ACI 346-09

ACI 346-09

Specification for Cast-in-Place Concrete Pipe

An ACI Standard

Reported by ACI Committee 346

American Concrete Institute®

First Printing
August 2009

American Concrete Institute®
Advancing concrete knowledge

Specification for Cast-in-Place Concrete Pipe

The technical committees responsible for ACI committee reports and standards strive to avoid ambiguities, omissions, and errors in these documents. In spite of these efforts, the users of ACI documents occasionally find information or requirements that may be subject to more than one interpretation or may be incomplete or incorrect. Users who have suggestions for the improvement of ACI documents are requested to contact ACI. Proper use of this document includes periodically checking for errata at **www.concrete.org/committees/errata.asp** for the most up-to-date revisions.

ACI committee documents are intended for the use of individuals who are competent to evaluate the significance and limitations of its content and recommendations and who will accept responsibility for the application of the material it contains. Individuals who use this publication in any way assume all risk and accept total responsibility for the application and use of this information.

All information in this publication is provided "as is" without warranty of any kind, either express or implied, including but not limited to, the implied warranties of merchantability, fitness for a particular purpose or non-infringement.

ACI and its members disclaim liability for damages of any kind, including any special, indirect, incidental, or consequential damages, including without limitation, lost revenues or lost profits, which may result from the use of this publication.

It is the responsibility of the user of this document to establish health and safety practices appropriate to the specific circumstances involved with its use. ACI does not make any representations with regard to health and safety issues and the use of this document. The user must determine the applicability of all regulatory limitations before applying the document and must comply with all applicable laws and regulations, including but not limited to, United States Occupational Safety and Health Administration (OSHA) health and safety standards.

Order information: ACI documents are available in print, by download, on CD-ROM, through electronic subscription, or reprint and may be obtained by contacting ACI.

Most ACI standards and committee reports are gathered together in the annually revised *ACI Manual of Concrete Practice* (MCP).

American Concrete Institute
38800 Country Club Drive
Farmington Hills, MI 48331
U.S.A.
Phone: 248-848-3700
Fax: 248-848-3701

www.concrete.org

ISBN 978-0-87031-336-3

Specification for Cast-in-Place Concrete Pipe

An ACI Standard

Curtiss W. Gilley
Chair

Eric T. Moran
Secretary

Dale V. Anderson
Robert D. Gofonia

Keith Jolly
Alfred L. Kaufman, Jr.

Anthony M. Sorcic
Patrick L. Stiehr

James M. Willson

The Architect/Engineer can make this specification applicable to any project by citing it in the Project Specification. Supplements can be made by designating or specifying individual project requirements as needed. This document must be used in conjunction with ACI 301. Inclusion of this document in a Project Specification, with mandatory checklist items, will provide necessary default values for mandatory checklist items in ACI 301.

Keywords: cast-in-place concrete pipe (CIPCP); circumferential cracking; concrete pipe; longitudinal cracking; no-joint pipe.

CONTENTS

(mandatory portion follows)

PART 1—GENERAL

1.1—Scope

1.1.1 This specification covers construction of earth-supported cast-in-place concrete pipe (CIPCP). This specification covers construction of CIPCP with a diameter up to 120 in.

1.1.2 CIPCP shall conform to ACI 301, Section 1 for general concrete requirements, Section 4 for concrete mixture design, and Section 5 for concrete handling or as specified in Contract Documents.

1.2—Definitions

This list supplements ACI 301, Section 1.2. Defined for general use in these specifications are the following:

backfill—fill starting at top of pipe and continuing to surface or finished grade or subgrade.

boulders—rocks having any dimension larger than 12 in.

Contract Documents—a set of documents supplied by Owner to Contractor as the basis for construction; these documents contain contract forms, contract conditions, specifications, drawings, addenda, and contract changes.

differential displacement—linear offset distance between two pieces of pipe measured along plane of crack.

earth—soil or rock other than flowable granular materials.

jetting—water densification of backfill accomplished by the use of a jet pipe to which a hose is attached, carrying a continuous supply of water under pressure to the lift of backfill material to be densified.

ACI 346-09 supersedes ACI 346-01 and was adopted and published August 2009.

metal finish—finish imparted to interior of pipe by casting machine and hand-troweling devices manufactured from metal.

offset tolerances—difference in pipe thickness, transverse and longitudinal, resulting from metal form used in casting process.

over excavation—process by which material unsuitable for CIPCP is removed and replaced with engineered fill prior to trench excavation.

pipe haunch—either side of pipe, extending to a point vertically approximately 25 degrees above springline.

repair—process by which cracks and defects in concrete surfaces are corrected to bring pipe into conformance with this specification.

sensitive clays—clays with an undisturbed strength that is at least 10 times greater than remolded or reworked strength.

soffit—uppermost portion of inside cross section of pipe.

trench—an excavation in ground engineered for placement of pipe.

trench form—semicircular bed of trench shaped to provide full, firm, and continuous support throughout the bottom of the pipe from pipe haunch to pipe haunch.

trench form envelope—area of soil adjacent to and under pipe, required to provide lateral support and bedding support needed for CIPCP.

trench grade—design invert elevation minus wall thickness of pipe.

1.3—Referenced standards

1.3.1 *ACI standards*

301-05 Standard Specifications for Structural Concrete

1.3.2 *ASTM standards*

A615-03 Standard Specification for Deformed and Plain Billet-Steel Bars for Concrete Reinforcement

C171-07 Standard Specification for Sheet Materials for Curing Concrete

C309-07 Standard Specification for Liquid Membrane-Forming Compounds for Curing Concrete

C497-05 Standard Test Methods for Concrete Pipe, Manhole Sections, or Tile

D698-07^{e1} Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft^3 (600 kN-m/m^3))

1.4—System description

CIPCP shall be constructed underground as a continuous concrete conduit that has no steel reinforcement or seams except as specified. CIPCP is used to convey irrigation water, storm water, or industrial waste under a maximum internal operating head of 15 ft and external loads as subsequently discussed.

1.5—Submittals

1.5.1 *Pipe geometry reports*—Pipe dimensions shall be as specified in Table 1.5.1. When a design differs from Table 1.5.1, provide a pipe geometry report. Report shall specify inside and outside dimensions and include minimum wall thickness and additional sacrificial thickness needed for abrasion.

Table 1.5.1—Pipe dimensions

Pipe diameter, in.	Wall thickness, in.
24, 27, and 30	3
36	3.5
42	4
48	5
54	5.5
60	6
66	6.5
72	7
78	7.5
84	8
90	8.5
96	9
102	10
108	10.5
114	11
120	12

1.5.2 *Concrete mixture*—Submit a concrete mixture report as specified in ACI 301.

1.5.3 *Test reports*—Submit a test report of results and recommendations when load testing, as specified in 3.4.1, or hydrostatic testing, as specified in 3.4.2, is required in Contract Documents.

1.5.4 *Sealants*—Submit sealant material when repair of circumferential cracks as specified in 3.3.2, or longitudinal cracks as specified in 3.3.3, is required in Contract Documents.

1.5.5 *Quality assurance*—Submit a quality assurance plan that addresses pipe geometry, concrete mixture, concrete curing process, geotechnical conditions, test reports, and repair methods as required by the Contract Documents.

PART 2—PRODUCTS

2.1—Materials

2.1.1 *Concrete*

2.1.1.1 *Slump*—Slump shall be within limits shown in Table 2.1.1.1.

2.1.1.2 *Compressive strength*—f_c' shall not be less than 4000 psi except for irrigation pipe, which shall not be less than 3000 psi, unless specified otherwise.

2.1.1.3 *Sulfate resistance*—When sulfate resistance is required, the concrete mixture shall be proportioned as specified in the Contract Documents.

2.1.2 *Reinforcement dowel*—Dowel shall be ASTM A615 Grade 40 or greater.

2.1.3 *Sealant*—Chemically cured elastomeric material as specified in the Contract Documents.

2.1.4 *Polyethylene film*—Polyethylene film complying with ASTM C171 with the exception, nominal thickness of 0.0015 in.

2.1.5 *Curing compound*—Pigmented membrane curing compound shall conform to ASTM C309.

Table 2.1.1.1—Slump requirements

Pipe diameter	Slump
Less than 42 in.	2-1/2 ± 1-1/2 in.
42 to 72 in.	2-1/2 ± 1 in.
Greater than 72 in.	2 ± 1/2 in.

Table 3.2.1.4—Offset tolerances

Pipe diameter	Allowable offsets
Less than 42 in.	1/2 in.
42 to 72 in.	3/4 in.
Greater than 72 in.	1 in.

PART 3—EXECUTION

3.1—Preparation

3.1.1 *Trench*

3.1.1.1 *Excavation*—Excavate trench to establish grade and alignment. Trench shall be shaped to outside diameter of pipe to provide trench form. Trench form shall provide a full, firm, and continuous support by undisturbed earth, rock, or compacted fill. Trench form shall be stable and free of protrusions, mud, debris, and running water. Maintain trench form moisture in a manner such that water does not escape the wet concrete. Remove boulders projecting into the trench to at least 6 in. beyond trench form. Fill the resulting void in accordance with 3.1.1.3 or with concrete.

3.1.1.2 *Unstable soils*—Stabilize or over excavate noncohesive, unstable strata, or lenses of loose sand, silt, or other noncohesive soils within trench form. Reconstruct as engineered fill.

3.1.1.2.a Sensitive clays in trench form shall be stabilized or over excavated and trench form reconstructed as engineered fill.

3.1.1.3 *Trench repair*—Reconstitute the grade by filling voids with sand, pea gravel, crushed rock, or noncohesive soil. Compact material used to reconstitute the grade to a minimum of 95% maximum dry density in accordance with ASTM D698, unless specified otherwise.

3.1.1.4 *Backfill material*—In-place backfill material shall meet compaction requirement, as specified in Contract Documents.

3.2—Construction

3.2.1 *Tolerances and geometry*

3.2.1.1 *Horizontal and vertical alignment*

3.2.1.1.a *Grade*—Departure from and return to a grade shall not exceed 1 in. per 10 linear ft. Maximum departure shall be limited to 1-1/2 in.

3.2.1.1.b *Alignment*—Departure from and return to established alignment shall not exceed 2 in. per 10 linear ft. Maximum departure shall be limited to 4 in.

3.2.1.2 *Wall thickness*—Wall thickness shall be as shown in Table 1.5.1. Grade and alignment shall be controlled so that pipe wall thickness is uniform. Wall thickness tolerance is –0 and +0.07 the inside diameter.

3.2.1.3 *Pipe diameter tolerances*—inside diameter of pipe at any point shall not be less than 98% of design diameter.

3.2.1.4 *Offset tolerances*—Offset tolerances shall be as indicated in Table 3.2.1.4.

3.2.2 *Concrete placement*

3.2.2.1 *Placement method*—Construct the pipe monolithically. Concrete shall be vibrated, rammed, tamped, or worked until thoroughly consolidated. Sufficiently wet soil adjacent to the pipe so that it does not absorb water from the concrete or expand upon additional wetting.

3.2.2.2 *Construction joint*

3.2.2.2.a *Cold joint*—At the end of concrete placement or any stoppage requiring a casting machine to pull away from pipe construction, leave the pipe end in a rough condition at a slope of approximately 45 degrees from soffit to invert, with 24 in. long No. 4 reinforcement dowels embedded around the pipe circumference as specified. Place the dowels at 12 in. intervals for pipe sizes up to 72 in. in diameter and at 18 in. intervals for pipe sizes 78 to 120 in. in diameter. Within 30 minutes before pipe casting resumes, thoroughly clean the pipe end surface of foreign materials, coatings, and loose or defective concrete and thoroughly wet the surface. Cast a tie-in cap over the joint across the top of pipe from trench wall to trench wall. The tie-in cap shall be a minimum length of 24 in. and centered over the joint. Thickness shall be 1.5 times the wall thickness, as indicated in Table 1.5.1.

