter, is frequently unloaded with the use of skid timbers and ropes. When this method is used, care should be taken that the pipe being unloaded does not roll against other pipe. If pipe is to be stored for future distribution, it should be carefully stacked in even layers with stringers between each layer and with heavy blocks at the end of each row to prevent rolling. Pipes should not rest on their bells.

Ductile iron pipe is not as brittle and susceptible to cracking or impact damage as cast iron pipe, but care should be used in handling it as with any pipe material. When loaded for shipping the pipes should be secured so that they cannot shift during transport. Cranes should be used for off-loading. If the pipes are stored or strung along the trench they should be blocked so that they do not rest on their bells.
<table>
<thead>
<tr>
<th>Fitting</th>
<th>ANSI</th>
<th>BSI</th>
<th>ISO</th>
<th>JIS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bends</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>90°</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>45°</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>22 1/2°</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>11 1/4°</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Tees</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Crosses</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Base Bends</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Base tees</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reducers</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Tapped tees</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Offsets</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Collars</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Caps</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plugs</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Change collars</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wyes</td>
<td></td>
<td></td>
<td></td>
<td>x</td>
</tr>
</tbody>
</table>
Installation

Prior to installation in the trench, the pipe should be inspected for damage to coatings, linings or joints. Damaged coatings and linings should be repaired.

Excavation, bedding, and backfill of grey cast iron pipe must be carried out in the same manner as other types of rigid pipe, with due attention paid to the assumed type of bedding.

Ductile iron pipe, being a flexible material which relies on bedding and sidefills for support, must be backfilled with more care than grey cast iron pipe. In tests conducted at the University of Utah (145), cement-mortar lining in ductile iron pipe experienced hairline cracking at deflections in excess of two percent of diameter and spalling began at deflections of about four percent.

Methods of making up the joint will vary with the type of joint furnished, but in common with other pipe types, certain basic requirements must be met. These are:

1. All jointing surfaces must be clean.
2. All parts of the joint must be in their proper position.
3. Manufacturers instructions as to jointing procedures must be strictly followed.
CHAPTER X. STEEL PIPE

Steel pipe has been used for gas, water, oil and other purposes for many years, essentially since the time mass production of steel began. The qualities of steel which make it useful in pipe work are its ability to be shaped and welded, and its high yield strength which enables the material to resist stresses due to high pressures, vibration and shocks such as created by water hammer. Because of its high tensile strength, the wall thickness of steel pipe used in waterworks applications is usually determined from external load or handling considerations rather than pressure, and flexible pipe design procedures are employed.

Manufacture

Steel pipe is made by two general methods: (1) various welding methods, and (2) a seamless process. Lap welding is a commonly used welding technique, but it is not generally allowable in standards for fabrication of steel pipe, although acceptable for circumferential field joints. It should be noted that in seismically active areas, the failure rate in severe earthquakes of lap welded joints in steel pipe has been observed to be more frequent than butt welded or flexible joints.

Table 24 presents a selected list of the available standards for steel pipe and Table 25 the diameters and pressure ranges included within these standards. Both carbon and stainless steels are used in tubing and pipe manufacture. British Standard Code of Practice 2010 lists 18 grades of carbon steel having minimum yield strengths from 2,110 kg/cm² to 4,570 kg/cm². The higher yield stresses are for pipe specified for oil and gas line work, but may be used for water pipe when justified by project conditions. In addition, American National Standards Institute Standard
<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISO 336</td>
<td>Plain End Steel Tubes Welded or Seamless, General Table of Dimensions and Masses per Unit Length</td>
</tr>
<tr>
<td>ISO 559</td>
<td>Welded or Seamless Steel Tubes for Water, Sewage and Gas</td>
</tr>
<tr>
<td>ISO 3183</td>
<td>Ordinary Steel Line Pipe (in draft stage)</td>
</tr>
<tr>
<td>BS 534</td>
<td>Steel Pipes, Fittings and Specials for Water, Gas and Sewage</td>
</tr>
<tr>
<td>BS 3601</td>
<td>Steel Pipes and Tubes for Pressure Purposes, Carbon Steel: Ordinary Duties</td>
</tr>
<tr>
<td>BS 4515</td>
<td>Field Welding of Carbon Steel Pipelines</td>
</tr>
<tr>
<td>BS CP 2010</td>
<td>Part 2. Design and Construction of Steel Pipelines in Land</td>
</tr>
<tr>
<td>DIN 2460</td>
<td>Steel Tubes for Gas and Water Supply</td>
</tr>
<tr>
<td>AWWA C-200</td>
<td>Steel Water Pipe 150 mm and larger</td>
</tr>
<tr>
<td>AWWA C-206</td>
<td>Field Welding of Steel Water Pipe</td>
</tr>
<tr>
<td>AWWA C-208</td>
<td>Dimensions for Steel Water Pipe Fittings</td>
</tr>
<tr>
<td>ASTM A 120</td>
<td>Black and Hot-Dipped Zinc-Coated (Galvanized) Welded and Seamless Steel Pipe for Ordinary Uses</td>
</tr>
<tr>
<td>ASTM A 134</td>
<td>Electric-Fusion (Arc) Welded Steel Plate Pipe (Sizes 16 Inch and Over)</td>
</tr>
<tr>
<td>ASTM A 135</td>
<td>Electric-Resistance-Welded Steel Pipe</td>
</tr>
<tr>
<td>ASTM A 139</td>
<td>Electric-Fusion (Arc) Welded Steel Pipe (Sizes 100 mm and Over)</td>
</tr>
<tr>
<td>ASTM A 381</td>
<td>Metal-Arc Welded Steel Pipe for High-Pressure Transmission Service</td>
</tr>
<tr>
<td>ASTM A 312</td>
<td>Seamless and Welded Austenitic Stainless Steel Pipe</td>
</tr>
<tr>
<td>ASTM A 211</td>
<td>Spiral-Welded Steel or Iron Pipe</td>
</tr>
<tr>
<td>Standard</td>
<td>Description</td>
</tr>
<tr>
<td>---------------</td>
<td>------------------------------------------------------------</td>
</tr>
<tr>
<td>ASTM A 53</td>
<td>Welded and Seamless Steel Pipe</td>
</tr>
<tr>
<td>ANSI B 36.19</td>
<td>Stainless Steel Pipe</td>
</tr>
<tr>
<td>ANSI B 36.10</td>
<td>Wrought and Wrought Iron Pipe</td>
</tr>
<tr>
<td>JIS G3442</td>
<td>Galvanized Steel Pipes for Water Service</td>
</tr>
<tr>
<td>JIS G3452</td>
<td>Carbon Steel Pipes for Ordinary Piping</td>
</tr>
<tr>
<td>JIS G3454</td>
<td>Carbon Steel Pipes for Pressure Service</td>
</tr>
</tbody>
</table>

X-3
<table>
<thead>
<tr>
<th>Standard</th>
<th>Material</th>
<th>Outside Diameter Range (mm)</th>
<th>Nominal Pressure Range (kg/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISO 559</td>
<td>Series A</td>
<td>48.9 to 1016</td>
<td>19.7 to 84.0</td>
</tr>
<tr>
<td></td>
<td>Series B</td>
<td>48.3 to 1016</td>
<td>23.5 to 127.0</td>
</tr>
<tr>
<td></td>
<td>Series C</td>
<td>48.3 to 1016</td>
<td>33.4 to 154.8</td>
</tr>
<tr>
<td></td>
<td>Series U</td>
<td>1220 to 2220</td>
<td>15.3 to 23.6</td>
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<tr>
<td>IIS 534</td>
<td>Steel 22</td>
<td>60.3 to 457.2</td>
<td>46 to 70</td>
</tr>
<tr>
<td></td>
<td>Steel 27</td>
<td>60.3 to 457.2</td>
<td>52 to 70</td>
</tr>
<tr>
<td></td>
<td>Steel 22 BW</td>
<td>60.3 to 114.3</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>Steel 22 EW</td>
<td>60.3 to 168.3</td>
<td>50 to 70</td>
</tr>
<tr>
<td></td>
<td>Steel 27 EW</td>
<td>60.3 to 168.3</td>
<td>60 to 70</td>
</tr>
<tr>
<td></td>
<td>Steel 26 EFW &amp; S.PN</td>
<td>114.3 to 134</td>
<td>16 to 70</td>
</tr>
<tr>
<td>DIN 2440 &amp; 2441</td>
<td>St. 00, St. 33</td>
<td>10.2 to 165.1</td>
<td>Up to 25</td>
</tr>
<tr>
<td>DIN 2442</td>
<td>St. 35, St. 37-2</td>
<td>10.2 to 165.1</td>
<td>Up to 100</td>
</tr>
<tr>
<td>DIN 2450, 2451, 2456 &amp; 2457</td>
<td>St. 35, 45, 55 &amp; 52</td>
<td>10.2 to 508</td>
<td>Up to 25</td>
</tr>
<tr>
<td>DIN 2458</td>
<td>DIN 1626</td>
<td>10.2 to 1016</td>
<td>All pressures</td>
</tr>
<tr>
<td>DIN 2460</td>
<td>St. 00</td>
<td>60.3 to 508</td>
<td>Up to 25</td>
</tr>
<tr>
<td></td>
<td>St. 35</td>
<td></td>
<td>Up to 64</td>
</tr>
<tr>
<td>DIN 2461</td>
<td>St. 33</td>
<td>60.3 to 2020</td>
<td>Up to 20</td>
</tr>
<tr>
<td></td>
<td>St. 37-2</td>
<td></td>
<td>Up to 64</td>
</tr>
</tbody>
</table>
B36.19 provides a standard for welded and seamless stainless steel pipe in nominal sizes from 1/8 inch (3.2 mm) to 30 inches (760 mm). Use of the higher strength steels permits the design of thin wall piping systems to resist internal pressure. However, as mentioned earlier, buried pipe must be able to resist the external loads of earth and traffic, and it will normally be found that the effects of these will control the pipe wall thickness in lower pressures, generally below about 7 kg/cm².

**Fields of Application**

Steel pipe is probably the most versatile of the materials used for pipelines. In water and sewerage systems, it is used for transmission mains and distribution systems as well as pumping plant manifolds, intake and discharge lines and power plant piping. It has been used for industrial and domestic sewerage, although in these applications special attention must be given to the internal coating of the pipe.