3.2.2.2.b *Collar*—Make the joint for connections to another pipe or structure by squaring off the end of the CICIP. Excavate the trench form along the sides and bottom of pipe to permit casting of concrete collar. Collar shall be a minimum length of 24 in. and centered on joint. Collar thickness shall be 1.5 times wall thickness shown in Table 1.5.1. Collar shall extend around the full circumference of pipe.

3.2.2.3 *Finish*—Interior surface of pipe shall receive a metal finish.

3.2.3 *Curing, backfilling, and cleanup*

3.2.3.1 *Curing*—Use one of the methods specified in 3.2.3.2 for exterior curing and use the method specified in 3.2.3.3 for interior curing of the pipe.

3.2.3.2 *Exterior curing*—The pipe shall be cured by polyethylene film or pigmented membrane-curing methods.

3.2.3.2.a *Polyethylene film curing method*—Place polyethylene film on exposed top surface immediately after pipe is cast. Anchor the film in place to ensure continuous, adequate curing.

3.2.3.2.b *Pigmented membrane-curing compound method*—Apply membrane-curing compound to exposed exterior surfaces immediately after the pipe is cast. Apply compound at no less than 1 gal. for each 150 ft^2 of exposed concrete.

3.2.3.3 *Interior curing*—Humid atmosphere within pipe shall be maintained for at least 7 days following concrete placement. Measures shall be taken to prevent air drafts from drying pipe. Pipe end openings shall be covered, but not sealed.

3.2.3.4 *Backfill operations*—Backfill operations shall not begin until concrete attains a compressive strength of 2500 psi.

3.2.3.4.a First lift over pipe shall be not less than 2 ft or more than 3 ft before compaction. Backfill material shall be free of all organic material, rubbish, and debris. Backfill shall be mechanically compacted. Jetting shall not be permitted. Second and subsequent lifts shall be placed in horizontal layers of thickness compatible to material being placed and type of equipment used to achieve required compaction specified in 3.1.1.4.

3.2.3.4.b Controlled low-strength material (CLSM) may be used as backfill.

3.3—Repair

3.3.1 *Crack repair*—Crack repair shall not be made until completion of backfill. Determine crack width by penetration to more than 0.25 in. of a standard machinist gauge leaf defined in ASTM C497.

3.3.2 *Circumferential cracks*—Circumferential cracks 0.01 in. or less in width shall not require treatment. Cracks greater than 0.01 in. in width and less than 0.05 in. in width shall be cleaned and filled with cement mortar. Cracks 0.05 in. in width and greater shall be cleaned and filled with a sealant, unless specified otherwise.

3.3.3 *Longitudinal cracks*—Longitudinal cracks more than 0.01 in. in width and less than 0.0005 multiplied by outside diameter shall be cleaned and filled with mortar or a sealant.

3.3.3.1 Longitudinal cracks having differential displacement greater than 0.08 in. or width greater than 0.0005 when multiplied by outside diameter shall be repaired by full-depth epoxy pressure grouting as specified in Contract Documents.

3.4—Field quality control

3.4.1 *Load tests*—Perform load tests as specified in Contract Documents. Test load applied to the top of pipe shall be at least 125% of the maximum earth load plus live load to which pipe will be subjected. Inspect pipe before and after load testing. Load tests shall be made without disturbing earth supporting trench form of pipe. Apply test load in accordance with 3.4.1.1 or 3.4.1.2.

3.4.1.1 *Sandbox test*—Load shall be applied to a 4 ft length of pipe through a sandbox in such a manner that sand forms a bedding over 1/4 of the pipe circumference, measured and centered over the crown. A sandbox shall be made of metal or dressed timber so heavy as to maintain constant soil pressure. A strip of cloth or plastic film may be attached to inside of the sandbox on each side, along the lower edge, to prevent the escape of sand between sandbox and pipe. Bedding depth above pipe at the thinnest point shall be 1/4 inside diameter of pipe. The sandbox shall not contact pipe or sides of trench. Fill sandbox with clean sand containing no less than 5% moisture and passing a No. 4 sieve. Upper surface of sand shall be leveled with a straight edge and covered with a rigid top-bearing plate. Lower surface of plate shall be a true plane made of heavy timbers or other rigid material capable of distributing test load uniformly. Test load shall be applied to bearing plate by piling weights directly on the bearing plate or by moving heavy equipment of predetermined weight onto the bearing plate. Bearing plate shall not be in contact with sandbox.

3.4.1.2 *Wheel load test*—A wheel load equivalent to test load shall be applied to pipe. Maintain 2 ft of compacted fill between pipe and wheel load.

3.4.2 *Hydrostatic test*—As specified by Contract Documents, a hydrostatic test shall be made on completed pipe any time after concrete has reached design strength. Default head is 6 ft, unless specified otherwise in Contract Documents. Pipeline shall be filled with water to specified head above inside pipe crown and kept filled for a minimum of 48 hours before test. Line may be filled in one length or between bulkheads or structures. Water used shall have a temperature above 50 °F. Test shall be for 4 hours. Filtration rate shall not exceed 1000 gal./in. diameter/mile/24 hours.

3.4.3 *Trench grade*—Trench grade shall be constructed using electronically guided equipment.

(nonmandatory portion follows)

NOTES TO SPECIFIER

General notes

G1. ACI Specification 346 is to be used by reference or incorporation in its entirety in the Project Specification. Do not copy individual Sections, Parts, Articles, or Paragraphs into the Project Specification, because taking them out of context may change their meaning.

G2. If Sections or Parts of ACI Specification 346 are copied into the Project Specification or any other document, do not refer to them as an ACI Specification, because the specification has been altered.

G3. A statement such as the following will serve to make ACI Specification 346 a part of the Project Specification:

"Work on (Project Title) shall conform to all requirements of ACI 346-09, 'Specification for Cast-in-Place Concrete Pipe,' published by the American Concrete Institute, Farmington Hills, Michigan, except as modified by these Contract Documents."

G4. Each technical Section of ACI Specification 346 is written in the three-part Section format of the Construction Specifications Institute, as adapted for ACI requirements. The language is imperative and terse.

G5. ACI Specification 346 is written to the Contractor. When a provision of this specification requires action by the Contractor, the verb "shall" is used. If the Contractor is allowed to exercise an option when limited alternatives are available, the phrasing "either...or..." is used. Statements provided in the specification as information to the Contractor use the verbs "may" or "will." Informational statements typically identify activities or options that "will be taken" or "may be taken" by the Owner or Architect/Engineer.

FOREWORD TO CHECKLISTS

F1. This foreword is included for explanatory purposes only; it is not a part of ACI Specification 346.

F2. ACI Specification 346 may be referenced by the Specifier in the Project Specification for any building project, together with supplementary requirements for the specific project. Responsibilities for project participants must be defined in the Project Specification. ACI Specification 346 cannot and does not address responsibilities for any project participant other than the Contractor.

F3. Checklists do not form a part of ACI Specification 346. Checklists assist the Specifier in selecting and specifying project requirements in the Project Specification.

F4. The Mandatory Requirements Checklist indicates work requirements regarding specific qualities, procedures, materials, and performance criteria that are not defined in ACI Specification 346. The Specifier must include these requirements in the Project Specification.

F5. The Optional Requirements Checklist identifies Specifier choices and alternatives. The checklist identifies the Sections, Parts, and Articles of ACI Reference Specification 346 and the action required or available to the Specifier. The Specifier should review each of the items in the Checklist and make adjustments to the needs of a particular project by including those selected alternatives as mandatory requirements in the Project Specification.

F6. The Submittals Checklist identifies information or data to be provided by the Contractor before, during, or after construction.

F7. *Recommended References*—Documents and publications that are referenced in the Checklists of ACI Specification 346 are listed below. These references provide guidance to the Specifier and are not considered to be part of ACI Specification 346.

ASTM International

D1557-07 Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft/lbf/ft^3 (2,700 kN-m/m^3))

The above publication may be obtained from the following organization:

ASTM International
100 Barr Harbor Drive
West Conshohocken, PA 19428
www.astm.org

MANDATORY REQUIREMENTS CHECKLIST

Section/Part/Article in ACI 346 (in ACI 301)	Notes to Specifier
1.1.2 (4.2.2.6)	Cast-in-place concrete pipe (CIPCP) does not require structural reinforcing steel and, therefore, Table 4.2.2.6 of ACI 301 is not applicable.
1.1.2; 2.1.1.3 (4.2.2.7)	When sulfate resistance is required, specify degree of protection required in Contract Documents.
1.1.2 (4.2.2.9)	Specify concrete strength if different than default.
1.1.2 (5.3.1.4)	5.3.1.4 is not applicable to CIPCP.
3.1.1.4	Backfill material and compaction shall be as specified in the Contract Documents.
3.2.2.1	Trench form moisture.

OPTIONAL REQUIREMENTS CHECKLIST

Section/Part/Article	Notes to Specifier
2.1.1.2	Default strength is 4000 psi. Irrigation pipe may be 3000 psi.
3.1.1.2	When over-excavation of trench form is required, width and depth of trench form shall be specified.
3.1.1.3	May use 95% ASTM D698.
3.3.2	Where pipe function does not require repair of circumferential cracks, specify "circumferential crack repair not required in Contract Documents."
3.4.1	When load test is desired, specify requirement in Contract Documents.
3.4.2	When a hydrostatic test is desired, specify the requirement in Contract Documents. Default head is 6.0 ft measured from pipe soffit.

SUBMITTALS CHECKLIST

Section/Part/Article	Notes to Specifier
1.5.1	Pipe geometry report.
1.5.2	Mixture proportions.
1.5.3	If specified by Optional Checklist Item 3.4.1 or 3.4.2, provide test report.
1.5.4	Sealant material.
1.5.5	QA program confirm compliance with project documents. Provide geotechnical report to confirm soil conditions and confirm competency for CIPCP.

American Concrete Institute®
Advancing concrete knowledge

As ACI begins its second century of advancing concrete knowledge, its original chartered purpose remains "to provide a comradeship in finding the best ways to do concrete work of all kinds and in spreading knowledge." In keeping with this purpose, ACI supports the following activities:

- Technical committees that produce consensus reports, guides, specifications, and codes.
- Spring and fall conventions to facilitate the work of its committees.
- Educational seminars that disseminate reliable information on concrete.
- Certification programs for personnel employed within the concrete industry.
- Student programs such as scholarships, internships, and competitions.
- Sponsoring and co-sponsoring international conferences and symposia.
- Formal coordination with several international concrete related societies.
- Periodicals: the *ACI Structural Journal* and the *ACI Materials Journal*, and *Concrete International*.

Benefits of membership include a subscription to *Concrete International* and to an ACI Journal. ACI members receive discounts of up to 40% on all ACI products and services, including documents, seminars and convention registration fees.

As a member of ACI, you join thousands of practitioners and professionals worldwide who share a commitment to maintain the highest industry standards for concrete technology, construction, and practices. In addition, ACI chapters provide opportunities for interaction of professionals and practitioners at a local level.

American Concrete Institute
38800 Country Club Drive
Farmington Hills, MI 48331
U.S.A.
Phone: 248-848-3700
Fax: 248-848-3701

www.concrete.org

Specification for Cast-in-Place Concrete Pipe

American Concrete Institute®
Advancing concrete knowledge

The AMERICAN CONCRETE INSTITUTE

was founded in 1904 as a nonprofit membership organization dedicated to public service and representing the user interest in the field of concrete. ACI gathers and distributes information on the improvement of design, construction and maintenance of concrete products and structures. The work of ACI is conducted by individual ACI members and through volunteer committees composed of both members and non-members.

The committees, as well as ACI as a whole, operate under a consensus format, which assures all participants the right to have their views considered. Committee activities include the development of building codes and specifications; analysis of research and development results; presentation of construction and repair techniques; and education.

Individuals interested in the activities of ACI are encouraged to become a member. There are no educational or employment requirements. ACI's membership is composed of engineers, architects, scientists, contractors, educators, and representatives from a variety of companies and organizations.