**Limitations**

Steel pipe is subject to corrosion by galvanic or electrolytic action and requires protective linings and coatings and cathodic protection when exposed to conditions conducive to such action. Where flexible joints are used, the joints should be electrically bonded to allow the installation of cathodic protection, either by impressed current or sacrificial anodes, at any time it is found advisable. Test leads should be provided to permit monitoring of the pipeline's pipe to soil potential.

Steel pipe is a flexible pipe and requires the same care in installation as other flexible pipe materials. Where rigid lining and coatings are used, pipe deflection must be limited to the value of \( \frac{D^2}{d_{000}} \) as discussed in Chapter II. A general rule is to limit the deflection of flexibly coated and lined pipe to five percent. It should be noted
that if backfill under the lower pipe sector is not satisfactorily installed, the overall vertical or horizontal deflection may be acceptable, but localized deflections may exceed acceptable limits.

Joints

Various kinds of field joints are used with steel water pipe. Two common types are the mechanical joint and the field-welded joint. Bell and spigot rubber-gasket joints are also used on welded steel pipe. Some field joints for steel pipe are illustrated in Figures 30 and 31.

Linings and Coatings

Steel pipe installed below ground requires lining and coating to protect it from corrosion. Even where soil resistivity measurements indicate cathodic protection not to be required it is prudent to provide for its future installation, and it is necessary to coat the pipe to limit the amount of induced current required to a minimum. Discussed herein are a number of the various coatings available.

Asphalt

Asphalt coatings may be either pure asphalt or asphalt mastic systems and are used in conjunction with wrapping systems. The coating is easy to apply by hot dip. It has a lower density than other coatings and is more susceptible to damage. As noted in Chapter II, a survey of older pipelines by the United States Bureau of Reclamation,(23) revealed many failures of asphalt coatings having an age of 20 years or more. The probable life of asphalt coatings must be considered to be on the order of 20 years and design of long life pipelines should consider other materials unless there are compelling reasons such as cost considerations, etc.
LAP WELDED SLIP JOINT

SINGLE BUTT WELD JOINT

DOUBLE BUTT WELD JOINT

STRUCTURAL SHAPE RUBBER GASKET JOINT

FORMED RUBBER GASKET JOINT

ROLLED GROOVE RUBBER GASKET JOINT

FIELD JOINTS COMMONLY USED WITH STEEL PIPE
Coal Tar

Coal tar enamel has high dielectric strength and high resistance to water absorption. It is susceptible to physical damage and generally a wrap of glass mat is embedded in the enamel for reinforcement and an outer wrap of asbestos felt is applied for protection. The coated pipe must be handled with care from shop to installation to avoid coating damage. Coal tar is not recommended for pipe exposed to weather. The life of coal tar enamels is probably in excess of 50 years.

Coal Tar Epoxy

Coal tar epoxy has excellent resistance to water immersion, good chemical resistance and retains adhesion over long periods of exposure. It does exhibit progressive hardening with age with reduced impact resistance, but this is not a matter of great concern in a buried pipeline. It is difficult to obtain adhesion to old coating material during repair.

Vinyl Resin

The resistance to water and moisture vapor of vinyl resin linings is excellent and in addition they are resistant to a broad range of chemicals. Properly applied they have excellent adhesion, and because they are flexible and extensible are not affected by climatic changes in temperature. Vinyl resin is difficult to apply over previously painted surfaces, and because the coats are relatively thin multiple coats are required.

Fusion Epoxy

Fusion epoxy provides a hard, dense coating of high dielectric strength. It is applied to preheated pipe sections and requires close temperature control. The most satisfactory method of application is by preheating the
section of pipe to be coated and dipping it in a fluidized bed of epoxy resin. The size of the section to be coated is limited by the size of bed available and the need to complete immersion before the section has cooled. The material can be field patched by electrostatic techniques but field application on large areas is not satisfactory.

**Tapes**

A number of plastic tapes which depend on dielectric strength for protection are on the market at the present time. Intended primarily for protection of valves, fittings and field joints, they have also been used for pipe coatings. The tapes consist of a backing material such as polyvinyl chloride or polyethylene and an adhesive material of coal tar or other resins or a blend of synthetic and natural rubber. The tape is applied by hand or machine over prized metal. Regardless of the method used for application, tapes should be applied uniformly, under tension and should be free of wrinkles, voids and breaks.

**Cement Mortar**

Cement mortar protects steel by forming a protective film which is maintained by the alkaline environment. The lining or coating must remain in contact with the steel to be effective. This requires that deflection be controlled during shipping and installation. Pipe should be braced for shipping and the bracing should remain in place until backfilling is complete.

A coating which is being used in the petroleum industry and has been applied to small diameter water pipe is a product identified as X-Tru-Coat, which is extruded onto the steel pipe. This coating is applied as a hot butyl rubber adhesive immediately overcoated with a high density polyethylene. The material is very resistant to abrasion, has a low water absorption factor and a high dielectric strength.
Recently, an oil company had occasion to excavate a railroad crossing where several pipes coated with X-Tru-Coat had been installed in a bare steel casing pipe which had corroded through in eight months. The coated pipes were found undamaged although the surrounding soil was found to be saturated with nitric and hydrofluoric acid. The pH of the soil was between 2.2 and 6.1 with most less than 3.0. Chlorides were found to be between 5,200 and 106,000 mg/l and sulfates between 9,200 and 61,200 mg/l.

Pipes coated with any of the coatings which depend on dielectric strength should be tested after coating or lining with an electrical holiday detector. It is also recommended that pipelines with these coatings be inspected after installation with a Pearson type detector to locate areas of coating damaged in installation.

Regardless of the material used, proper surface preparation, priming and application are required for successful coating. An example of improper application of a material which has performed satisfactorily when properly used is the recent report of coating failure on the Ayleska pipeline. In this application, the epoxy, which has been successfully applied to fittings by dipping heated units in a fluidized bed of the material, was sprayed on heated sections of pipe. This technique has been used for repair of damaged areas in epoxy-coated materials. Although no details have yet been reported, it appears that the temperature of the metal at the time the epoxy is applied is critical and that in this case at least it was not properly controlled.

Most aboveground pipelines and pipe installations utilize steel pipe materials. In these applications, electrolytic attack is avoided and coatings are required only for protection against rust, primarily the various types of longlasting paints.
Fittings and Appurtenances

Fittings for steel pipe in sizes up to about 1,000 mm are available from various manufacturers. In sizes over 1,000 mm, they are usually produced by the fabricating and welding process. With the use of fabricated fittings, nearly any problem of layout and fitting may be solved. Fittings are fabricated from either pipe or from plate or sheet steel. Fittings are tested hydraulically after fabrication, to 1-1/4 or 1-1/2 the specified hydrostatic test pressure.

Handling and Shipping

Pipe should be handled at all times with proper equipment using canvas or rubber covered slings and padded skids to prevent damage to the exterior coating. Bare cables, chains, hooks, metal bars or narrow skids should not be used on pipe coated with coal tar or asphalt materials or wrapped with tape and should only be used with caution on cement mortar coated pipe. Mortar coated or lined pipe should be handled so as to avoid bending or deformation.

Coal tar enameled pipe requires more care at temperatures below freezing than in warmer weather. It is not advisable to transport or lay such pipe when the temperature is less than -12°C, and special care should be taken at temperatures below -7°C. In cold climates, it is not advisable to store coal tar enameled pipe through a winter season prior to installing.

Installation

Pipe which is coated with coal tar enamel, asphalt or is tape wrapped should not be placed directly on rough ground when stored at trenchside, nor should it be rolled or dragged along the ground. The cautions given above for handling the pipe should be observed until the final installation is complete. The coating should be inspected,
including inspection of the coating on the underside of the pipe, while it is suspended from slings, and any damaged coating repaired before the pipe is lowered into the trench.

Proper procedure for assembly of field welded joints is set forth in several standards such as BS 4515, Field Welding of Carbon Steel Pipelines, and AWWA C 206, Field Welding of Steel Water Pipe. Assembly of pipe using proprietary couplings should be in accordance with the manufacturer's recommendation. Rubber gasket joints are assembled in the same manner as for concrete pipe.

After assembly, all exposed metal at the joints must be coated with the same material as the pipe coating.

**Field Testing**

Steel pipelines using rubber gasket or mechanical joints may be subjected to a leakage loss test after completion of the pipeline. However, when pipelines are assembled using welded joints, it is possible to test individual joints immediately after assembly. In the case of butt welded pipe, various devices are used, one of which is the "look box" shown in Figure 32. In use the weld is painted with a soap solution, the look box is placed over the weld and a vacuum drawn. Bubbles will disclose any leak. Lap welded pipe can be tested in the same way, but if the joint is welded inside and out, a tap hole is sometimes placed in the overlapping portion. By painting the welds with a soap solution and applying air pressure to the joint, leaks can be detected by observing bubbles in the soap solution.
FIGURE 32

Looking Box

- Safety Plate Glass or Plexiglass
- Vacuum Gage
- Welded Seam
- 2-Way Valve
- Air Ejector
- Hose to Compressor
CHAPTER XI. THERMOPLASTIC PIPE

Probably the most rapidly growing use of pipe materials is in plastic pipe, both thermoplastics and reinforced thermosetting resins. Other than the use of fiberglass reinforcing in the thermosetting resins, the primary difference in these materials is that the thermoplastic resins can be melted and reformed. The thermosetting resins cannot. Table 26 lists the most commonly used thermoplastic pipe materials including Acrylonitrile-Butadiene Styrene (ABS), Polyethylene (PE), Polybutylene (PB), and Polyvinyl Chloride (PVC). It should be noted that the term "rigid" in this table does not refer to pipe design as discussed in Chapter II. All thermoplastic pipelines should be designed as flexible pipe.

In the ASTM Standards the terms "Hydrostatic Design Basis" and "Hydrostatic Design Stress" are used in respect to plastic pipe. Essentially, the Hydrostatic Design Basis is the stress in the pipe wall at which plastic pipe is estimated to perform for 100,000 hours. The Hydrostatic Design Stress is the stress in the pipe wall at which the pipe will perform indefinitely. The "Service Factor" times the Hydrostatic Design Basis equals the Hydrostatic Design Stress. The Hydrostatic Design Stress varies with the resin type and also within the resin family. The physical characteristics of a resin compound play an important role in the resin's ability to perform as a pressure pipe.

The Hydrostatic Design Stress is used to determine the pressure rating of the pipe in the ISO formula:

\[ S = \frac{P(D-t)}{2t} \]

Where

- \( S \) = Hydrostatic Design Stress
- \( D \) = Average outside diameter
- \( t \) = Minimum wall thickness
- \( P \) = Pressure ratio

XI-1
<table>
<thead>
<tr>
<th>Material</th>
<th>Type</th>
<th>Applications</th>
<th>Joining Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABS</td>
<td>Rigid</td>
<td>Drain, Waste &amp; Vent (DWV)</td>
<td>Solvent Cement</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Building Sewers &amp; Sewer Mains</td>
<td>Threading</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Electrical &amp; Communications Conduit</td>
<td>Transition Fittings</td>
</tr>
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<td></td>
<td>Water Piping</td>
<td></td>
</tr>
<tr>
<td>PE</td>
<td>Flexible</td>
<td>W. r Service &amp; Water Mains</td>
<td>Insert Fittings</td>
</tr>
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<td></td>
<td>Gas Service &amp; Gas Mains</td>
<td>Socket Fusion</td>
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<td></td>
<td></td>
<td>Chemical Waste</td>
<td>Butt Fusion</td>
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<td>Irrigation Systems</td>
<td>Transition Fittings</td>
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<tr>
<td>PB</td>
<td>Flexible</td>
<td>Water Service &amp; Water Mains</td>
<td>Insert Fittings</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Gas Service &amp; Gas Mains</td>
<td>Butt Fusion</td>
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<tr>
<td></td>
<td></td>
<td>Irrigation Systems</td>
<td>Transition Fittings</td>
</tr>
<tr>
<td>PVC</td>
<td>Rigid</td>
<td>Water Service &amp; Water Mains</td>
<td>Solvent Chemical</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Gas Service &amp; Gas Mains</td>
<td>Elastomeric Seal</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Building Sewers &amp; Sewer Mains</td>
<td>Threading</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Drain, Waste &amp; Vent (DWV)</td>
<td>Mechanical Couplings</td>
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<td></td>
<td></td>
<td>Electrical &amp; Communications Conduit</td>
<td>Transition Fittings</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Industrial Process Piping</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Irrigation Systems</td>
<td></td>
</tr>
</tbody>
</table>

*See text for full name of material.*
Any of the plastic pipes have a predictable lift expectancy based on the resin formulation and the hoop stress in the pipe wall. The Hydostatic Design Basis is derived from a stress regression line developed from a plot of a series of test data. For a given stress level thermoplastics have a given lift. There is a point at which the plastic will have infinite lift from a practical standpoint and the Hydostatic Design Stress should be below this point.

Thermoplastic pipe is pressure rated at 20°C (23°C in the United States). When any pipeline will operate at temperatures in excess of this, the pipe must be derated. That is, it must operate at a lower pressure or its life expectancy must be reduced. The amount of derating required is dependent upon the resin formulation. Table 27, derived from the British Standards Institution Code of Practice for Plastics Pipework, illustrates the effect of temperature.

### TABLE 27

<table>
<thead>
<tr>
<th>Temperature</th>
<th>PVC Working Pressure as Percent of that at 20°C</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Ambient Temperature</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Less than 20°C</td>
<td>20°C</td>
<td>Type 32</td>
</tr>
<tr>
<td>20°C</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>30</td>
<td>85</td>
<td>80</td>
</tr>
<tr>
<td>40</td>
<td>70</td>
<td>60</td>
</tr>
<tr>
<td>50</td>
<td>55</td>
<td>40</td>
</tr>
<tr>
<td>60</td>
<td>40</td>
<td>20</td>
</tr>
<tr>
<td>70</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
A number of the thermoplastic materials, notably ABS, PE and PVC are susceptible to loss of impact strength when exposed to sunlight. The effect of the ultraviolet rays is to create a very thin film of brittle material on the surface of the pipe, reducing the impact strength by about half. Removal of the brittle layer with fine sandpaper will restore the impact strength. Manufacturers add various inhibitors, principally carbon black, to their pipes to prevent this effect.

Table 28 is a summary of methods of joining thermoplastic pipe. Solvent cement joints require particular care. Solvents used for solvent cementing are toxic and the joint should be made outside the trench and the pipe lowered in. At low temperatures the joint may require up to two hours to cure and at high temperatures the solvent evaporates rapidly requiring fast assembly. At high temperatures the cement must be shielded from direct sunlight and cans must be kept closed except when actually in use. The cement must be discarded when it begins to thicken or becomes stringy. The actual point when it should be thrown out is a matter of judgement based on experience. There are no standards for this but inspection must be close and competent.

Polyvinyl chloride (PVC) and chlorinated polyvinyl-chloride (CPVC) can be joined provided that CPVC solvent is used. Other dissimilar materials cannot be joined with solvent cement. The materials have different thermal expansion characteristics and connecting them requires special adapters.

Acrylonitrile - Butadiene Styrene (ABS)

ABS is a tough, high-impact material widely used for sanitary drain, waste and vent systems. ABS products used for sewer pipe are of two types: solid wall and truss pipe. Truss pipe is composed of a double wall of ABS braced with a
<table>
<thead>
<tr>
<th>Method</th>
<th>Pipe Materials</th>
<th>Disadvantages</th>
<th>Advantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solvent-cementing</td>
<td>PVC, ABS, CPVC</td>
<td>Cannot be done properly under adverse conditions; requires waiting to test joint; leaks difficult to repair; joint is permanent.</td>
<td>Quick; easy; joint is strong; no special tools required</td>
</tr>
<tr>
<td>Threading</td>
<td>All (Schedule 80 and over)</td>
<td>Possible to over-torque joint; reduces pressure rating; requires special tools for threading.</td>
<td>Can prefabricate; leaks easy to repair; joint can be tested immediately.</td>
</tr>
<tr>
<td>Butt heat fusion</td>
<td>PE, PP, PB</td>
<td>Requires special tools; hard to do in cold weather; joint is permanent.</td>
<td>Very strong joint; joint can be tested almost immediately; can be used with large diameter pipe.</td>
</tr>
<tr>
<td>Electrical resistance</td>
<td>PP</td>
<td>Requires expensive tooling; electrical source needed; coil may come in contact with fluid in line.</td>
<td>Quick; leaks easy to repair.</td>
</tr>
<tr>
<td>Flanging</td>
<td>All</td>
<td>High initial cost and labor; limited to about 10.5 kg/cm².</td>
<td>Essentially same as threaded.</td>
</tr>
<tr>
<td>Socket heat fusion</td>
<td>PE, PP, PB</td>
<td>Same as butt heat fusion.</td>
<td>Same as butt heat fusion.</td>
</tr>
<tr>
<td>Grooving</td>
<td>All</td>
<td>Requires expensive tools; couplings expensive; reduces pressure rating.</td>
<td>Can prefabricate; easy to assemble and disassemble; can be tested immediately.</td>
</tr>
<tr>
<td>Compression insert</td>
<td>PC, PB, FR</td>
<td>Limited to about 80 mm diameter; reduces flow capacity of system.</td>
<td>Easy to install; no special tools required; leaks easy to repair.</td>
</tr>
<tr>
<td>O-ring</td>
<td>PVC</td>
<td>Not recommended for fluid other than water and sewage; thrust blocking required; should not be used above ground.</td>
<td>Easy to install in all weather; no special tools required; joint can be tested immediately; high pressure ratings; expansion and contraction of system.</td>
</tr>
</tbody>
</table>

*Adverse conditions are considered to be temperatures outside the range of 4° to 32° C, wetness, direct sun exposure, or winds of 24 km/hr or higher.
truss type structure, all formed in one extrusion. The truss voids are filled with lightweight concrete to provide additional ring strength and bracing.

ABS pipe is highly resistant to chemical corrosion and has found use in oil field service, chemical handling systems, and gas and water transmission and distribution lines. It is claimed that in the United States at present nearly two-thirds of all plastics piping used for sanitary drain, waste and vent systems is made of ABS.

Solid wall ABS pipe is produced in diameters from 80 mm to 300 mm. Truss wall pipe is produced in diameters from 200 mm to 380 mm and generally manufactured in lengths of 570 cm.

**Joints**

Joints in ABS pipe are made by the solvent weld method. Outlets may be made by applying solvent to the area around the opening in the pipe wall and attaching an ABS outlet saddle by strapping it in position with stainless steel straps.

**Fittings**

A complete line of ABS fittings for both solid wall and truss pipe is available, including adapters between the two types of pipe and repair couplings.

**Polyethylene (PE)**

Polyethylene is one of the oldest and most widely used plastic materials for piping. Polyethylene pipe is flexible, chemically inert and has high strength to weight ratio, is lightweight, coilable and resistant to corrosive environments. It can be obtained in several grades and densities ranging from low density to ultra-high molecular weight. It has found wide use for water service, gas distribution and service, drainage and waste systems and irrigation. Table 29
<table>
<thead>
<tr>
<th>Standard</th>
<th>Range of Outside Diameters</th>
<th>Pressure Classes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Afnor 54-043</td>
<td>25-200 mm.</td>
<td>4 kg/cm²</td>
</tr>
<tr>
<td>Afnor 54-043</td>
<td>16-110 mm.</td>
<td>6 kg/cm²</td>
</tr>
<tr>
<td>Afnor 54-043</td>
<td>16-90 mm.</td>
<td>10 kg/cm²</td>
</tr>
<tr>
<td>Din 8074</td>
<td>75-1000 mm.</td>
<td>Class 1 2.5 kg/cm²</td>
</tr>
<tr>
<td>Din 8074</td>
<td>63-1000 mm.</td>
<td>Class 2 3.2 kg/cm²</td>
</tr>
<tr>
<td>Din 8074</td>
<td>40-1000 mm.</td>
<td>Class 3 4 kg/cm²</td>
</tr>
<tr>
<td>Din 8074</td>
<td>25-800 mm.</td>
<td>Class 4 6 kg/cm²</td>
</tr>
<tr>
<td>Din 8074</td>
<td>10-500 mm.</td>
<td>Class 5 10 kg/cm²</td>
</tr>
<tr>
<td>Bs 1972</td>
<td>6.4-102 mm.</td>
<td>Type 32 32 kg/cm²</td>
</tr>
<tr>
<td>Bs 328</td>
<td>6.4-152 mm.</td>
<td>Type 50 50 kg/cm²</td>
</tr>
<tr>
<td>Jis K 6762</td>
<td>10-50 mm.</td>
<td>7.5 kg/cm²</td>
</tr>
<tr>
<td>Awwa c901</td>
<td>25-76 mm.</td>
<td>Varies with plastics formulation</td>
</tr>
</tbody>
</table>
lists standards for polyethylene pipe including diameters and pressure classes.