Members are encouraged to participate in committee activities that relate to their specific areas of interest. For more information, contact ACI.

www.concrete.org

Recommendations for Cast-in-Place Nonreinforced Concrete Pipe

Reported by ACI Committee 346

Donald L. Weesner, Chairman

Ernest R. Comstock
Earl R. Koller
Frederick J. May
Robert A. Midthun
Noel A. Negley
William G. Reynolds
Pete W. Terrell
Carl R. Wilder
Kenneth R. Wipff

The Committee voting on proposed revisions to ACI 346/346R-81:

Gilbert G. Lynch, Chairman
Ernest R. Comstock
Leonard J. Erie, II
Morgan Johnson
Curtiss W. Gilley, Secretary
Robert D. Gofonia
Robert E. Leake, Jr.
William G. Reynolds

This report presents a general view of present knowledge of cast-in-place concrete pipe, together with recommendations for design, construction, and testing procedures. Construction specifications are contained in "Specifications for Cast-in-Place Nonreinforced Concrete Pipe."

Keywords: admixtures; aggregates; air entrainment; backfilling; cast-in-place pipes; compressive strength; concrete construction; concrete pipes; curing; finishing; formwork (construction); inspection; joints (junctions); load tests (structural); mixing; mix proportioning; patching; placing; repairs; safety; slump tests; structural design; temperature; tests; tolerances; vibration; water-cement ratio.

CONTENTS

CHAPTER 1—INTRODUCTION

1.1—General description

Cast-in-place pipe, as considered here, is an underground continuous nonreinforced concrete conduit having no joints or seams except as necessitated by construction requirements. It is intended for use to convey irrigation water, storm water, sewage, or industrial waste under a maximum internal operating head of 15 ft (45 kPa) and external loads as subsequently discussed. Construction specifications are contained in ACI 346.

The pipe is cast in a previously excavated trench which has a semicircular bottom and vertical or near-vertical side walls. See Fig. 1.1 for typical section of cast-in-place concrete pipe. Concrete is usually delivered to the trench from transit-mix trucks.

The outside lower portion of the pipe is formed by the trench and the corresponding inside is formed by a specially designed slipform commonly called a boat or sled, or a more complex slipform machine. The inside of

The 1990 revisions consisted of minor changes throughout this document and the addition of a new Chapter 6.

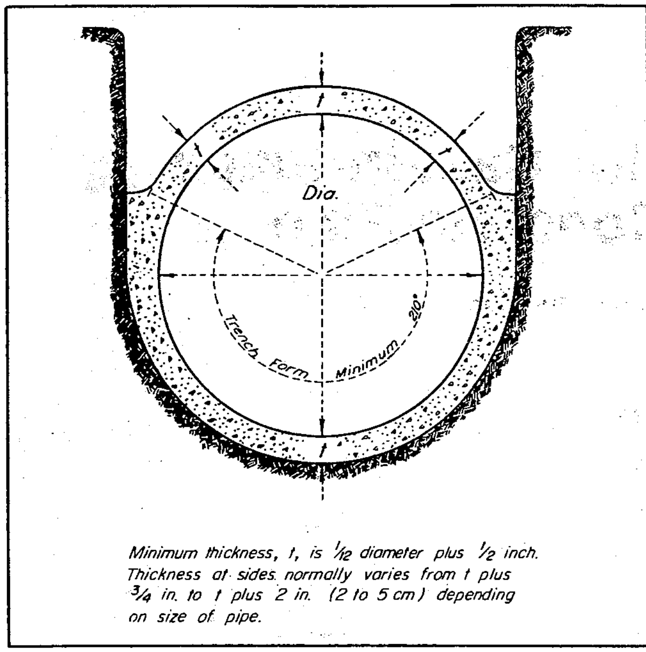

Fig. 1.1 — Typical section; 12-120 in. (305-3050 mm) cast-in-place concrete pipe.

the remainder of the pipe is formed either by metal forms or a pneumatically inflated form. The finished bore of the pipe is circular except for minor structural deformation and surface imperfections, as allowed in Chapter 5 of the specifications.

Cast-in-place pipe has been built in diameters of 12 to 120 in. (305 mm to 3050 mm) generally in 6 in. (150 mm) increments. Where the process requires access to the inside for removal of metal forms, the smallest practical diameter is about 24 in. (610 mm). The inflatable inner form, however, can be removed from 12 in. (305 mm) pipe and has been used successfully up to a diameter of 84 in. (2135 mm).

Cast-in-place pipe has been used for agricultural purposes in the San Joaquin Valley of California for more than 40 yrs. In recent years, this type of pipe has been used in other states and countries and its application has been broadened to include sanitary, storm, and industrial sewers.

Cast-in-place pipe has been used in sewers where the earth fill above the pipe exceeded 20 ft. (6.1 m). Sewers and storm drains have been successfully installed under city streets and highways carrying heavy traffic. Irrigation lines are operating successfully under heavily traveled roads with 18 in. (455 mm) of cover. Structural computations and load tests have demonstrated that such pipe can withstand loads of 50 ft (15.2 m) or more of earth fill.[1-5]

1.2—Methods of construction

Two general categories of construction methods are discussed in this section:

- Two-stage construction by machine method.
- Single-stage construction by machine methods.

Initially, cast-in-place pipelines were constructed entirely by hand in two separate operations or "stages." In the first stage, the bottom half was placed and shaped by a semicircular form or "boat." In the second stage, semicircular

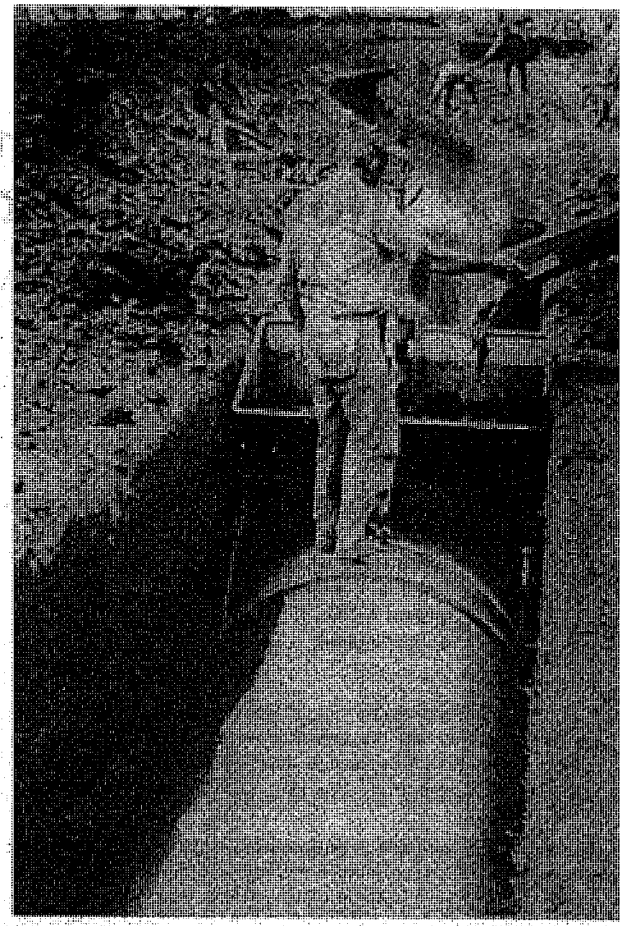

Fig. 1.2.1.1a — Single-stage process using me forms. Construction of 48 in. (1220 mm) diame storm water drain. Concrete from transit mixer c charges into hopper of machine where electrica operated tampers move it downward around me forms. Further consolidation is accomplished w electric vibrators attached near base of mandrel.

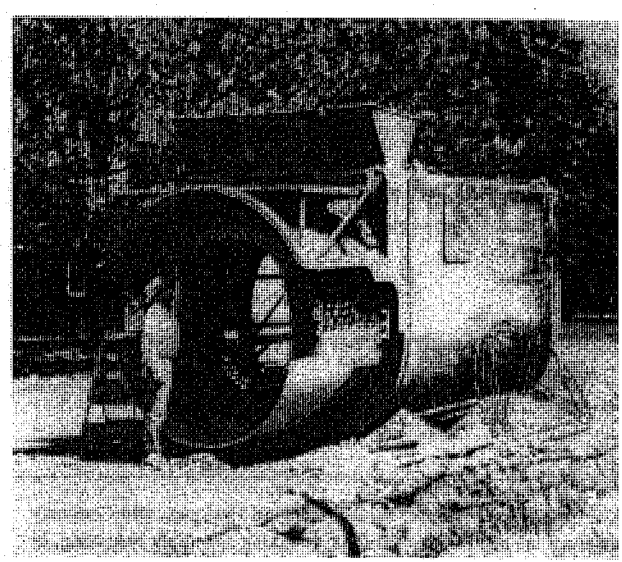

Fig. 1.2.1.1b — Single-stage construction using m forms. Rear view of 84 in. (2135 mm) single-st. machine. Six ft (1.8 m) long aluminum forms are into machine over rollers attached to the mand Metal arch spreaders, used to support the forms, shown leaning against the machine.

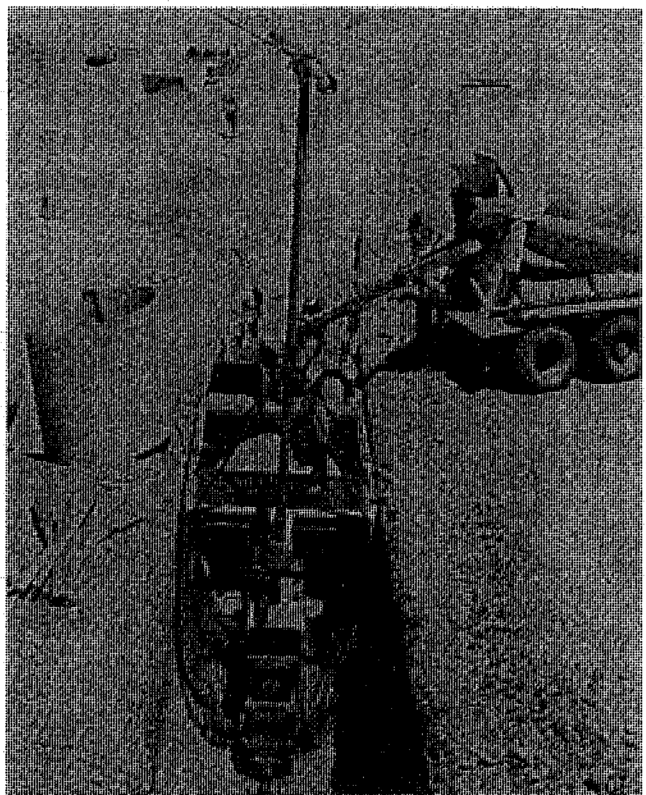

Fig. 1.2.1.1c — Single-stage construction using metal forms. Front view of 84 in. (2135 mm) diameter machine. Power unit and winch are mounted on front of machine. Large metal forms are lowered into place by machine mounted boom as concrete is fed into the hopper.

Fig. 1.2.1.1d — Single-stage construction using metal forms. Interior view of 54 in. (1370 mm) machine. Forms are fed through the machine, locked into position, and braced with metal arch spreaders to ensure uniform internal diameter of the pipe.

metal forms were positioned on the previously placed invert concrete and the upper half of the pipe completed. The committee does not know of any recent use of this two-stage process by hand methods.

Two-stage placement resulted in a longitudinal construction joint at about midheight of the pipe. This joint was difficult to keep free of any material that sloughed off of the sidewalls of the trench. It was necessary to place the upper half while the lower half was still sufficiently plastic to obtain satisfactory bonding of the two placements.

To eliminate the horizontal construction joint and to improve on concrete placing and consolidation methods, machines were invented which could construct the entire periphery of the pipe in one operation or stage. This method used metal forms for supporting the upper portion of the pipe. Subsequently, another single placement method was developed which is quite similar to that just described except that it uses a dimensionally stable, pneumatically inflated inner form in lieu of metal forms.

There are many variations within the broad spectrum of the foregoing categories, several of which are patented processes. Nothing contained herein is intended to imply the superiority or recommendation of any proprietary process over any other, nor is the omission of any process or procedure intended to indicate that it is deficient in any manner.