Polyethylene pipe up to 1,200 mm in diameter is manufactured by DuPont of Canada and has been used for submarine intakes and outfalls, and for relining deteriorated sewers and water pipelines. The material has been used for slurry pipelines and has good abrasion resistance.

Because of its flexibility and low surface hardness, proper support is essential to minimize deflection. Its relatively low softening point makes it necessary to avoid installation and service at high temperatures. Pressure ratings in the various standards are for water at 20°C (23°C in the United States). Pressure ratings will decrease as the temperature increases. Polyethylene pipe is not fractured by freezing, but the flow of water may be stopped, and if this occurs methods of applying heat must not raise the temperature of the piping above 50°C.

**Joints**

There are no solvents for polyethylene pipe. Joints in PE piping are made by thermal butt-fusion which is a process whereby two pipes or fittings to be joined are held in a fixture, their ends are softened by means of heat and then pressed together under controlled pressure, or by sleeve connections using special heating elements. These special elements include embedded high resistance wire and a technique in which a PE conical ring is pressed between the pipe and sleeve and then rotated until the welding temperature is reached.

**Limitations**

Polyethylenes are sometimes subject to a type of chemical attack called "stress cracking." Stress cracks develop in polyethylene when the material is stressed (bent, twisted, cut, etc.) and then exposed to some chemical environments.
The rate and degree of attack is a function of the stress level and the chemical environment and is specific for each combination.

Polyethylene without stabilizers has a limited life outdoors in direct sunlight due to the deterioration caused by the ultra-violet rays of the sun. Polyethylene pipe usually is manufactured with a stabilizer system that protects it from harmful radiation. If the pipe is to be used in above-ground service, it should be stabilized with suitable additives, the most common of which is carbon black.

As with all plastic pipes, polyethylene pipe cannot be located by the devices normally used to locate metallic pipes. A copper or galvanized wire, however, can be spiralled around, taped to, or laid alongside the pipe during installation to permit the use of locating devices.

Installation

In making fusion joints in polyethylene pipe, the ends to be joined are placed in a joining machine where the ends are trimmed and the ends heated and fused. The joints are normally made above ground and the pipe then lowered into the trench. Testing is usually carried out prior to placing in the trench.

Polyethylene pipe, as well as polyvinylchloride and small diameter steel pipe, may be installed by use of plows. In this method, a small hole is excavated at the starting point and the pipe is fed through guides and anchored. As the tractor-drawn plow moves forward the pipe is pulled off a reel down through guides and into place. In the case of pipe which is too rigid to be coiled the material can be strung out along the alignment and fed into the guides. The success of the operation is directly affected by soil type as well as pipe size. It works well in sandy soils but in
heavier soils the equipment required for pulling the plow becomes uneconomical, and it should not be attempted in rocky soils. However, with proper project conditions, savings of up to 50 percent on installation costs may be realized.

**Polybutylene (PB)**

Polybutylene is a relative newcomer to the family of plastics which has demonstrated some superior performance characteristics. Polybutylene is flexible like high density polyethylene, but with higher temperature pressure characteristics. The material has high abrasion resistance. PB piping has been used in water distribution, industrial sewer lining and sewer relining, hot water plumbing, gas distribution systems, chemical process piping, irrigation lines, outfall lines and water intakes and mains. It is available in sizes up to 600 mm and larger sizes are under development. Joints in polybutylene pipe are made in the same manner as joints in polyethylene pipe, and the installation procedures are the same.

**Polyvinyl Chloride (PVC) and Chlorinated Polyvinyl Chloride (CPVC)**

Rigid polyvinyl chloride is the name applied to a family of thermoplastics having a wide variety of properties. PVC pipe was developed in Germany in 1935 and has gained wide acceptance throughout the world. It is being manufactured in many locations worldwide and is used in water and gas distribution and service piping, industrial process piping, irrigation and drainage systems, sewers, drain waste and vent, electrical conduit and marine systems. Equipment for producing the pipe is not expensive and incompetent manufacturers are frequently encountered. Pipe suppliers should be required to furnish proof of their ability to produce pipe conforming to the specifications requirements.
A list of standards for PVC pipe is shown in Table 30; however, the list is not exhaustive. The DIN Standards list ten standards applying to PVC pipe and fittings and the ASTM Standards list 19. Careful review of the standards to ensure that those referenced are applicable to the intended service is recommended.

Also Table 31 lists diameters and ranges of pressure classes provided for in the standards of each organization.

Joints

Joints in PVC piping are solvent weld, rubber gasket type or threaded. Where pipes up to about 180 mm in diameter are being installed, it is possible to assemble solvent welded joints above ground and then lower the pipe into the trench. The solvents used in joint makeup are toxic and adequate ventilation must be provided. The notch effect on PVC pipe requires that pipe strength be derated for threaded connections.

Storage and Handling

Polyvinyl chloride pipes are lightweight, and as a result, are liable to be thrown about more than pipes made of heavier materials. Care should be taken that it is not handled in such a way as to damage it by impact, abrasion or gouging. PVC pipe should be so stored as to prevent sagging or bending. It is subject to ultra-violet damage and if stored outdoors should be protected from direct exposure to sunlight. Storage of the pipes in heated areas exceeding 20°C should be avoided.

Installation

PVC pipe and tubing can be joined to itself and to other piping materials by a variety of methods. Solvent cementing is used with socket type PVC fittings and with bell end PVC pipe. While the method is simple, strong
<table>
<thead>
<tr>
<th>Standard</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BS 3505</td>
<td>Unplasticized PVC Pipe for Cold Water Services Plastics</td>
</tr>
<tr>
<td>AFNOR NF T54-003</td>
<td>Plastics - Unplasticized PVC Pipes - General Specifications</td>
</tr>
<tr>
<td>AFNOR NF T54-016</td>
<td>Plastics - Unplasticized PVC Pipes and Fittings for the Transport and Distribution of Water Under Pressure - Specifications</td>
</tr>
<tr>
<td>AFNOR P 16-352</td>
<td>Unplasticized Polyvinyl Chloride Tubes for Sewers - Requirements</td>
</tr>
<tr>
<td>AFNOR T 54-017</td>
<td>Unplasticized PVC Pipes and Fittings for Sanitary Installations - Specifications</td>
</tr>
<tr>
<td>DIN 8061</td>
<td>Pipes of Rigid PVC; General Quality Requirements, Testing</td>
</tr>
<tr>
<td>DIN 8062</td>
<td>Pipes of Rigid PVC; Dimensions</td>
</tr>
<tr>
<td>DIN 8078</td>
<td>Pipes of Chlorinated Polyvinylchloride; General Quality Requirements, Testing</td>
</tr>
<tr>
<td>DIN 8079</td>
<td>Pipes of Chlorinated Polyvinylchloride; Dimensions</td>
</tr>
<tr>
<td>JIS K6742</td>
<td>Unplasticized Polyvinyl Chloride Pipes for Water Works Service</td>
</tr>
<tr>
<td>ASTM D 2672-73</td>
<td>Bell-End Poly(Vinyl Chloride) (PVC) Pipe</td>
</tr>
<tr>
<td>ASTM D 2846-73</td>
<td>Chlorinated Poly(Vinyl Chloride) (CPVC) Plastic Hot Water Distribution Systems</td>
</tr>
<tr>
<td>ASTM D 2836-72</td>
<td>Filled Poly (Vinyl Chloride) (PVC) Sewer Pipe</td>
</tr>
<tr>
<td>ASTM D 2665-74</td>
<td>Poly(Vinyl Chloride) (PVC) Plastic Drain, Waste, and Vent Pipe and Fittings</td>
</tr>
<tr>
<td>ASTM D 1785-74</td>
<td>Poly (Vinyl Chloride) (PVC) Plastic Pipe, Schedules 40, 80, and 120</td>
</tr>
<tr>
<td>ASTM D 2241-74</td>
<td>Poly (Vinyl Chloride) (PVC) Plastic Pipe (SDR-PR)</td>
</tr>
<tr>
<td>ASTM D 2464-74</td>
<td>Poly (Vinyl Chloride) (PVC) Plastic Pipe Fittings, Threaded, Schedule 80</td>
</tr>
<tr>
<td>ASTM D 2729-72</td>
<td>Poly (Vinyl Chloride) (PVC) Sewer Pipe and Fittings</td>
</tr>
<tr>
<td>ASTM D 2855-73</td>
<td>Making Solvent Cemented Joints with Poly (Vinyl Chloride) (PVC) Pipe and Fittings</td>
</tr>
<tr>
<td>AWWA C900</td>
<td>Polyvinyl Chloride (PVC) Pressure Pipe 4 in. (100 mm) through 12 in. (305 mm) for Water</td>
</tr>
</tbody>
</table>
### TABLE 31

POLYVINYL CHLORIDE PIPE
DIAMETERS AND RANGES OF PRESSURE CLASSES

<table>
<thead>
<tr>
<th>Standard</th>
<th>Range of Outside Diameters</th>
<th>Pressure Classes</th>
</tr>
</thead>
<tbody>
<tr>
<td>BS 3505</td>
<td>17-610</td>
<td>Class B 6 kg/cm²</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Class C 9 kg/cm²</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Class D 12 kg/cm²</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Class E 15 kg/cm²</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Class 7 Suitable for screw threading at Class C Pressures</td>
</tr>
<tr>
<td>DIN 8062</td>
<td>75-1000</td>
<td>Class 2 4 kg/cm²</td>
</tr>
<tr>
<td></td>
<td>40-1000</td>
<td>Class 3 6 kg/cm²</td>
</tr>
<tr>
<td></td>
<td>25-630</td>
<td>Class 4 10 kg/cm²</td>
</tr>
<tr>
<td></td>
<td>10-400</td>
<td>Class 5 16 kg/cm²</td>
</tr>
<tr>
<td>AWWA C900</td>
<td>100-305</td>
<td>7 kg/cm²</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10.5 kg/cm²</td>
</tr>
<tr>
<td></td>
<td></td>
<td>14 kg/cm²</td>
</tr>
<tr>
<td>AFNOR T 54-016</td>
<td>200-400</td>
<td>6.4 kg/cm²</td>
</tr>
<tr>
<td></td>
<td>90-250</td>
<td>10 kg/cm²</td>
</tr>
<tr>
<td></td>
<td>63-125</td>
<td>16 kg/cm²</td>
</tr>
<tr>
<td>JIS 6742</td>
<td>13-150</td>
<td>7.5 kg/cm²</td>
</tr>
</tbody>
</table>
pressure-tight joints require the use of proper solvent cementing technique, with pipe and fittings that meet specified dimensional tolerances. The required skill and knowledge on the part of the operator can be obtained by making joints under the guidance of skilled operators and testing them until good quality joints are obtained. Details of this technique are given in ASTM D-2855 "Recommended Practice for Making Solvent Cemented Joints with Polyvinyl Chloride Plastic Pipe and Fittings."