Two aspects of the construction operation are common to all cast-in-place construction methods:

Fig. 1.2.1.1e — Single-stage construction using metal forms. A 42 in. (1065 mm) machine installing storm drain pipe. Metal forms are lined up at the side of the trench before manually lowering into machine. As pipe is formed the outside top is covered with polyethylene to retain moisture and ensure proper curing.

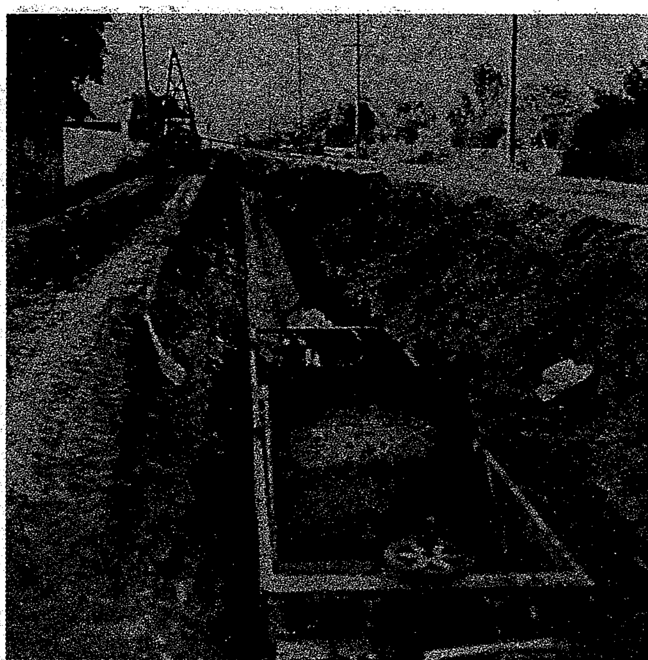

Fig. 1.2.1.2a — Single-stage construction using inflatable form. Machine in trench with inflatable form extended in trench prior to inflation.

Fig. 1.2.1.2b — Single-stage construction using inflatable form. Machine in trench with form being inflated just prior to concrete placement.

The trench has vertical or nearly vertical side-walls and a semicircular bottom.

The upper portion of the pipe is supported and formed by an inside form.

1.2.1 *Single-stage construction by machine*—The first known installation of machine-placed, monolithic, cast-in-place pipe was made in 1950 by a rancher on the Alves Ranch near Woodland, Calif. The machine used for this installation served as the basis for the first patented cast-in-place concrete pipe machine. Other firms have developed pipe making machines since the first was introduced.

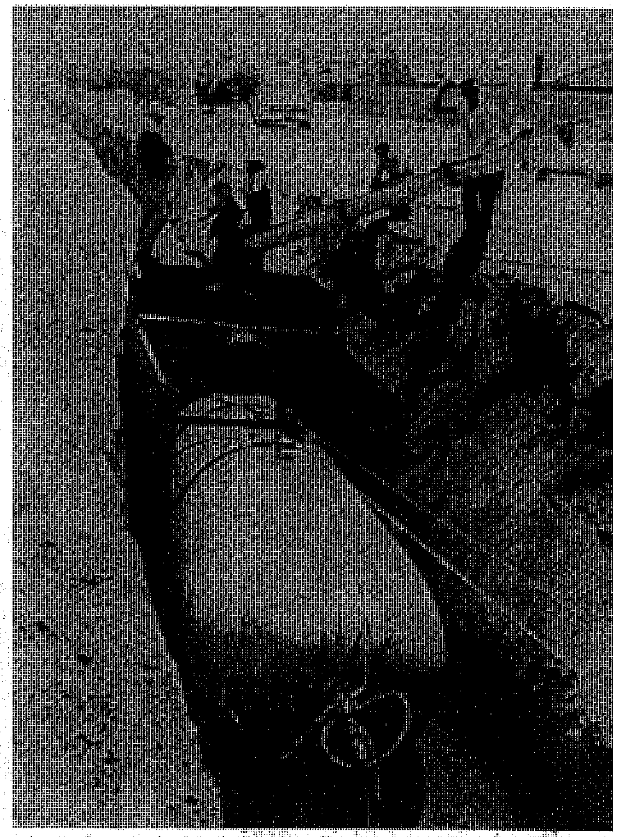

Fig. 1.2.1.2c — Single stage construction using flatable form. Machine with inflated inner f being pulled down the trench with concrete be fed into the hoppers. As the machine moves it p up the form and guides it on rollers through the chine as the concrete is moved around the form v tampers and vibrators.

1.2.1.1 *Single-stage construction using metal form* The pipe casting machine consists of a steel sled an mandrel assembly supported by and attached to the slec hinges permitting it to adapt itself to the trench. The n drel assembly consists of the inside bottom and outside troweling skirts and hopper. An engine mounted on bottom front of the sled powers a generator and a wir The machine moves forward by a variable speed winch cable hooked to a deadman inside or outside the trench separate machine is required for each pipe size.

As the machine moves forward, metal forms suppor about 230 deg of the top inside of the pipe are inserted the front of the mandrel, hooked to the preceding form sprayed with oil. Metal struts are manually placed inside forms near each joint to hold the proper shape of the] and support the weight of the concrete. Concrete is mc from the hopper into the mandrel by tampers. Vibrator each side of the machine consolidate the concrete in monolithic cast-in-place pipe. The speed of the tampers the frequency of vibration can be independently contrc to suit the consistency of the concrete being used.

The metal forms are usually constructed of alumi alloy and are about 4 to 6 ft long (1.2 to 1.8 m). A faste hook is provided at the top on one end and an eye on other for hooking the forms together. The forms remai place until the concrete is strong enough for form remc usually 4 to 6 hr. The supporting struts are removed and the inner form pulled forward into the trench which has been excavated for the next placement. Usually this is done in one withdrawal by using one of the pieces of equipment available at the site. Sometimes, however, the forms are separated inside the pipe and drawn forward in two or more pulls. After the forms are withdrawn, they are unhooked, stacked on the bank, and prepared for the next use. On completion of a placement, the machine is thoroughly cleaned and prepared for further use.

This process has been used to make pipe ranging in size from 24 to 120 in. diameter (610 to 3050 mm) and larger sizes are considered feasible.[6-10]

1.2.1.2 *Single-stage construction using pneumatically inflated inner forms*—With this method the pipe casting machine is a one-piece steel sled and with an outside top troweling skirt, two concrete hoppers, with tampers and variable-speed vibrators. The machine is moved forward by a truck-mounted variable speed winch. Power to the machine is supplied from a generator on the winch truck. Separate machines and forms are required for each pipe size.

The inner form of desired size and approximately 300 to 600 ft (91 to 183 m) in length is placed in the trench and inflated to approximately 3 psi (0.02 MPa). As the machine moves forward, the form is picked up on rollers and guided into the barrel of the machine. Concrete from the forward hopper is moved by tampers down to form the bottom half of the pipe, while concrete from the rear hopper forms the upper half. Vibrators move and consolidate the concrete into a monolithic cast-in-place pipe. The outside top is struck off smooth by the outside top troweling skirt.

When the concrete has cured sufficiently, normally in 3 to 4 hours, the inner form is partially deflated, pulled down the trench and re-inflated for the next section of pipe. Meanwhile, the casting machine is removed from the trench, thoroughly cleaned, and prepared for the next use.

The inflatable form was developed using specially woven fabrics, coated with abrasion and chemical resistant neoprene coatings. They remain dimensionally stable under repeated use and will withstand extensive wear.

Cast-in-place pipe has been made by this process in sizes ranging from about 12 to 84 in. (305 to 2135 mm). This process is the only one which can be used to make pipe

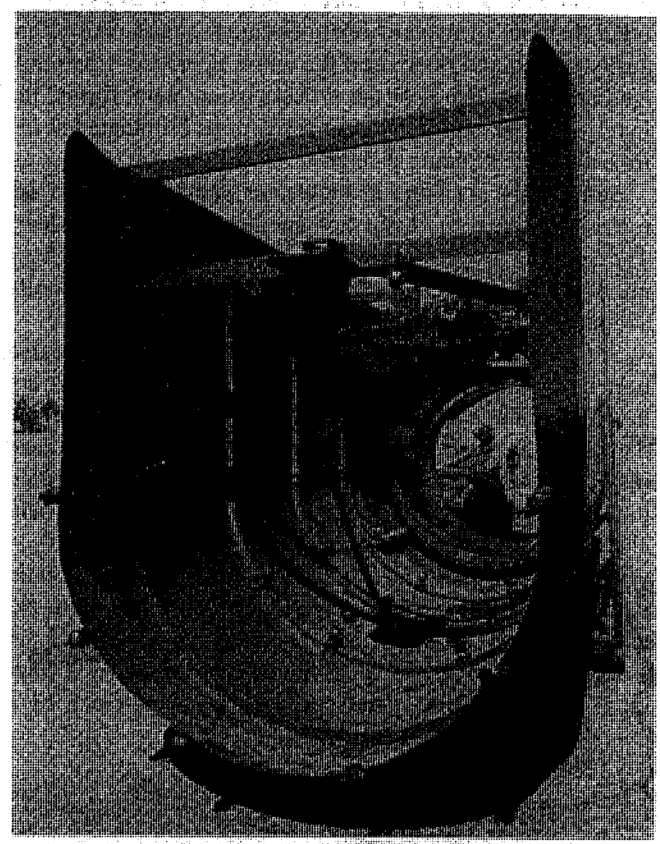

Fig. 1.2.1.2d — Single-stage construction using inflatable form. Front view of the machine sitting in shipping stand. Partially inflated form being inspected for leaks can be seen in background through the machine. Shipping stand is not attached to the machine.

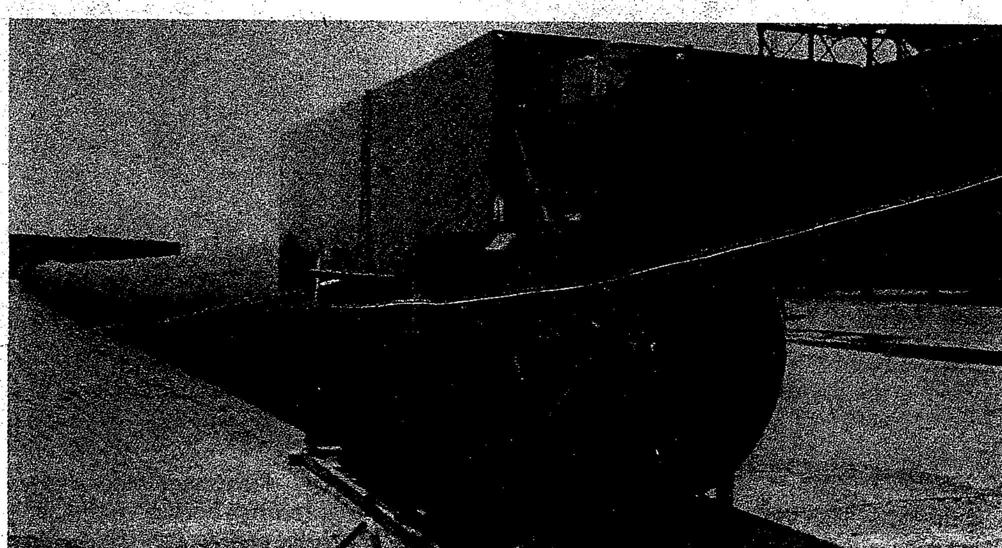

Fig. 1.2.1.2e — Single-stage construction using inflatable form. Rear view of the machine in shipping stand with inflated form. Concrete is placed between solid steel ring and inner form. Shipping stand is not attached to the machine.

smaller than 24 in. diameter (610 mm) since it is not necessary to enter the pipe to remove the inner form.[11]

1.2.1.3 *Evaluation of the single-stage method*—Construction of cast-in-place pipe by the single stage machine method offers speed of construction and low manpower requirements. Although a certain amount of concreting skill is required, no specially trained or highly skilled technicians other than one or two key operators are required. Forms are easily placed and oiled, and the entire operation is centralized and controlled. For the process using metal forms, the invert can be inspected and imperfections eliminated at the time concrete is being placed.