A variety of proprietary elastomeric seal joints made of plastic and/or metals, are commercially available in both pipe and fittings. These systems make use of rubber gaskets and the "push-on" method or the mechanical compression method of assembly. The recommendations of the manufacturers should be followed in the use of these systems. Proper assembly of this type of joint generally requires less skill than solvent cementing and can be successfully executed under less than ideal field conditions.

The heavier walled PVC pipe can be threaded with conventional pipe threading tools used for metal pipe but the pressure rating of threaded pipe should be reduced to 50 percent of that of the pressure rating of unthreaded pipe. A wide variety of threaded PVC pipe fittings are commercially available. Threaded metal fittings can also be used with PVC pipe at constant temperatures. Thread sealing compounds are normally not recommended, however, various thread lubricants and thread tapes are useful when used as recommended by their manufacturers. Care should be taken not to mar or distort the pipe or fitting during threading and assembly operations. Where possible, use fabric strap wrenches.
CHAPTER XII. REINFORCED THERMOSETTING RESIN PIPE

Thermosetting resin reinforced with fiberglass is being used for numerous structural purposes, including pipe. At present two types of pipe are produced: reinforced thermosetting resin pipe, designated with the letters RTR, GRP or FRP; and reinforced plastic mortar pipe designated as RPM. The RTR pipe consists of resin and fiberglass while the RPM pipe includes inert fillers, such as sand, with the resin and fiberglass.

The fiberglass reinforcing may be in the form of continuous fibers, mat, glass flakes, chopped fibers, woven fabric rovings, or a combination of these. Resins include both orthophthalic and isophthalic polyesters, phenolic vinyl esters, bisphenol-A and epoxies. Combinations of these materials will vary the strength and resistance of the pipe, and various manufacturers make use of different materials. It is critical that the inner liner be able to accept deflection without cracking and for this reason a flexible resin material should be used.

Because thermosetting resin pipe is one of the most recent developments in the pipe industry, there is a proliferation of standards applying to it and a proliferation of methods of manufacture. In time these will no doubt be consolidated, and the more successful procedures will prevail. As an example, a paper entitled "Thermosetting Resin Pipe" by B. J. Schrock (143) listed 32 existing applicable standards and codes and 8 more in the preparation and approval process in the United States alone. A selected list of standards is contained in Table 32. The standards listed include pipe diameters from 25 mm to 4,000 mm. Although some of the standards specify pressure classifications, others are manufacturing standards. ASTM Standards D2996 and D2997 provide guidelines for a designer to specify a designation code the type of resin and liner, the short-term rupture
<table>
<thead>
<tr>
<th>Standard Designation</th>
<th>Description</th>
<th>Range of Diameters</th>
<th>Pressure Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASTM D2996</td>
<td>Filament-Wound Reinforced Thermo-setting Resin Pipe</td>
<td>25-305 mm</td>
<td></td>
</tr>
<tr>
<td>ASTM D2997</td>
<td>Centrifugally Cast Reinforced Thermosetting Resin Pipe</td>
<td>38-305 mm</td>
<td></td>
</tr>
<tr>
<td>ASTM D3262</td>
<td>Reinforced Plastic Mortar Sewer Pipe</td>
<td>200-2740 mm</td>
<td></td>
</tr>
<tr>
<td>ASTM D3517</td>
<td>Reinforced Plastic Mortar Pressure Pipe</td>
<td>200-2740 mm</td>
<td>1.5-15.2 kg/cm²</td>
</tr>
<tr>
<td>BS 5480:Part 1</td>
<td>Reinforced Plastics (GRP) Fittings for use for Water Supply or Sewerage</td>
<td>25-4000 mm</td>
<td>0-64 kg/cm²</td>
</tr>
<tr>
<td>AFNOR HFT57-200</td>
<td>Pipe and Fittings of Composite Glass Thermoplastic Material</td>
<td>50-1200 mm</td>
<td>2.5-6 kg/cm²</td>
</tr>
</tbody>
</table>
strength, the longitudinal tensile strength, the tensile modulus and the apparent stiffness of the pipe.

There are a large number of manufacturers of this pipe worldwide. A recent call for tenders from the Abu Dhabi Sewer Board for supply of 107 km of fiberglass reinforced plastic mortar pipe resulted in submittals from eighteen fiberglass pipe manufacturers.

**Fields of Application**

Fiberglass reinforced thermosetting resin pipe has found use in industry as well as water and sewerage systems. In industry, it has been used for transporting pickling solutions for the steel industry, pulp stock and various industrial chemicals. Because it is an inert material, it finds application in areas where metal pipes are subject to corrosion or where the transported fluid is aggressive. It has been used for lining deteriorated pipes of other types, and has been installed in aboveground and subaqueous applications as well as belowground.

**Manufacturing Methods**

Although there are variations, the basic procedure used in manufacture of reinforced thermosetting resin pipe is to apply the various constituents to a mandrel simultaneously but layers, or to cast them in a mold with centrifugal action. After the full pipe wall has been constructed the mandrel or mold is then placed in a curing oven where the materials are cured, and the spigot ends, and sometimes the bells, are attached after curing.

Shop tests are run of each of the materials being used in the pipe. In addition, hydrostatic tests and ring deflection tests of stiffness may be performed.
Joints

In addition to the varieties of materials available, there is a wide selection of joints. Joints used include bell and spigot with rubber gasket, bolted flanges and plain ends for wrapped butt joints or slip-on couplings applied to plain ends on the pipe. Several joint configurations are shown in Figure 33 and Figure 34 shows a picture of a spigot end of RPM pipe used in the bell spigot type joint.

Fittings

A complete line of fittings in thermoplastic materials is available for RTR pipe including tees, reducers, wyes, elbows and manholes. Steel fittings lined and coated with cement mortars or epoxies and cast iron fittings are used for both RTR and RPM pipe. For small diameter connections, service saddles may be used.

Handling and Shipping

When transporting RTR or RPM pipe, the pipe sections should be supported on cradles spaced not more than 6 meters apart. The pipes should be strapped down to the vehicle with pliable straps or ropes located over the cradle points. Steel cables or chains should never be used as straps or to lift the pipe, nor should hooks be used on the pipe ends.

Figures 35 and 36 show packaging and handling of RPM for shipping (in this case for overseas).

If the pipe is stored directly on the ground, the ground should be flat and free of rocks or other debris that may cause point loading. Individual pipes should be blocked. The pipe is light and it is possible that individual sections can be moved by wind.

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Installation

RTP and RPM pipe is a flexible pipe material which relies on the soil for support. Precautions and special procedures outlined previously for installation of flexible pipe should be closely followed.

Pictures of installation of RPM pipe are shown on Figures 37 and 38. In Figure 37, the workmen are lowering the pipe into the trench with hand held rakes. Figure 38 shows the assembly of a bell and spigot joint using a "come-along".

Because of the varieties of joints used, assembly procedures are not discussed herein. Pipe manufacturers provide installation instructions and these should be closely followed. Adhesive bonded joints require careful preparation and assembly. Recently the Peabody Testing X-ray Engineering Company of Foster City, California has offered a qualification and certification program for assemblers of these joints.

Special Comments

Several firms have specified and managed the design and construction of irrigation pipelines utilizing reinforced plastic materials in diameters up to 1,400 millimeters. Some of this pipe has been manufactured by United Technology Corporation under the name Techite. This pipe was some of the first in commercial production. Most of this pipe has been in the ground for five to eight years.

Failures have occurred in some of these pipelines and the causes are still under investigation. Some of these failures are attributable to improper installation, but there is evidence that the manufacturer's design and/or fabrication was faulty. The manufacturer of this line of pipe has made a number of changes in design and manufacturing processes which resulted from this early experience.
Figure 3: Typical Joints for Fiberglass Reinforced Pipe

Bell and Spigot Joint (Gasket in Bell)

Slip-On Coupling

Bell and Spigot Joint (Gasket on Spigot)

Flanged Joint

Butt and Strap Joint

Bell Ring

Gasket

Inside Face

Spigot Ring
FIGURE 34

SPIGOT END OF REINFORCED PLASTIC MORTAR PIPE
FIGURE 35

REINFORCED PLASTIC MORTAR PIPE PACKAGED FOR OVERSEAS SHIPMENT
FIGURE 36

HANDLING REINFORCED PLASTIC MORTAR PIPE
FIGURE 37

INSTALLATION OF 900mm REINFORCED PLASTIC MORTAR PIPE – JORDAN
FIGURE 38

ASSEMBLY OF REINFORCED PLASTIC MORTAR PIP® JOINTS – JORDAN
Early Techite pipe manufactured for sanitary sewers experienced failures which have been attributed to sulfuric acid attack on the glass fibers. This action is termed "strain corrosion". In the development of the pipe it was tested for acid resistance in the same manner as clay pipe, i.e., specimens of pipe material were immersed in an acid solution, and was reported to be inert. However, further investigation revealed that the resin forming the inside surface of the pipe wall was relatively rigid and surface crazing occurred when the pipe was deflected allowing the acid to reach the glass fibers. Apparently the glass fibers, which are inert in an unstrained state, can be attacked by the acid when strained. As a result, a more flexible resin is now being used for the liner, and the 1976 edition of ASTM D3262 requires that the pipe be tested for acid resistance in a strained state.
CHAPTER XIII. SPECIFICATIONS

Specifications are the means by which the designer transmits to the contractor the detail requirements of quality and workmanship that are necessary for a project. To this end, the specifications must be complete in order that confusion is not created, and the specification writer who refers to various standards must understand the differences between those standards and what effect such differences will have on the project.

The specifications and the contract drawings are complementary documents which together define the work required of the Contractor. Neither set of documents can stand alone, and what is required in one must be performed as if called for in both.

The drawings should indicate the limits of each size and class of pipe, the elevations and gradients, the appurtenances required, trench cross section details and other required details. The drawings must be coordinated and in sufficient detail so that the project can be completed.

The specifications should define the type of pipe and fittings to be installed, and the related materials, and backfilling. Any special requirements such as cathodic protection should be completely defined. In addition, testing and disinfection requirements must be specified.