Some of the machines available are patented and their use requires a rental or royalty payment to the patent holder. The self-contained machines are heavy, but the weight is not beyond the handling capabilities of equipment normally available on the job.

Since the machines depend on the previously excavated trench for line and grade, any irregularities, nonuniformity in firmness or density of the subgrade, or failure to remove debris or other loose material from the trench bottom ahead of the machines, may cause them to deviate from desired grade and alignment. Therefore, it is necessary to maintain close check on grade and alignment.

1.2.2 *Two-stage construction by machine*—This method is similar to the single stage construction using metal forms, except that two separate machines are used to perform the work. The lower half of the pipe is constructed by a traveling slipform which is moved forward in the trench by a cable and drum arrangement powered by a gasoline eng The cable extends forward and is anchored in the trencl a deadman or other suitable anchorage. Adjustments cai made to the machine to permit varying the wall thickn Concrete is placed in a hopper and flows around the riphery of the trench bottom. Final finish is obtained t semi-circular boat attached to the rear of the machine.

The top half of the pipe is constructed by a second chine following closely behind the lower machine and tached to it by cables. Oiled forms are used to support form the upper half of the pipe. Wood bearing plates pla on the invert serve as a base for vertical wooden posts wl support the top section metal forms. Spreader bars are stalled horizontally across the pipe form at the approxin center line to prevent inward deformation of the otherv unrestrained lower ends. One bearing plate, vertical p and spreader bar is used for each form. The machine constructing the upper half of the pipe is placed in posi over the metal forms. It is supported by rubber-tired wh in front and a shaping form in the rear, both adjustabl permit variation of the wall thickness. Concrete is place a metal hopper on the form from which it flows to the v between the metal forms and the trench walls. Mechan steel tampers consolidate the concrete on each side. outside top of the pipe is struck off and smoothed by the of the machine.

1.2.3 *Rate of production*—Rate of production is usu governed by factors other than the production capabilit

Fig. 1.2.2a — Two-stage construction by machine. Construction of 30 in. (760 mm) diameter pipe showing the machine that places the top half of the concrete pipe.

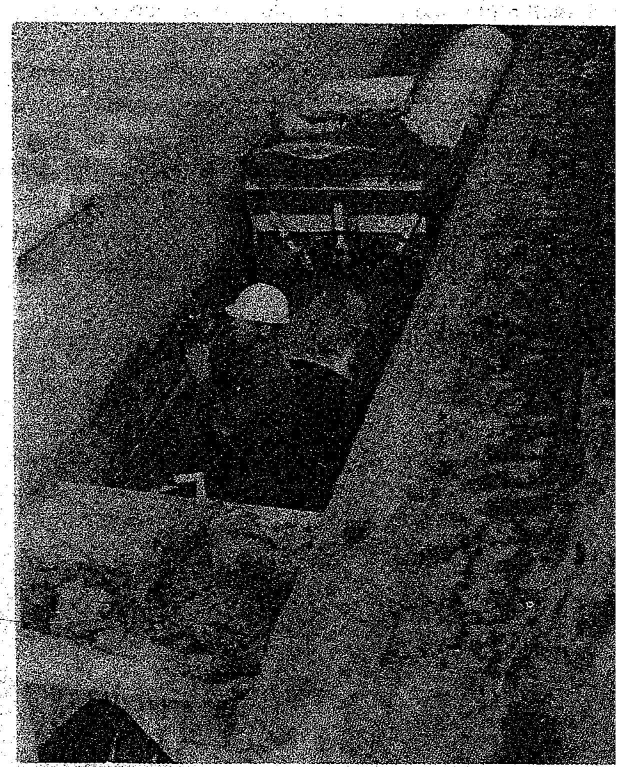

Fig. 1.2.2b — Two-stage construction by macl Workman standing between the two pieces of making equipment has just placed metal semicirc form into position together with wooden spre and bearing board for vertical strut; and is in j tion to receive another metal form as the mac moves forward in unison.

the pipe making machines. In irrigation work the rate of advance is affected by the time required to remove the inner forms, the nature of the soil such as a loose sandy soil or a rocky or spongy foundation, length of trench excavated ahead of concrete placement, and the condition of the equipment. Rate of production in open country is usually in the range of 400 to 700 ft (120 to 210 m) per day. However, as much as 1700 ft (515 m) of 36 in. (910 mm) pipe were placed in one shift when all conditions were favorable. For storm and sanitary sewers in city streets production progress is slowed by such obstacles as interference from underground utilities, deep trenches, shoring problems, handling of trench excavation, control of traffic, and underground water. Rate of progress under such conditions may be in the range of 150 to 250 ft (45 to 75 m) per day.

CHAPTER 2—LOAD CARRYING ABILITY

2.1—General

Most of the early nonreinforced cast-in-place concrete pipelines were used for conveying irrigation water where earth loads were not an important consideration except at road crossings. Cover for such lines was usually in the range of 2 to 3 ft (610 mm to 915 mm). As pipe making processes improved, with corresponding increase in quality of concrete, nonreinforced cast-in-place concrete pipe came into use for storm drains and sanitary sewers as well as for irrigation lines crossing and parallel to paved roads carrying heavy traffic with cover of 24 in. (610 mm) or less. The ability of such pipe to carry the heavy loads imposed on them by deep earth fills and traffic loads has been demonstrated by load bearing tests conducted independently by several agencies and by structural analyses also conducted independently by a number of consulting engineers using different design methods. All such load tests and analyses demonstrated conclusively that nonreinforced concrete pipelines could successfully sustain the external loads normally encountered in sanitary and storm sewers and irrigation lines.[1,3,4,5,12,13]

2.2—Load tests

From 1955 to 1958, load tests were conducted by the No-Joint Concrete Pipe Co., under the direction of E. C. Fortier, consulting civil engineer, Fresno, California, on 24, 30, and 60 in. (610, 760, and 1525 mm) pipe, and also on a simulated section of 120 in. (3050 mm) pipe. In September 1955 the Salt River Project, Phoenix, Arizona, conducted load tests on seven sections of 30 in. (760 mm) cast-in-place pipe.

In January 1961, Arizona Testing Laboratories in Phoenix, Arizona, conducted load tests on an isolated 4 ft (1.2 m) section of 48 in. (1220 mm) cast-in-place pipe, constructed using the inflatable form process. The purpose of the test was to determine the load carrying capacity of 48 in. (1220 mm) Fullerform pipe in a typical trench under normal field conditions.

The test procedure conformed to the sand-bearing method of ASTM C 76-57T, except that the pipe was supported by natural soil and by the vertical sides of the trench in which the pipe was cast. The load was applied at a uniform rate of 8000 lbf (36 kN) per min by jacking against a steel box containing approximately 45 tons (approximately 41,000 kg) of sand and supported over the pipe by sills and blocks. A hairline crack appeared at the top and bottom of the pipe at 45,600 lbf (203 kN). This crack opened to 0.01 in. (0.25 mm) when a total of 65,100 lbf (290 kN) was reached. When additional load was applied, the cracks opened slightly and at 71,600 lbf (318 kN) a hairline crack appeared at the spring line on both sides. At this load cracks also began to appear in the soil adjacent to the sides of the pipe. When a total load of 78,600 lbf (350 kN) was recorded, additional jacking resulted only in the pipe sinking into the ground, but no increase in the pressure reading. It was apparent that ultimate failure could not be reached under these conditions, so the test was stopped.

In 1969, static and dynamic load tests were applied to each of two locations of 96 in. (2440 mm) pipe installed in Dallas, Texas. Twenty-eight day compressive strengths ranged from 4000 to 5000 psi (27.5 to 34.5 MPa). Howard Needles Tammen and Bergendoff of Dallas coordinated the test program.

In order to determine the stresses induced in the pipe under test loads, a circumferential ring of 17 strain gages was attached to the inner and outer pipe faces at each location. Deflectometers were installed at the horizontal and vertical diameters to measure the actual wall deflections of the pipe under load.

For the initial static load test, a sandbox frame of dimensions prescribed by ASTM C 76-57T was used. The box enclosed a 4×6 ft (1.22×1.83 m) area spanning one quarter of the pipe circumference. The box frame for the second static load test enclosed a 4×4 ft (1.22×1.22 m) area to concentrate the uniform load nearer the pipe crown.

Incremental loads to a maximum of 205,000 lbf (912 kN) were applied to the pipe through both the standard ASTM and the narrow sandboxes at each of the test locations. Test gage readings increased quite uniformly as the increments of load were applied. The pipe exhibited slight vertical deformation under the load and this was accompanied by an increase in horizontal diameter of lesser magnitude than the vertical deformation.

Under the maximum test load of 205,000 lbf (912 kN) the vertical deformation was only about 1/32 in. (less than 1 mm) with the narrow sandbox loading. The horizontal diameter increased by only about 1/64 in. (0.40 mm) under this loading.

The unit pressure on the test area of the pipe was in excess of 11,000 lbf per sq ft (525 kPa). No visible evidence of cracking or spalling occurred under this heavy loading.

A dynamic load test was conducted to investigate the pipe response to impact loads which could occur with shallow cover above the pipe. The action of dual wheel truck axles was simulated by placing four wooden railroad ties across the pipe on about 12 in. (300 mm) of compacted earth fill at the usual location of truck wheels, and dropping one of the 16,000 lb (7250 kg) concrete blocks used for the static load tests on the ties, from increasing heights of 6 to 36 in. (150 to 915 mm) in 6 in. (150 mm) increments. Under the condition of maximum impact, a vertical deformation of only about 1/16 in. (1.6 mm) was measured with a horizontal deformation of only about 1/32 in. (less than 1 mm). Again, it is significant that no damage to the pipe occurred under this severe loading.

2.3—Structural analysis

Following the successful early load test, showing what appeared to be unusually high supporting strength, it was desired to determine if the test results could be substantiated by structural design analysis. Such a study was undertaken by Ernest C. Fortier of Fresno, Calif., in the fall of 1958. He made calculations of outer fiber stresses in the concrete shell for pipe sizes 24 to 72 in. (610 to 1830 mm) in diameter for earth fills of 4, 10, 20, and 30 ft (1.2, 3.0, 6.1, and 9.1 m) above top of pipe and live load of AASHTO H-20-44. Subsequently, computations were made for a combination of stresses due to external loads and internal hydrostatic head of 10 ft (29.9 kPa). Live load was for H-20-44 loading with impact factor of 2. Fiber stresses were computed for sizes 24 to 72 in. (610 to 1830 mm) in diameter and for earth fills of 2, 3, 4, 10, 20, and 30 ft (0.6, 0.9, 1.2, 3.0, 6.1, and 9.1 m) plus live load and 10 ft (29.9 kPa) hydrostatic head. Earth loads were computed from the Marston formula assuming weight of soil to be 110 lbf per cu ft (1760 kgf/m³), active and passive pressure $K_u = K'_u = 0.150$ and Curve C to determine coefficients. Live loads transmitted from the surface to the buried pipe were determined in accordance with the procedure outlined in the publication by Thomas K. Breitfuss.[14] Moments and thrusts at the invert of the pipe were computed using coefficients developed by the elastic arch theory. These coefficients were published by James M. Paris.[15] Maximum fiber stress at the invert was computed from the formula:

$$f = \frac{6M}{t^2} - \frac{T}{12t}$$

where f = stress in extreme fiber in psi; M = moment at invert in ft-lb per ft of pipe; T = thrust (direct stress) at invert in lb per ft of pipe; and t = thickness of pipe shell in inches.

In metric units:

$$f = \frac{6M}{t^2} - \frac{T}{t}$$

where f is in kg/cm²; M is in kg-cm/cm of pipe; T is in kg/cm of pipe; t is in cm. The vertical load was assumed to be uniformly distributed over the top 180 deg of pipe and the vertical soil reaction on bottom 180 deg of pipe. The uniform lateral load was assumed to be 33 percent of the vertical load and applied horizontally to a height from the bottom of the pipe equal to 0.712 times the external diameter. Moments and thrusts were computed for weight of pipe and weight of water and for thrust due to hydrostatic pressure head.