It is generally not advisable to specify construction methods, but rather the results required. Various contractors may use different methods of pipe installation, and some have developed their own specialized equipment. By specifying construction methods, competitive bidding may be unnecessarily restricted.

Pipeline projects can be constructed under a program where pipeline materials are purchased by one contract and installation is performed under another contract, i.e., the "separate
contracts" approach. The philosophy behind this procedure is that there is a saving in costs because the installation contractor may be expected to apply overhead and profit factors to his cost of pipeline materials and add this to his bid prices. Those who utilize this procedure also believe that they can exercise better control of the pipe manufacturer and his manufacturing process.

The principal difficulties with the "separate contracts" approach are that:

1. Scheduling of pipe manufacturing and delivery is difficult and late delivery can result in lengthy disputes with the installation contractor and probable claims for additional payment; and
2. Pipe materials delivered to a stockpile or strung along the alignment are subject to damage and the responsibility for such damage as between the manufacturer and the installation contractor cannot always be clearly established. In either of these situations the constructing agency may experience substantial increases in its overall project cost which can partially or wholly negate any savings which may be realized in the separate contracts approach.

However, it is necessary to evaluate conditions respecting contracting procedure for each project individually because there may be countries or regions where installation contractors are unwilling or unable to purchase pipe materials and install them totally under their sole superintendency. Regardless of which approach is selected, the elements of the specifications are the same. Presented in this chapter is a check list to assist a reviewer to determine that all of these elements are included, either in the published specification or in referenced standard

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specifications. For convenience, the installation specifications are listed separately herein, but since varying types of pipe have their own installation peculiarities, it is recommended that these be specified under the various pipe headings.
Pipe Installation Specifications

I. Earthwork
   A. Classification
   B. Cutting and Breaking Pavement
   C. Trench Excavation
      1. Foundation for pipe
         Unsuitable material removed and replaced
      2. Overexcavation
      3. Maximum length of open trench
      4. Bracing excavations

II. Open Trench Operations

III. Installation of Pipe
   A. Bedding
      1. Definition
      2. Soft foundations
      3. Placement
      4. Material
   B. Pipe Laying
   C. Field Jointing

IV. Backfill and Densification

V. Field Hydrostatic Testing

VI. Disinfection

VII. Measurement and Payment
Pipe Material Specifications

I. Non-reinforced Concrete Pipe
   A. General
      1. Purpose for which pipe is to be used
      2. Required strength
      3. Reference to standard specifications
   B. Materials
      1. Cement — reference to standard specifications
      2. Aggregates
      3. Gaskets — if applicable
   C. Dimensions and Tolerances
      1. Lengths
      2. Diameters
      3. Wall thickness
   D. Joints — Acceptable Types
   E. General Manufacturing Requirements
   F. Curing
   G. Shop Testing
      1. Load Test
      2. Hydrostatic test
   H. Causes for Rejection
   I. Basis of Acceptance
   J. Marking
   K. Loading and Shipping

II. Reinforced Concrete Pipe
   A. General — Required strengths and reference to standard specifications
   B. Materials
      1. Cement
      2. Aggregates
      3. Reinforcing steel
      4. Gaskets — if applicable
   C. Dimensions and Tolerances
      1. Lengths
      2. Diameters
      3. Wall thicknesses
   D. Reinforcement

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E. Joints - Acceptable Types
F. General Manufacturing Requirements
G. Curing
H. Shop Testing
   1. Load test
   2. Hydrostatic test
I. Causes for Rejection
J. Basis of Acceptance
K. Marking
L. Loading and Shipping

III. Cylinder Reinforced Concrete Pipe

All of the elements included in II above plus the following:

   Cathodic Protection - Rubber gasket joints should have bonding jumpers and test leads

IV. Monocylinder Prestressed Concrete Pipe

A. General
B. Materials
   1. Cement
   2. Aggregate
   3. Steel reinforcement
C. Dimensions and Tolerances
   1. Lengths
   2. Diameters
   3. Wall thicknesses
D. Concrete in Pipe Core
   1. Mixture
   2. Placement of concrete in pipe core
   3. Curing of pipe core
E. Reinforcement
   1. Circumferential reinforcement
   2. Longitudinal reinforcement
F. Cement-Mortar Coating
G. Joints
   1. Acceptable types
   2. Rubber gaskets

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H. Shop Testing

Hydrostatic test requirements

I. Causes for Rejection
J. Basis of Acceptance
K. Marking
L. Loading and Shipping

V. Cylinder Prestressed Concrete Pipe

All of the items listed under IV plus:

1. B-4 Steel cylinders
2. G-3 Attachment of joint rings to cylinder
3. Cathodic Protection
4. An additional section for fabrication of steel cylinders.

VI. Cast Iron and Ductile Iron Pipe

A. General - Reference to standard specifications
B. Pipe Joints
C. Fittings
D. Lining and Coating
E. Polyethylene Encasement for External Corrosion
F. Marking
G. Loading and Shipping

VII. Asbestos-Cement Pipe

A. General
B. Selection of Design Type
C. Materials

1. Statement as to whether autoclaved or not
2. Gaskets
3. Coating or lining

D. Dimensions and Tolerances
E. Joints
F. Shop Testing

1. Hydrostatic proof tests
2. Hydrostatic bursting strength tests
3. Crushing strength tests

G. Specials and Fittings

1. Steel specials and fittings
2. Cast iron specials and fittings
3. Outlets
H. Marking
I. Loading and Shipping
J. Basis of Acceptance

VIII. Vitrified Clay Pipe

A. General
B. Dimensions and Tolerances
C. Joints
D. Fittings
E. Testing Requirements
   1. Hydrostatic pressure test
   2. Load test
   3. Acceptance

F. Imperfections and Repairs
G. Marking
H. Loading and Shipping

IX. Steel Pipe

A. General — Reference Standards
B. Materials
   1. Class of pipe
   2. Grade of steel

C. Design Criteria
   1. Working water pressure including waterhammer allowance
   2. Backfill
   3. Safety factor
   4. Minimum wall thickness

D. Dimensions and Tolerances
   1. Diameter
   2. Length

E. Joints
F. Specials and Fittings
G. Welding
H. Shop Testing
I. Protective Coating and Lining
J. Loading and Shipping
K. Cathodic Protection

X. Pretensioned Concrete Cylinder Pipe

A. General
B. Materials

XIII-8
1. Steel cylinders
2. Rod wrap
3. Cement

C. Design Criteria
D. Dimensions and Tolerances
E. Joints
F. Shop Testing
G. Special Sections
   1. Steel specials and fittings
   2. Minor curves and bends
   3. Outlets
   4. Mortar lining and coating

H. Loading and shipping
   Strut bracing

I. Cathodic Protection

XI. Polyvinyl Chloride Plastic Pipe
   A. General
   B. Materials
      1. Plastic compound
      2. Gaskets
      3. Solvent
   C. Test requirements
   D. Basis of Acceptance
   E. Marking
   F. Loading and Shipping

XII. Reinforced Thermosetting Plastic Pipe
   A. General
   B. Materials
      1. Resin
      2. Glass reinforcement
      3. Filler
      4. Rubber gaskets
   C. Selection and Classes of Pipe
   D. Basis of Acceptance
   E. Joint Design
      1. Rubber gasket joints
      2. Field laminated joints
      3. Mechanically coupled joints
      4. Flanged joints

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F. Dimensions and Tolerances

1. Diameter
2. Length
3. Joints

G. Workmanship and Finish

H. Shop Testing

1. Hydrostatic proof tests
2. Ultimate hoop tensile strength
3. Stiffness factor tests

I. Specials and Fittings

1. Materials
2. Curves and bends
3. Outlets

J. Rejections

K. Repairs

L. Marking

M. Loading and Shipping
CHAPTER XIV. COST ESTIMATING PROCEDURES

Estimates of capital costs of pipeline projects or systems are normally prepared at four levels of activity in the process of bringing such projects to operational status. Estimates at each of these points in time have slightly to substantially differing objectives which influence the procedures employed.

The four estimating situations are summarized following:

(1) Reconnaissance - A cost estimate at this stage is very rough, may have little or no mapping or topographic information, and will generally have the objective of determining if a particular undertaking is worthy of any further consideration.

(2) Feasibility - Cost estimates at this level will probably cover a number of alternatives and will have the benefit of reliable topographic mapping and/or ground surveys as well as soils investigations and water or sewage information (if applicable). Cost estimates at this level provide the basis for a "go" or "no go" decision and must reflect direct attention to all important elements of cost in the project, with liberal allowance for contingencies, in order that project sponsors and financing agencies will not be misled, and to assure a successful undertaking.

(3) Financing - Cost estimates at this level establish the capital fund requirements of the project and are the basis for a loan commitment or other financing arrangements. The feasibility estimate may be used for this purpose, but often it is necessary to modify the feasibility estimate to reflect inflation which may have occurred after completion of the feasibility report, or that which is imputed for the project construction period. Also some
changes in the project may be required in regard to staged or phased construction or changes in physical works.

(4) Construction - Based upon the final design plans and specifications, the "Engineer's Estimate" is prepared as the basis for evaluation of bids for the construction work.

Pipeline Costs

The costs of pipeline projects quite obviously are heavily influenced by the costs of pipeline materials. However, many types of projects, such as sewers or municipal distribution systems which are installed in city streets, involve a large element of installation costs.

In many municipal projects excavated materials must be hauled away and then returned; progress is impeded by measures for handling extremes of temperature and weather and buried utility pipelines and conduits, as well as traffic and other municipal activities; and/or special pipe bedding must be provided because of unusual surface loads or foundations of adjoining structures, including possible tunnelled or bored installation for portions of the alignments. Cost items in addition to pipeline materials also may include valves, fittings, thrust blocks, pumping and pressure control stations, etc.

Because of the wide variation in installation conditions just mentioned, and because of the substantial influence of cost inflation as well as technological advances, primary reliance is placed on current cost and price data obtained from pipe manufacturers.
Reconnaissance Level Estimates

As mentioned previously, cost estimates at various stages in project planning and development involve somewhat different procedures. For example, at the reconnaissance level the authors employ cost factors based almost entirely upon experience data.

For purposes of this type of estimate, records of bid prices for furnishing and installing pipe materials are compiled and adjusted for inflation utilizing price indexes of the United States Bureau of Reclamation and the Engineering News Record (a magazine published in the United States).