For the condition of 20 ft (6.1 m) of earth fill, live load for AASHTO H-20-44 with impact factor of 2 and hydrostatic head of 10 ft (29.9 kPa), the fiber stress was found to be:

Pipe size, in.	(cm)	(mm)	Flexural fiber stress, psi	(kg/cm²)	(l
24	(61)	(610)	143	(10.0)	(
30	(76)	(760)	255	(17.9)	(1
36	(91)	(915)	295	(20.7)	(2
42	(107)	(1065)	334	(23.5)	(2
48	(122)	(1220)	320	(22.5)	(2
54	(137)	(1370)	359	(25.0)	(2
60	(152)	(1525)	385	(27.1)	(2
72	(183)	(1830)	433	(30.4)	(2

Since the ultimate flexural strength (or outer fiber st at rupture) is in excess of this for good concrete, it app that the values for fiber stress for the severe conditions c above are conservative.[16,17]

In 1960, Edib Kirdar of the Salt River Project in Ariz made a structural analysis similar to that made by Er Fortier. The objective was to demonstrate by struct analysis that cast-in-place nonreinforced concrete pip sizes 12 to 72 in. (305 to 1830 mm) could safely be insta under or across any roadway in the area with a minimur 2.0 ft (0.6 m) of compacted soil cover. The elastic theory was used with assumptions similar to those use Fortier. The report concludes that cast-in-place nonr forced concrete pipe is capable of withstanding load excess of H-20 surface load with an impact factor transmitted through 2.0 ft (0.6 m) of compacted soil we ing 110 lb per cu ft (1760 kg/m³).[1]

In 1959, John P. Esvelt, structural engineer, Spok Wash., made an analysis of the load bearing strengt cast-in-place nonreinforced concrete pipe known as ' truda-Cast'' pipe for R. A. Hanson Co. Inc., Palo Washington.[2] Extruda-Cast pipe is cast in a single op tion. Esvelt states that his calculations were intended theoretical determination of the load-bearing strengt ''Extruda-Cast'' pipe of different sizes for comparison load-bearing test results and for use in suggesting mo cations in design of the pipe barrel to improve the stre characteristics. His thought was that if a correlation is tablished between theoretically derived strengths and results for a few sizes or loading conditions, the calcula can proceed to the determination of pipe strengths for c sizes and/or cross sections. Fortier had much the s thought in extending the calculations verified by load of pipe 24 to 60 in. (610 to 1525 mm) in diameter diameter of 120 in. (3050 mm). Load-carrying calcula for the 120 in. (3050 mm) section were verified by an a load bearing test (see Section 2.2).

For his analysis, Esvelt calculated bending momen accordance with PCA Bulletin IS164 W.[18] Soil reaction based on the bulb theory advanced by H. C. Oland USBR Engineering Monograph No. 6.[19]

Earlier in 1959, load-bearing tests on a section of 3 (760 mm) Extruda-Cast pipe had been made by the W ington Testing Laboratories, Inc., Spokane, Wash. ' were made with various conditions of side restraint and various types of loading, that is, single edge, sand bea and uniform loading.[12,13]

TABLE 2.3 — Maximum safe depths of backfill

(Computed 1977, Edib Kirdar, Salt River Project, Phoenix, Arizona)

Pipe size		Safe load lbf		Maximum safe backfill depth to top of pipe ft (m)			
				Granular soil (no cohesion) *W = 100 (1600) Ku = 0.1924	Saturated top soil W = 100 (1760) Ku = 0.150	Sand and gravel W = 120 (1920) Ku = 0.165	Saturated clay W = 130 (2080) Ku = 0.110
in.	(mm)	1bf/1in ft	KN/m				
24	610	5,800	(84)	No limit	No limit	No limit	No limit
30	760	7,200	(105)	No limit	No limit	No limit	No limit
36	915	8,500	(124)	No limit	No limit	No limit	No limit
42	1065	9,800	(142)	No limit	No limit	No limit	38 (11.6)
48	1220	11,000	(160)	No limit	No limit	No limit	30 (9.1)
54	1370	12,200	(178)	No limit	No limit	No limit	26 (7.9)
60	1525	13,300	(193)	No limit	49 (14.9)	47 (14.3)	24 (7.3)
66	1675	14,300	(209)	No limit	36 (11.0)	30 (9.1)	21 (6.4)
72	1830	15,500	(226)	No limit	32 (9.8)	31 (9.4)	21 (6.4)
78	1980	17,000	(247)	45 (13.7)	32 (9.8)	24 (7.3)	20 (6.1)
84	2135	18,000	(262)	39 (11.9)	30 (9.1)	24 (7.3)	20 (6.1)
90	2285	19,000	(277)	33 (10.1)	28 (8.5)	23 (7.0)	20 (6.1)
96	2440	20,000	(290)	32 (9.8)	28 (8.5)	22 (6.7)	19 (5.8)
102	2590	21,500	(313)	32 (9.8)	26 (7.9)	21 (6.4)	19 (5.8)
108	2745	22,600	(329)	31 (9.4)	24 (7.3)	21 (6.4)	19 (5.8)
114	2895	23,700	(346)	30 (9.1)	24 (7.3)	21 (6.4)	18 (5.5)
120	3050	25,700	(375)	29 (8.8)	21 (6.4)	20 (6.1)	18 (5.5)

*W = lb per cu ft (kg/m³)

On the basis of these several analyses and load tests, Table 2.3 was prepared and expanded to show the maximum safe depths of backfill in vertical-sided trenches for various sizes of cast-in-place pipe.

CHAPTER 3—DESIGN RECOMMENDATIONS

3.1—Location requirements

In general, the procedures and practices followed for the location of cast-in-place lines are similar to those for other pipelines. Precautions to take for installation through fills, in rock or unstable ground, and in areas where the ground water is above the bottom of the pipe are discussed in Section 4.2, Excavation.

Right-of-way requirements for cast-in-place pipelines are similar to those for other types of pipelines. The right-of-way should be wide enough for the trench, stockpile material, a walkway on one side of the trench, and a 12 to 14 ft (3.7 to 4.3 m) roadway for equipment on the other.

Curves in horizontal alignment can be negotiated with relative ease, but angular changes in direction should be avoided. The minimum radius of curvature is in general controlled by the type of excavation equipment used. The following formula is recommended for minimum radius:

$$R = 30D$$

where R = radius of curvature, and D = nominal internal pipe diameter, with R and D expressed in the same units.

In irrigation work, cast-in-place pipelines are frequently laid in existing irrigation channels. Such location has the advantage of holding additional right-of-way to a minimum. Regardless of type of pipe used, it has been found advantageous in public systems, such as for irrigation districts, to locate irrigation lines outside of the road right-of-way. By so doing, the large open-gate structures, as well as standpipes and vents, present minimum interference to traffic and to travel vision, particularly at intersections.

For additional information on surveys for sanitary and storm sewers, refer to the ASCE Manual of Engineering Practice, No. 37, entitled "Design and Construction of Sanitary and Storm Sewers."

3.2—Hydraulic

3.2.1 *Head*—Cast-in-place pipe is intended for use under a maximum head of not more than 15 ft (4.6 m) above the pipe center line, including the effects of pipe surges, water hammer, or other pressure rise. Concrete with the specified compressive strength of 3000 psi (20.7 MPa) has sufficient tensile strength to resist somewhat higher heads. Leakage from even minor defects increases with head. Consequently, it has been found desirable to (1) keep the operating head as low as possible consistent with the topography, not to exceed 15 ft (4.6 m), and (2) use check and control structures to limit the operating head.

3.2.2 *Coefficient of friction*—Actual field measurements to determine the coefficient of friction of cast-in-place pipelines are limited. The Salt River Project in cooperation with the United States Bureau of Reclamation conducted a 3-year series of tests to determine the value of n in Manning's formula. The details and test results are contained in their "Report on Resistance Coefficient Tests, Cast-in-Place Concrete Pipe," Dec. 1966. See also Reference 20. The report states that, "A total of 281 tests were made on pipes ranging in size from 24 to 54 in. in diameter. The roughness coefficient n in Manning's formula was calculated for each set of test measurements. The n values derived ranged from 0.008 to 0.018, but 241 of the tests, or 86 percent, had values of 0.013 or less. Only 26 tests, 9 percent, gave values higher than 0.014, the recommended n factor."

The test results indicate that an n of 0.013 may be acceptable, however, it is recommended that a value of 0.014 be used for the design of cast-in-place pipelines which are to be used for low head irrigation systems until more results become available. In the design of sanitary sewers that carry industrial waste or other matter of low viscosity, it is recommended that an n value of 0.015 or higher be used. In selecting an n value, the designer should consider the condition of the pipe surface and debris that may collect in the pipeline after a period of operation rather than just the surface conditions immediately after construction.

3.2.3 *Protection against water hammer and surges*—In irrigation lines, water hammer and surges or other pressure variations are especially troublesome and can cause extensive damage to cast-in-place as well as precast pipelines. Pressure drops as well as pressure rises should be carefully checked; negative pressure should not be permitted. Proper design of standpipes, vents, checks, and control structures can virtually eliminate damage from pressure variation. It is especially important in irrigation lines to vent all high points and to avoid shutoff gates in a main line unless the pipeline is protected by open structures or standpipes. In cross-sectional area, such structures or standpipes should be at least equal to that of the line pipe.

3.3—Structural

3.3.1 *Surcharge*—The maximum surcharge load to which a pipe should be subjected is the HS-20 live load defined in the American Association of State Highway and Transportation Officials (AASHTO) Specifications. Many structural analyses have been made of this loading using a minimum cover of 2 ft (0.6 m). The resulting fiber stresses are well within allowable conditions even when surcharge loads are combined with all other probable loading conditions.

3.3.2 *Foundation*—The foundation for the pipe should provide full, firm, uniform support throughout each continuous section. Most soils are capable of providing such support without special precautions. The exceptional conditions are generally of three types: rock, soft or spongy materials, and expansive clays. Because of the high cost of construction in rock and in soft or spongy soils, it may prove more economical to alter the alignment to avoid either condition when large quantities are encountered. Cast-in-place pipe may be satisfactorily installed through any of these conditions provided the appropriate special measures described in Section 4.2 are followed.

3.3.3 *Pipe dimensions*—Wall thicknesses for cast-in-place pipe have been established more by custom than by design. In the early days of precast concrete pipe, manufacturers of so-called "poured pipe," in which concrete was spaded between vertical steel forms, used wall thicknesses of 1/12 of the internal diameter of the pipe plus 1 in. (25 mm). This practice seems to have been rather generally adopted by the cast-in-place pipe constructors and has proved adequate to meet the load and head conditions generally encountered. In recent years, technical studies and load tests (see Section 2.2) also have demonstrated the adequacy of the wall thicknesses in general use.

To allow some leeway in casting concrete pipe, a decrease of ½ in. (13 mm) in wall thickness is usually allowed, thus establishing the specified minimum wall thi ness at 1/12 of the diameter plus ½ in. (13 mm).

To insure hydraulic performance in accordance with design, the actual cross-sectional area should not be l than nominal and the internal diameter of the pipe at a point should not be less than specified, usually 95 percent the nominal diameter. Deviations from nominal diamet caused by unbalanced forces on the inner forms can overcome by slightly increasing the nominal diameter of inner forms.

CHAPTER 4—CONSTRUCTION RECOMMENDATIONS

4.1—General

Cast-in-place pipe construction uses standard meth and equipment except for the concrete placing machi Even the machine needs no highly specialized operat personnel. Only a competent foreman and a well organi 4 to 6-man crew who have experience in conventio trenching, concreting, and backfilling methods are need Such a crew can easily adapt to any special techniq required. Operations required for cast-in-place pipe c struction are discussed below.

4.2—Excavation

The trench should be neatly excavated with vertical si and semicircular bottom. The width of the trench shoulc equal to the outside diameter of the pipe, so that the vert side walls and trench bottom serve as an outside form concrete placement. Side walls above the top of the p may be sloped if desired, or if necessary for stability.