Currently these data indicate that costs of pipe materials can be reasonably estimated on the basis of $1.00 per centimeter of diameter per meter of pipe length for diameters of about 20 centimeters up to 80 centimeters, and of $1.50 per centimeter of diameter per meter of pipe length for diameters exceeding 80 centimeters and up to about 300 centimeters.

For reconnaissance estimates these factors are increased by 10 percent for fittings and the total increased by 30 to 100 percent to reflect installation costs, the lowest factor being applicable for rigid pipe in open fields, as in irrigation work, and the highest being for installation in city streets or other difficult construction conditions. Other project elements such as valves, pumping stations, storage facilities, rights-of-way, etc. are separately estimated. Estimates of costs of this are further increased by 25 percent as an allowance for contingencies and 15 percent for engineering and project administration.
feasibility Level Estimates

At this level pipe materials costs should be based upon manufacturer's list prices and the foregoing reconnaissance factors can be relied upon to check for reasonability. Estimates at this level are based upon relatively detailed mapping of topography and surface and underground improvements which provide information for determining possible types of pipeline materials and evaluation of installation conditions and costs.

The elements which are evaluated in a feasibility level cost estimate are:

- Clearing the right-of-way
- Construction surveying
- Trench excavation, including preparation of the trench bottom
- Purchase and delivery of pipe materials
- Installation of pipe and below ground appurtenances
- Placing backfill
- Densifying backfill
- Installation of aboveground appurtenances
- Hydrostatic testing
- Disinfection
- Cleanup

For feasibility estimating the costs of fittings may be estimated at from five to ten percent of the cost of pipe, depending upon the complexity of the system.

At the present time, costs of pipe materials, as with nearly everything else, are escalating as a result of cost inflation. It is generally necessary to impute inflation in the feasibility estimate to reflect the time period which may elapse before final design and construction are completed. Inflation allowances must be developed on the basis of the situation found in the particular area of the world where the project will be constructed and/or pipe material will be manufactured.
The cost of installing the pipe material will vary with the working conditions. The estimate of cost can only be made by someone familiar with the project conditions and competence of local labor, since the range of manpower requirements may be as much as 400 percent between favorable and adverse project conditions. The range of size of crew required for trenching, backfilling and compaction by hand is: crew leader, 2 to 10 men excavating, 1 to 2 men digging bell holes, and 2 to 8 men backfilling and tamping. For machine work, the range in size of the crew may be 1 crew leader, 2 men on the excavating equipment, 1 to 2 men digging bell holes, 1 man on backfilling equipment and 1 to 3 men on compacting equipment.

As with material prices, wage rates worldwide are on an upward trend, but at widely varying amounts. A regression analysis of wage rates published in Engineering News Record over the past four to five years for various countries, converted to United States dollars indicated the following rates of increase may be applicable:

- Brazil  
  $1.52 per day per year
- India  
  $0.07 per day per year
- Mexico  
  $1.12 per day per year
- Singapore  
  $0.10 per day per year
- Turkey  
  $0.48 per day per year

The prudent estimator should carefully investigate and analyze the labor requirements, wage rates and inflation rates in the project area. Projection of costs from one area to another without assurance that project conditions are similar is foolhardy.

The feasibility level cost estimate should include an allowance for contingencies, which is generally taken to be about 15 percent, and an allowance for engineering and project administration which is normally taken to be 10 to 15 percent.
Financing Level Estimates

At this level an estimate of overall project requirements is needed to establish the fund requirements for a loan commitment or other financing arrangement. The feasibility estimate may, and usually is, utilized for this purpose, but because of passage of time the estimate may need to be adjusted to reflect inflation or project changes. In some instances a full feasibility type estimate may be necessary, but in any case costs of pipe materials estimated in the feasibility report can usually be employed with appropriate adjustments for inflation.

The aforementioned factors for contingencies and for engineering and project administration must be reflected in this estimate and any applicable costs for rights-of-way also must be identified.

Construction Level Estimates

As a part of the preparation of final plans and specifications, an "Engineer's Estimate" is prepared for purposes of evaluating bid proposals and possibly to assure that adequate financing arrangements have been made.

The Engineer's Estimate is based upon detailed quantities, including pipe materials, identified from the final plans. During the design phase subsurface soils exploration and hydraulic design requirements will provide the basis for final selection of pipe materials which will be specified. Up-to-date costs of pipe materials should be obtained from pipe manufacturers for this estimate. Also, it is advisable to obtain estimating information on pipe trenching and backfilling from experienced construction contractors operating in the country where the construction will be carried out. This estimate must reflect more detailed treatment of all of the factors listed for the feasibility estimate.
CHAPTER XV. PROBLEMS OF PIPE PROCUREMENT UNDER WORLD BANK LOANS

International competitive bidding is required for procurement of pipe on World Bank financed projects. The usual statement on acceptability of "equal or better" standards of other countries is therefore required in all bidding documents where reference is made to a particular standard for purposes of informing bidders on the specifications to be met. Determination of what is an equal or better standard is not always simple, and is particularly difficult when related to pipes. While there are a number of side issues in pipe specifications which can create problems, the principal ones concern differences in size between metric and foot-pound standards, and between pressure classes. Unless specifications are written in a manner which describes fully how differences will be handled at the time of bid evaluation, serious problems and resulting delays can occur which have occasionally led to legal actions and, more commonly, have necessitated rebidding. The following discussion of these and related issues will not present foolproof approaches to all situations, but will expose some of the areas where misunderstanding and difficulties have been experiences on past Bank projects.

Standards Employed for Reference

There exist today two major categories of pipe standards, those using metric units and centered to a great extent around the ISO standards, and those using foot-pound units centered around AWWA standards. In the latter group are North American countries and others closely associated with the U.S.A. and Canada. In the metric group are all the other major countries of the Western Hemisphere and most of those in the Far East. It should be noted that the ISO standards are "recommended." A country may therefore adopt the reference standard either "as is"
or with such modifications as it feels necessary. Reference to various editions of the ISO standards will show that not all member countries of the Organization have approved the standards in toto and therefore continue to employ specifications that vary in certain respects from ISO.

Pipe Sizes

Pipe manufactured to metric standards has different dimensions than that manufactured to English units. The differences in diameter, while almost insignificant, have been sufficient to be the basis for legal action by certain bidders, who have contended that additional carrying capacity should be rewarded at the time of bid evaluation. A further problem created by size difference between metric and English standards occurs in the interpretation of the wording "equivalent or better". An AWWA standard 6 inch pipe has an internal diameter of 6 inches ± some tolerance. An ISO pipe of 150mm has an inside diameter of 5.90 inches ± some tolerance. A contractor who bids on the AWWA complying pipe has no problems. The bidder who has metric pipe to sell must go up to the next larger pipe (200mm), if the wording "equal or better" is interpreted strictly. Otherwise his pipe is not the equal in carrying capacity of the AWWA pipe. This means that he must provide a pipe which costs him more to make and is much larger than the size needed.

Specifications on which bids are asked can be framed to minimize problems on sizing by showing both metric and English units and stating that either will be considered as complying for inside diameter. It would also be worthwhile in the bidding document to state that no value is attached to the incremental difference between metric and English pipe sizes and that such differences will not be penalized or credited in the evaluation.
Pressure Classes

Differences exist on definition of pipe class, factors of safety, and hydrostatic test pressures between the standards of various countries. These differences have, so far as is known, created problems in procurement on past World Bank financed projects only for A.C. pipe. As will be noted in Chapter VII, the differences between AWWA and ISO standards in respect to A.C. pipe classes can create serious problems for bidders. Referring to Table II in that chapter it can be seen that if an ISO series II class 25 pipe is specified, it should pass a hydrostatic test of 25 Kg/cm². AWWA class 100 and Australian class D show a test pressure of 24.5 Kg/cm². These two pipe classes are reasonably comparable and for most projects could be interchangeable. If hydrostatic test pressure is used as one of the requirements in the specifications, bidders who would manufacture to AWWA specifications would have to go up to class 150 to comply. In reviewing bidding documents for A.C. pipe, it will be desirable to check on the means by which test pressures are defined. It is advisable to include a statement in the document which says, for example, that class 25 under particular country standards, (or a particular country standard if relevant), will be considered equivalent to AWWA class 100 and that during evaluation of bids, each will be treated the same. Reference to Table II on page VII-4 will help to show where major differences occur between standards and where attention should be given at the time of document review. Only experience is likely to owing a full appreciation of the subtle differences between the standards. Fortunately most of those of importance because of their ability to create problems concern only A.C. pipe. Pipe Size differences, of course, affect all kinds of pipe.

Miscellaneous Problems in Pipe Procurement

1. Bidding of one kind of pipe against another

It has been a common practice world wide to call for bids on
Pipe in certain sizes and to stipulate that cast iron, ductile, A.C. and plastics pipe, among others, will qualify for the bidding. Usually documents include details for one material. Cost of reordering to suit his own material is done by the supplier of the alternative. It is not proposed that this practice should be changed. It should be pointed out, however, that the Supreme Court in the Philippines ruled in one suit brought against a bank borrower, that it was improper to ask for general pipe bids; that engineers should determine the kind of pipe best suited to each situation and should then specify that pipe only in the bidding documents. It was contended in this case that cast iron could not compete in price with A.C. pipe but that iron warranted selection in many cases because of its superior strength. Apparently, the court felt it difficult to attach a measurable value to this characteristic, or on offsetting attributes of A.C. or other pipe. No other court tests of this practice were known to exist at the time the case was under trial in the Philippines. None are known to have occurred, since, in any part of the world.

2. **Comparison of Bids**

(a) **Supply and Lay Contracts**

Where the bidding documents permit submission of bids on alternate kinds of pipe, bidders should be informed that their tenders must include the full cost of supply and laying required for the kind of pipe proposed. This would include special bedding and cover, joints and jointing, special handling, etc.

(b) **Separate Supply and Lay Contracts**

Bidding documents which indicate that alternate kinds of
pipe can be tendered for should specify that bids must include differences in cost of laying from those of the specified pipe. These differences should include among others, special bedding and cover requirements, number of joints per mile, etc. The bidding document will have to specify how such additional items are to be costed for evaluation. This is not usually a simple and clean task and can involve everyone in differences of opinion that need to be avoided if at all possible. As will be noted in paragraph 4 below, a number of advantages occur when combined supply and lay contracts are required. Not the least of these will be the minimizing of disputes with the lay contractor.