4.2.1 *Equipment*—Commonly used types of excava equipment are wheel-type and ladder-type trench excava and backhoes, which should be fitted with rounded bucl suitable for excavating a semicircular-bottomed trench. lection is largely a matter of personal preference or util tion of equipment already available. Line and grade maintained by measuring offsets, both horizontally and tically, from a previously established offset line. A sin inverted L-shaped jig serves satisfactorily to detern whether the trenching equipment is following the prescri alignment and excavating to the proper grade. Some chines are fitted with "feeler fingers" into which the o line wire must fit to maintain the desired alignment grade. If the wire falls outside these fingers, appropi adjustments must be made on the equipment before resu tion of trenching operations. Other methods are used, they are not as simple as the two mentioned above.

A common practice is to assign one piece of excava equipment to each spread and to use it for other purp when not required for excavation. It may serve both deadman to which the winch cable is attached to move pipe casting machine forward and as a crane to lift machine into and out of the trench. A backhoe require modifications to serve satisfactorily as a crane, but bo must be added to trenchers if they are to be used for purpose. Sometimes a separate mobile crane is provi Various types of equipment may be assigned to the v and each type has a number of different uses.

4.2.2 *Rate of advance*—Normally the concrete placement and form removal time exceed that for excavating the same length of trench. Therefore, the rate of advance of the finished pipe is generally controlled by the speed at which the machine can be moved and the time required to remove the inner forms. This accounts for the other uses of the excavation equipment previously discussed. It may prove preferable for some projects to shift the excavators from one location to another and keep them fully productive. In this case, the number of excavators required would be determined by the output capabilities of the equipment and the time required to change locations.

4.2.3 *Length of trench ahead of placement*—The length of trench to be excavated ahead of concrete placement, or excavation "headway," is largely a matter of judgment. Under normal circumstances the trench headway will be roughly equal to the amount of form to be withdrawn from the previous placement or the length of pipe to be placed during the following shift. Headway is often limited to prevent drying of the trench walls and bottom against which concrete is to be placed, because rapid absorption of the water from the concrete can cause excessive cracking. Since dry trench walls can be moistened by sprinkling immediately prior to concrete placement, this criterion is of secondary importance. Construction should not be unnecessarily restricted by arbitrary headway requirements, if satisfactory alternatives can be agreed upon. The best rule to apply to headway is to keep excavation ahead of pipe fabrication by a distance sufficient to avoid interference with concrete placement.

4.2.4 *Trench stability*—From experience in a great variety of soils, it appears that from a standpoint of trench excavation most soils are suitable for installation of cast-in-place pipe. With either a backhoe or a trencher, it usually is possible to excavate trenches that are true, neat, and clean with a minimum requirement for fine grading. Subsequent sections deal with special treatments required in unstable soils.

In areas known to be excessively sandy, it is good practice to excavate short test sections of trench with a small rig to observe the action of the soil under actual trench conditions. A small backhoe mounted on a tractor has been found useful for this purpose. Some sandy soils show little or no tendency to slough if moist. For other sandy soils, a slight slope in the side walls may prevent excessive sloughing. If these measures do not produce the required stability it is necessary to replace the sand in the trench form with compacted soil, as provided in Section 4.2.7, or substitute another type of pipe.

4.2.5 *Prewetting*—In areas where the soils are too hard for efficient trenching or where additional moisture adds to the trench stability, trench excavation may be simplified by prior wetting. Prewetting may be accomplished by either of two methods or a combination of both. One method is to apply water just as though the land were being irrigated, by either furrow, flood, or sprinkler irrigation. The second method, often used in areas where large quantities of water are difficult to obtain, is to run water in a single ditch along the center line of the pipe.

4.2.6 *Trench form*—The "trench form" is that portion of the trench which will serve as the outer form for at least the bottom 210 deg of the pipe (see Fig. 1.1). It should be excavated to the lines and grades established by the Specifier and should be prepared to provide full, firm, and uniform support of the pipe by undisturbed earth or compacted fill.

4.2.6.1 *Trench cleanup*—The excavator normally digs a neat, clean trench suitable without further work for placement of concrete. It will be necessary to remove from the trench bottom any debris, foreign objects, or material from side wall sloughing before starting concrete placement. The machine fits the trench so closely that occasionally, as it moves forward, it scrapes the side walls and causes some sloughing. Care must be exercised to prevent this sloughed material from building up ahead of the machine and causing excessive departure from established grade. Where the metal inner form is used, excess material can be manually removed ahead of the slipform. With either method of construction, small transverse ditches may be excavated across the trench bottom to receive soil built up and pushed ahead of the slipform.

4.2.6.2 *Trench moisture*—Care should be taken to insure that at the time of concrete placement there is adequate moisture in the trench form so that water is not drawn from the freshly placed concrete. If the trench is too dry, all soil in contact with the concrete should be moistened. However, the trench form must be free of water and mud at the time of concrete placement.

4.2.7 *Rock and unstable materials*—When it is necessary to install the pipe in rocky areas, the rock should be removed and replaced with suitable fill material compacted to proper density. The rock shall be removed to at least 6 in. (150 mm) below the grade of the bottom of the pipe. Areas left void by rock removal should be completely filled with compacted material, then trenched for the pipe as though natural ground. If the rock below the pipe subgrade is fractured or fragmented, or if it consists of large cobblestones or boulders, the replacement fill material should be carefully selected to insure that it is of such gradation that it will not be moved downward by fluctuation of the water table. In no case should expansive soils be used for fill.

A procedure of over-excavation, backfill, compaction, and retrenching should be used where sloughing sand or soft or spongy conditions are encountered. Unstable trench walls may be shored if necessary, but this will reduce the pipe production rate. When expansive clays are encountered, they should be thoroughly moistened by ponding, to completely expand the soil, and the moisture maintained until the concrete is placed.

4.2.8 *Groundwater control*—Where the water table is above the grade line for the bottom of the pipe it is necessary to dewater the trench. In some cases, pumping from sumps in the bottom of the trench will adequately control the inflow. In other cases, it may be necessary to lower the water table by pumping from wells located along both sides of the trench. Sometimes systems as elaborate as well points may be required. Gravel or crushed rock may be used as a French drain by over-excavation and placing to grade. Drain tile may be required in the gravel or crushed rock if large amounts of water are encountered. The gravel or crushed rock must be compacted to provide a satisfactory surface on which to place concrete.

4.3—Concrete control and placement

The satisfactory performance of cast-in-place concrete pipelines requires concrete that is consistently watertight and durable, and has the necessary compressive strength. Such concrete may be readily obtained with proper attention to mix proportioning, with adequate testing to insure quality control, and with proper placement and curing. Proportioning shall be according to ACI 211.1.

4.3.1—*Materials*

4.3.1.1 *Portland cement*—Portland cement should meet the requirements of ASTM standard specifications for portland cement, C 150. Where soils or waters contain 150-1500 ppm of sulfates, Type II cement or a portland cement with a C_3A content of not more than 8 percent should be specified. For more than 1500 ppm of sulfates a Type V cement or a portland cement with not more than 5 percent C_3A should be specified, and the water-cement ratio should not exceed 0.50. Portland blast furnace slag cement [ASTM C 595, Type IS (MS)] or portland pozzolan cement (ASTM C 595, Type IP) also may be used for such exposures. For such severe exposures (1500 ppm or more) if none of those indicated is available, a cement with a C_3A content between 5 and 8 percent may be used with a water-cement ratio not exceeding 0.45, or with a substitution by weight of pozzolan (ASTM C 618) for such cement, not to exceed 25 percent by total weight of cement plus pozzolan. Where aggregates are alkali-reactive a cement containing less than 0.60 percent alkalies should be specified.

4.3.1.2 *Aggregates*—Aggregates should meet the requirements of ASTM C 33. Gradation and maximum size of aggregates are important because of their effect on mix proportions, water requirement, workability, cohesiveness, and finishing characteristics of the concrete. In general, good workability, cohesiveness, and finishing characteristics can be obtained when 15 to 30 percent of the fine aggregate passes the No. 50 (300 μm) sieve and 3 to 7 percent passes the No. 100 (150 μm) sieve. Coarse aggregate should be graded up to the largest size used. This reduces the amount of mortar used and can result in lower cost, less temperature rise, and less drying shrinkage.

4.3.1.3 *Admixtures*—An air-entraining admixture, conforming to ASTM C 260, should be used unless air-entraining portland cement is used. (See Specifications Section 4.4.) Any other chemical admixture used should meet the requirements of ASTM C 494. Fly ash or pozzolans, if used, should meet the requirements of ASTM C 618. All admixtures should be used only in accordance with ACI 212.1R/ACI 212.2R.

4.3.2 *Slump*—The contractor should be allowed to select the slump of the concrete while maintaining the required water-cement ratio because of the considerable difference in slump that may be required by different types of equipment. The required slump also may vary somewhat in accordance with local project conditions. To help minimize shrinkage cracking, the lowest usable slump should be maintained.

4.3.3 *Shrinkage and contraction*—Satisfactory cast-place concrete pipe is generally achieved without spec consideration of shrinkage and contraction. Ready-mi› concrete or job-mixed concrete which is satisfactory other respects generally does not exhibit excessive crack due to drying shrinkage and temperature contraction.

Any large cracks which do occur can be most eas patched with cement mortar within a few days after cast because bond is then most easily achieved. If epoxy ma rials are used for patching, they appear to give best resu if applied at a later time, preferably two weeks or more at concrete is cast.

Occasionally, circumstances occur which produce an satisfactory amount of cracking or there will be a job wh it is desired to reduce leakage to an absolute minimum. such cases, it is advisable to reduce cracking, drying shri age, and thermal contraction by some of the follow practices:

- Reduce water content of the mix.
- Establish optimum curing practices to retain mix water.
- Minimize temperature drop.
- Adjust mix proportions.
- Use selected aggregates if economically feasible.

Unit water content is least when the mix contains the le amounts that are feasible of cement and sand, and the la est practicable size of coarse aggregate. Water cont should be reduced by using the lowest slump that can fully consolidated as the pipe concrete is placed. Use of entrainment, well graded aggregate, water-reducing che ical admixtures, and fine materials when sands are defici in fines also can reduce water requirement. Admixtu which increase shrinkage should be avoided. Proper proportions using any or all of these ingredients must established by trial mixes. To minimize shrinkage crac early drying of the concrete from all surfaces must be p vented. Having adequate moisture in the trench form p vents drying from the lower part of the outer surface, the curing practices, including moist backfill, prevent d ing of the upper part of the outer surface. Bulkheading the introduction of water in the invert will prevent drying the inner surface.

To minimize thermal shrinkage the concrete should mixed, placed, and cured at the lowest possible temperat allowed in Section 7.3 of the specifications so that sub quent temperatures of the pipe in service will not be app ciably lower than the highest of these initial temperatu Low early temperatures can be attained by doing the w in the coldest available weather above freezing, work during the cooler part of the day, and shading the trencl keep surfaces against which concrete is to be placed as c as possible. Mixing and placing concrete at low temp tures can also be accomplished by substituting ice for par the mixing water, keeping moisture low in aggregate permit using more ice, and shading aggregate to red temperature of the aggregate the day it is used.

Mixture proportions which achieve slow strength g combined with extended curing at low temperatures, effective in reducing volume change cracking. High-ea strength cement should be avoided unless early strengt essential. Where early service after construction is not required, some of the principles of mass concrete can be applied. For example, strength may be specified at 90 days instead of 28 days, thereby permitting the use of mixtures with less heat of hydration, that is, mixtures containing less cement, cements with less heat of hydration (Type II rather than Type I), or a combination of cement and pozzolan with less total heat of hydration.

4.4—Backfill and clean-up

4.4.1 *Agricultural installation*—Where the pipe is used for agricultural purposes and subject only to loads due to agricultural equipment, backfill should be uniformly placed to the approximate density of the surrounding soil. A slight mounding over the trench may be desirable to compensate for additional or subsequent settlement of the backfill.

4.4.2 *Urban installations*—Where the pipe is installed in a city street, the backfill should be placed and compacted in accordance with local requirements or as directed by the engineer.

4.4.3 *Clean-up*—The work area should be restored to the same general condition that existed before the start of construction.

CHAPTER 5—SAFETY AND INSPECTION

5.1—Safety

All applicable codes and regulations should be observed including the following:

(a) Safety helmets and glasses should be worn by all persons working in or around the pipe casting machine. This also pertains to personnel who remove the forms from inside the pipeline.

(b) Gloves should be worn by workers handling forms and concrete chutes.

(c) Ear plugs should be used where excessive noises may injure hearing.

(d) An air blower of sufficient size should be used to adequately ventilate the pipeline while men are in the pipe to remove forms, and when repair work or inspection of pipeline is in progress.

(e) The pipe machine operator should not wear loose clothing.

(f) Workers should not be permitted in the open excavation during the operation of the machine or when the winch cable is in tension.

(g) The winch cable should be inspected prior to every use for burrs or parted strands. If the cable is found damaged, it should be replaced before further use.

(h) The engine and fuel system should be inspected daily during use to ensure that no fuel or exhaust leakage is occurring.

(i) Proper methods and cables should be used to lift the pipe machine in and out of excavations.

(j) When crossing or digging near gas pipelines, care should be taken to prevent rupture of such lines. The gas may enter concrete pipelines and create a hazard. If pipelines are constructed in the vicinity of gas lines, a gas detector should be used to assure that there is no explosive gas in the line.

(k) When crossing or digging near electrical lines, care should be taken to avoid contact by equipment and personnel.

(l) Bracing or shoring should be provided where needed to protect workmen exposed to danger of moving ground and as required by applicable codes and regulations.

(m) All utility companies or others who may have underground facilities in the area should be notified of the project and given sufficient notice so that they can locate and mark their facilities prior to the beginning of excavation.

5.2—Inspection

During the construction of cast-in-place concrete pipelines, the following procedures are recommended for inspectors:

5.2.1—Check alignment and grade, to ensure that the tolerances of Specifications Section 3.7 are adhered to.

5.2.2—Check condition of trench, including just before concrete placement, to ensure that the provisions of Specifications Sections 3.1 through 3.6, inclusive, are adhered to.

5.2.3—Measure and record temperature of the concrete as specified in specification Section 7.3 and take slump tests as necessary for control, as provided in Specifications Sections 6.4 and 9.2.7. Concrete with a slump higher than required may produce pipe with a rough interior, reduce the compressive strength of the concrete, and increase shrinkage.

5.2.4—Take at least two 6 × 12 in. (150 × 305 mm) test cylinders for the first 50 cu yd (38 m^3) and at least two 6 × 12 in. (150 × 305 mm) test cylinders for each additional 50 cu yd (38 m^3) or portions thereof for each day's work. Measure and record the slump of each concrete sample as provided in specification Sections 9.2.4 and 9.2.5.

5.2.5—Check the dimensions of the cast-in-place pipe machine prior to its use. Monitor wall thickness where possible around the periphery of the pipe as casting progresses.

5.2.6—Be sure that the freshly placed flow line area below the metal forms is troweled if necessary to obtain a smooth finish.

5.2.7—Where possible, inspect the interior of the pipe from the inside of the machine frequently. Excessive boil at the bottom of the metal forms will cause a horizontal ridge.

5.2.8—Be sure that the top of the pipe is properly protected to prevent rapid dehydration, as provided in specifications Sections 8.1.

5.2.9—At the completion of each placement, close the ends of the pipe with heavy canvas or equivalent to prevent drying of the fresh concrete, as provided in specifications Section 8.1.

5.2.10—Inspect the interior of the pipe as soon as the forms are removed. Check for voids, for form lap indentation, interior pipe dimension and smoothness in the flowline area where troweling is required. Any necessary repairs to the pipe should be made promptly.

5.2.11—Stay close to the operation and remain alert. The success of the operation and the end result may depend on how well the inspector does his job.

CHAPTER 6—EQUIPMENT CONSIDERATIONS

6.1—General

Anticipating problems and having a remedy on hand can result in substantial cost savings. A common concert of those installing cast-in-place pipe is that equipment might fail during the concrete placement process. If the equipment cannot be repaired quickly, the result may be the waste of concrete that is on the job or in transit. Many times these problems can be avoided by using good inspection and maintenance practices.

6.2—Cleanliness

It is very important that equipment be cleaned immediately after placement, before concrete hardens. Special attention should be paid to the mandrel, tampers, and any other parts that come in contact with concrete during the operation. This is commonly done by removing the machine from the trench and washing it.

6.3—Inspection and maintenance

Problems are often avoided by simply checking equipment prior to use. Inspection of the machine should include checking of rollers on the mandrel, mandrel seal, oilers, motors and hoses. Power unit inspection should include oil, water, fan belts, battery, fuel, hydraulic fluid, winch and cable.

6.4—Metal forms

Excess concrete should be removed from forms immediately after stripping. This is commonly accomplished by hitting the form lightly with a spreader stick or other tool. Forms should be checked for loose or broken hardware, bends, dents or tears prior to coating for reuse. This inspection should preclude use of forms that might jam in the machine or fail during concrete placement. It is very important that the forms be properly coated with a good form release material, just prior to inserting in to the machine. A program for keeping forms in proper curvature is also important in avoiding problems during placement and stripping operations.

6.5—Trenching equipment

Inspection of bucket dimensions, wear and setting of bucket digging teeth should be made prior to and during excavation. This will help insure proper trench width and eliminate two possible problems. A trench which is too wide will cause excessive use of concrete and possible tipping of the machine. Worn teeth or a warped bucket result in a trench that is so narrow that the machine cannot move freely.

6.6—"Deadman" Anchor

No single type of "deadman" is always effective in every type of soil. If a "deadman" begins to fail, a piece of equipment on the job site may be used to secure the winch cable so that concrete placement can be completed.

CHAPTER 7—REFERENCES

7.1—Specified and/or Recommended Reference

The documents of the various standards-producing org nizations referred to in this document are listed below w their serial designation.

American Concrete Institute

211.1-81	Standard Practice for Selecting Prop tions for Normal, Heavyweight and M Concrete
212.1R/212.2R	Admixtures for Concrete and Guide Use of Admixtures in Concrete
346-90	Standard Specification for Cast-in-Pl Nonreinforced Concrete Pipe

ASTM

C 33	Specification for Concrete Aggregate
C 76	Specification for Reinforced Concr Culvert, Storm Drain, and Sewer Pipe
C 150	Specification for Portland Cement
C 260	Specification for Air-Entrained Adm tures for Concrete
C 494	Specification for Chemical Admixtu for Concrete
C 595	Specification for Blended Hydraulic ments
C 618	Specification for Fly Ash and Raw or C cined Natural Pozzolan for Use as M eral Admixture in Portland Cement C crete

The above publications may be obtained from the followi organizations:

American Concrete Institute
P.O. Box 19150
Detroit, MI 48219

American Society for Testing and Materials
1916 Race
St. Philadelphia, PA 19103

7.2—References

1. "Loads and Minimum Cover for Cast-in-Place Unreinforced C crete Pipe," Salt River Project, Phoenix, 1960.

2. Esvelt, John P., "The Load-Bearing Strength of 'Extruda-C Pipe," R. A. Hanson, Company, Inc., Spokane, 1961.

3. "Sand Bearing Test on Field Installation of 54-in. No-Joint Pip City of Phoenix, Arizona, 1962.

4. "Load Testing of No-Joint Cast-in-Place Concrete Pipe," Pu Works Department, Division of Engineering, Phoenix, 1963.

5. Gabriel, L. H., "Load Testing of 72-in. Diameter No-Joint C in-Place Concrete Pipe with Shallow Cover," Sacramento State Col Foundation, Mar. 13, 1964.

6. Shipley, H., "Cast-in-Place Pipe for Irrigation," *Western Const tion*, V. 32, No. 11, Nov. 1957.

7. Fortier, E. C., "Cast-in-Place Concrete Pipe Cuts Time and Cos *Civil Engineering*—ASCE, V. 31, No. 12, Dec. 1961, pp. 65-67.

8. Campbell, T. C., "Cast-in-Place Drainage Pipe Proves to be Money Saving Way to Provide Drainage in Fast Urbanizing Sacram County," *The American City*, V. 81, No. 12, Dec. 1966, pp. 100-1

9. Fortier, E. C., "Large Diameter Non-Reinforced Cast-in-Place C crete Pipe," ACI Journal, *Proceedings* V. 65, No. 7, July 1968, 544-549.

10. Darden, Wesley F., "Use of Cast-in-Place Concrete Pipe in ramento County, California," Department of Public Works, Count Sacramento, 1969.

11. Etheridge, David C., "Three-Element Forming Speeds Concrete Pipe Job," *Construction Methods and Equipment*, V. 55, No. 12, Dec. 1973, pp. 54-56.

12. Marston, A., "The Theory of External Loads on Closed Conduits in the Light of the Latest Experiments," *Bulletin* No. 96, Engineering Experiment Station, Iowa State College, Ames, 1960.

13. Spangler, M. G., "Underground Conduits—An Appraisal of Modern Research," *Transactions*, ASCE, V. 113, 1948, pp. 316-345; discussion, pp. 346-374.

14. Breitfuss, Thomas K., "Loads and Supporting Strengths for Concrete Pipe Lines," American Concrete Pipe Association, Vienna, Va., 1957, 29 pp.

15. Paris, James M., "Stress Coefficients for Large Horizontal Pipes," *Engineering News-Record*, V. 87, No. 19, 1921, pp. 768-771.

16. Kesler, Clyde C., "Statistical Relation Between Cylinder, Modified Cube and Beam Strength of Plain Concrete," *Proceedings*, ASTM, V. 54, 1954, pp. 1178-1186.

17. "Studies of Flexural Strength of Concrete—Part 3: Effects of Variations in Testing Procedures," *Proceedings*, ASTM, V. 57, 1957, pp. 1122-1142.

18. "Analysis of Arches, Rigid Frames, and Sewer Sections," *Information Sheet* IS164W, Portland Cement Association, Skokie, 1942, 16 pp.

19. Olander, H. C., "Stress Analysis of Concrete Pipe," *Engineering Monograph* No. 6, U.S. Bureau of Reclamation, Denver, Oct. 1950, 13 pp.

20. Wilson, Thomas T., Jr., and Kirdar, Edib, "Manning for Cast-in-Place Concrete Pipe," *Proceedings*, ASCE, V. 95, HY3, May 1969, pp. 995-1007.

21. "Guamuchil Project. Cast-in-Place Pipe. Evaluation Report and Specification Review," International Engineering Company, Inc., San Francisco, 1965.

22. Corbin, V. Earl, "Cracking Patterns in Cast-in-Place Pipe," Salt River Project in Cooperation With U.S. Department of the Interior, Bureau of Reclamation, Oct. 30, 1970.

These proposed revisions were submitted to letter ballot of ACI Committee 346 and were approved in accordance with ACI balloting requirements.

P.O. Box 9094
Farmington Hills, Michigan
48333-9094
TEL: 248-848-3800
FAX: 248-848-3801

Specification for Cast-in-Place Concrete Pipe

The AMERICAN CONCRETE INSTITUTE

was founded in 1904 as a nonprofit membership organization dedicated to public service and to representing user interests in the field of concrete. It gathers and distributes information on the improvement of design, construction, and maintenance of concrete products and structures. The work of the Institute is done by individual members and by volunteer committees.

The committees, as well as the Institute as a whole, operate under a consensus format, which assures all members the right to have their views considered. Committee activities include the development of building codes and specification standards; analysis of research and development results; presentation of construction and repair techniques; and education.

Anyone interested in the activities of the Institute is encouraged to seek membership. There are no educational or employment requirements. Engineers, architects, scientists, constructors, and representatives from a variety of companies and organizations form the Institute membership.

All members are eligible and encouraged to participate in committee activities that relate to their specific areas of interest. Membership information, a publications catalog, and listings of educational activities are available.

aci international®

american concrete institute

P.O. BOX 9094
FARMINGTON HILLS, MICHIGAN 48333-9094