3. Problems associated with Insurance and Breakage of pipe, en transit

In one project, Managua, the problem of breakage of pipe (A.C.) during shipment was demonstrated. Bank procedures require the borrower to cover all goods with insurance against loss and damage during delivery. The A.C. pipe which was obtained from a European supplier received a somewhat greater amount of damage during delivery than normal. As is customary in adjusting the claim for damaged pipe, the insurance company had the damaged part of the pipe sawed off and paid for that amount. When the pipe laying contractor began work, he claimed that additional money was due him because of the greater number of pipe connections he was forced to make. The insurance company while paying for the additional couplings would not pay for additional contractor cost. It is not known whether examples exist on similar experiences elsewhere and on which insurance coverage did cover the added laying costs.

XV-5
4. Separate Supply and Lay Contracts

Numerous examples can be sited to point out problems created by separate supply and lay contracts. In most instances these problems have related to slow delivery and to leakage when pressure was applied to the newly laid pipe line. The installation contractor has blamed the pipe contractor and the latter blamed either the laying contractor or damage in shipment which was beyond his control. Recovery of claims against either has not been common. Several actions can be considered to minimize problems of this type. On World Bank projects where pipe supply is from outside the country, many advantages attend the use of combined supply and lay contracts. If, however, substantial savings appear to be possible through separate contracts, the bidding documents should indicate that the contractor for pipe installation will be responsible for scheduling of all deliveries and for take over and inspection of all pipe at the delivery point. His relationship to the pipe supplier should be the same as under a supply and lay contract. Any delays, leaks or damage should be the laying contractor's responsibility. The bidding documents should say this, or indicate other measures required to establish responsibility. Joint rings have also been a problem. Their supply and installation should be covered by the same safeguard as for pipe.
5. Local Manufacture of Pipe and Fittings

It has been the Bank's policy to encourage local manufacture of pipe and fittings in all instances where this will be to the economic benefit of the country. However, there should be no compromising of quality standards to accommodate local bidders. The emphasis has to be on building in safeguards and, where necessary, arranging for technical assistance which will assure full compliance with the specifications.

It has proven extremely difficult to evaluate bids submitted by local contractors for pipe which is locally manufactured and where evidence obtained during appraisal casts doubt on the ability of the manufacturer to meet the standards. Experiences of this type have occurred in respect to plastic pipe, A. C. pipe, concrete, and cast iron pipe. It has also involved valves and fittings. For locally extruded plastic pipe, problems have occurred because of variations in quality resulting from changes in the proportion of additives. A. C. pipe quality problems have stemmed from use of asbestos fiber of poor quality and short length, poor and unsuitable cement, and improper curing and handling. Problems have been encountered on pre-stressed concrete pipe, particularly of the non cylinder type when improper or no vibration of concrete occurred because of excess impurities introduced by uncontrolled use of scrap materials, and by failure to reject castings with known defects. Filling in, or covering over of defects to pass visual inspection is not uncommon.

Inspection by competent third party inspectors of all pipe and fittings provided under World Bank financing must be a part of the requirements.
set forth in the specifications. While past experience shows that such inspection has usually been provided on pipe and material of foreign manufacturer, inspection has not always been done by personnel with equal competence for items of local fabrication. Yet, it is here where it is most needed and where an opportunity exists to help local manufacturers improve their products. Bidding documents should be reviewed to insure that adequate provision is made for third party, in plant, inspection during the manufacture of all pipe and fittings irrespective of where they originate. Provisions for inspection will usually be difficult for developing country suppliers because competent third party inspection agencies are not always available locally, and arrangements will have to be made to bring them in. This may be done as part of the consultants contract but unless specifically mentioned and the means spelled out by which it is to be provided, it may occur that one of the engineers assigned for general supervision will be given this task as an additional duty. Unless such an engineer has had specialized training in this type work, the quality of inspection given to the locally manufactured items will be considerably less than that provided on foreign supplied pipe. Furthermore the inspector will probably lack the technical expertise to assist the manufacturer to improve his operations and overcome problems leading to an unusually high rejection rate.
USE OF LARGE DIAMETER ASBESTOS CEMENT PIPES
FOR CITY WATERWORKS PURPOSES

(Survey by Mr. R. Bowering)

1. In Manila Water Supply Project the Consultants, specified that asbestos cement pipes should only be used and accepted for pipelines up to 24" (600 millimeters) in diameter. A question was raised by the borrower’s Board as to whether it would be in the Authority’s interest to permit AC pipe size above 24".

2. It is pertinent to note here that the British Standards Specification only applies to asbestos cement pipes up to 24" diameter whereas the AWWA specification covers pipes up to 32" diameter and the ISO covers pipes up to 1 meter in diameter.

3. In order to assist the Board in reaching a decision and to obtain a wide consensus of opinion on the use of large diameter asbestos cement pipes, various consulting engineers enjoying a high reputation in Europe and North America were approached and requested to answer a questionnaire. The list of firms concerned is recorded at Table I and a general summary of the various opinions is recorded at Table II.

4. It is perhaps worthy to note that of the various firms approached one firm did not reply, whereas two that did reply provided no views on this subject. Only a few of the other seven returns answered all the questions contained in the questionnaire. Certain replied that they had never used AC pipes in diameters larger than 24" for water mains although one had allowed up to 28" diameter for the purpose of alternative bidding and another used a short length of less than 300 feet of 36" diameter but under very special conditions and low pressure. It was generally noted by the firms that their experience on works requiring large diameter asbestos cement pipes was very limited, but that the views they expressed were substantiated by the performance of smaller diameter AC pipes. None of the firms replying had ever recommended the use of AC pipes larger than 24" diameter for waterworks services.

5. Four returns stated that asbestos cement pipe over 24" diameter could be used as an aqueduct when laid in a right-of-way where there would never be any vehicular traffic, but two of the four stated that they definitely would not recommend it.

6. No one was enthusiastic about using the pipe under water, although one reply stated that it might be satisfactory if there were no sulphates in the water. Some referred to difficulty in jointing such pipes under water and another stressed the necessity that the joints were properly restrained.
7. Three out of five replies received stated that they would not recommend the use of large AC pipes in city streets subject to vehicular traffic mainly because of poor transverse crushing strength. The two other firms were not entirely against its use, one expressing the view, however, that the test pressure of the pipe must be three times the working pressure. (Note: ISO specifications require that the bursting pressure be at least three times the working pressure and AWWA specification requires that the bursting pressure be at least four times the working pressure.) The other reply stated that we would require at least Class 200 pipe built to AWWA specification together with extreme care in laying and back filling to avoid direct transfer of traffic loads to the pipe.

8. Five replies were received with respect to surge. None considered that surge created any special problems but all had specific requirements for dealing with it. Three firms stated that in performance under surge conditions AC pipe was not as good as steel ductile iron or prestressed concrete pipe of the same general pressure class. The other two noted that it was not as good as cast iron. One of the five replies said that it was as good as cast iron. Two firms expressed the view that the maximum surge anticipated should be added to the static pressure in order to arrive at the working pressure. One mentioned the problem of joint fatigue if the surges were frequent.

9. Six replies were received regarding the maximum pressures that asbestos cement pipe should be asked to withstand under working conditions. One said that there is no maximum pressure but that the pipe would become very heavy to withstand high pressures. One said that the pipe should be workshop tested to 1.5 times the working pressure plus the expected surge. Regarding maximum working pressures, two recommended limits set at 400 feet (174 p.s.i.), one said 250 to 300 feet (109 to 130 p.s.i.) and one said 75 p.s.i. for Class 150 pipe, but if used on any street with vehicular traffic 75 p.s.i. for Class 200 pipe.

10. Four replies expressed the view that they would not anticipate any serious jointing problems and the fifth reply referred to site difficulties in cutting the joints in bad weather.

11. Of the five replies received on the question of handling and installation, all agreed that the material was subject to excessive damage in handling and that this was a major defect of asbestos cement pipes. One with considerable experience in AC pipe mentioned that in addition to inspection before installation the pipe should be given a test of two times the working pressure after laying. He stated that on several occasions moderately large pipes (16" to 24" diameter) had only shown defects after this final test. Two others mentioned this same problem and remarked that it was very expensive to remove the pipes following their installation.

12. Of four views received three mentioned that the hazard of damage by later excavations near the pipe was a major defect when comparing AC pipes with those of other materials. The fourth firm felt that this was not important provided adequate care was taken. However, the one which appeared to have the most experience stated that the removal of the lateral support
by excavation later would prove a very serious problem in addition to the hazards of damage by mechanical tools. One stated definitely that it should not be used if sewers are to follow in the same street.

14. Of the four replies answering the question, all stated that they had previously bid AC pipes against other materials. Two reported that they would pay premium prices for pipes of other materials and two stated that AC pipes did not meet the competition for steel and prestressed concrete in sizes over 24". One firm felt that it was not a good practice to bid asbestos cement pipe against steel or prestressed concrete pipe in the larger sizes, as it probably would not be competitive in price anyway and also because the engineer should dictate which type of pipe should be used for the particular project.

15. Two of those replying mentioned that they had used large AC pipes of 1 meter in diameter for sewers and in both cases found them satisfactory.

16. Two of those writing mentioned that AC pipe had excellent corrosion resistant properties, and one, although not recommending the use of large diameter pipes, felt that AC pipes in general laid under very good laying specifications might have a useful life of 100 years.

Attachments:

Tables I and II
### TABLE I

**List of Firms Approached in the Survey**

1. Metcalf and Eddy, U. S. A.
2. Hazen and Sawyer, U. S. A.
3. Camp, Dresser and McKee, U. S. A.
4. Rennie and Partners, U. K.
5. Howard Humphreys, U. K.
6. Pahal, Israel
7. Sogres, France
8. James McLaren, Canada
9. City of Winnipeg, Canada
10. V.B.B., Sweden
<table>
<thead>
<tr>
<th>Item</th>
<th>No. of Answers</th>
<th>Favorable to Use of Large AC Pipes</th>
<th>Favorable with Qualifications</th>
<th>Not Favorable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aqueduct with no vehicular traffic</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Aqueduct under water</td>
<td>4</td>
<td>0</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Aqueduct in city street</td>
<td>5</td>
<td>0</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Resistance to surge</td>
<td>5</td>
<td>0</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Jointing problems</td>
<td>5</td>
<td>4</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Easily damaged during handling</td>
<td>6</td>
<td>0</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Easily damaged during later excavation</td>
<td>4</td>
<td>0</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Difficulty in discovering fine cracks</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Resistance to corrosion</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
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CLAY PIPE


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